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EFFECT OF FAT CONTENT ON PHYSICAL PROPERTIES AND CONSUMER ACCEPTABILITY OF VANILLA ICE CREAM

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by

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ABSTRACT

Over the past few decades, the food industry has been seeking to reduce the energy density of many products. Fat reduction is often pursued as a strategy to decrease the overall caloric content of foods, since it provides the highest amount of energy per gram (9 kcal/g), when compared to proteins and carbohydrates (4 kcal/g). However, fat-reduced products are often perceived to be of inferior sensory quality, when compared to the full-fat alternative.

Ice cream is a complex food matrix due to the coexistence of multiple physical phases: ice crystals, air bubbles, partially coalesced fat globules and a concentrated, highly viscous unfrozen solution. In ice cream, removal of one ingredient may affect not only physical properties but also multiple sensory characteristics that are important to consumers. Fat, in particular, contributes to texture, mouthfeel and flavor, in addition to serving as a structural agent supporting the other physical phases, in particular the air bubbles. Moreover, it contributes to the characteristic smoothness, dryness and melting rate of the products. Removal of fat from ice cream without replacement of solids has been shown to decrease sensory quality indicators, while the addition of ingredients to replace the fat has provided better results. However, the perfect replacement strategy has yet to be found. Previous work evaluating fat removal strategies has focused on changes in key sensory descriptors, with surprisingly little information available about consumer acceptability of reduced-fat products.

In this study, the effect of replacing fat with maltodextrin (MD) on selected physical properties of ice cream and on consumer acceptability were evaluated simultaneously. Vanilla ice creams were formulated to contain 6, 8, 10, 12 and 14% fat and 8, 6, 4, 2, and 0% maltodextrin, respectively. Physical characterization included measurements of overrun, apparent viscosity, fat particle size, fat destabilization, hardness and melting rate. A series of consumer acceptability tests were conducted, each with ~100 participants, to measure liking and intensity of various sensory attributes. The experiment was replicated three times. Data were analyzed using one-way Analysis of variance (ANOVA) and a mixed model ANOVA for the physical and sensory data, respectively. Correlation analysis was used to assess relationships between consumer acceptability, physical variables and sensory attributes. Consumer tests were also conducted after 19 weeks of storage at -18°C, to assess changes in sensory acceptance due to prolonged periods of storage. Later, a discrimination test was used to determine the difference in fat content that consumers are able to discriminate among the products tested in this study. Results indicated that viscosity of the mixes decreased with increasing fat content and decreasing maltodextrin concentration. Fat particle size and fat destabilization significantly decreased with fat reduction. However, consumer acceptability did not significantly differ across the samples for fresh or stored ice cream. Even in the absence of significant differences, overall liking was correlated with slower melting rate in fresh ice cream. Following storage, ice creams with 6, 12 and 14 % fat did not differ in consumer acceptability compared to fresh ice cream. However, ice creams with 8 and 10% fat (and 6 and 4% MD), each showed a significant drop in liking score following storage by 2.8 and 5.7%, respectively. When asked to discriminate, consumers were unable to distinguish ice creams with 2% fat difference when maltodextrin was included in the formulation. A 4% difference was found to be discriminated when comparing 6% vs 10% fat ice creams but not for 8% vs 12% fat. Collectively, the changes in the physical structure of ice creams with fat contents ranging from 6 to 14% did not show evidence of gross changes in consumer acceptability for either fresh or aged ice cream.

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LIST OF ABREVIATIONS

ANOVA	Analysis of Variance
CFR	Code of Federal Regulations
CMC	Carboxymethylcellulose
CSS	Corn syrup solids
DE	Dextrose Equivalent
HTST	High Temperature Short Time
LAMS	Labeled Affective Magnitude Scale
LR-NMR	Low Resolution time domain Nuclear Magnetic Resonance
MD	Maltodextrin
MPC	Milk protein concentrate
MSNF	Milk solids non-fat
NFDM	Non-fat dried milk
NMR	Nuclear Magnetic Resonance
PGMS	Propylene glycol monostearate
PD	Polydextrose
QDA	Quantitative Descriptive Analysis
S/E	Stabilizer/emulsifier blend

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Chapter 1

Literature review

1.1 Introduction

Frozen desserts are a mixture of water, milk fat or non-dairy fats, proteins, sugars, stabilizers, emulsifiers, flavors and air that are consumed in the frozen state (Goff and Hartel, 2013). By selecting appropriate formulation and manufacturing conditions, producers aim to create a smooth and palatable dessert that is appealing to consumers. Ice cream is a category of frozen desserts with a composition that is defined by a Standard of Identity in the Code of Federal Regulations (CFR) (21 CFR §135.110). It must have at least 10% milk fat and 10% milk solids non-fat (MSNF) from which no more than 25% may come from whey ingredients. The ice cream mix, the liquid blend of ingredients prior to freezing, must be pasteurized and partially frozen under agitation. If the formula and process conditions do not meet this criteria, the product cannot be called "ice cream". Other frozen desserts also have Standards of Identity including Frozen Custard, Sherbet and Water Ice. Other terms often used to describe frozen desserts, such as "frozen yogurt" and "gelato", do not have legal guidelines of composition and manufacturing conditions.

1.2 Ingredients commonly used in frozen desserts

Ice cream manufacturing requires a concentrated source of fat, a concentrated source of milk solids non-fat, a source of water and sweeteners; stabilizers and emulsifiers may be added as optional ingredients due to their functionality to improve texture. Fat is included to provide the expected creamy flavor and to produce a smooth texture. Common milk fat sources employed include cream (40% fat), unsalted butter (80% fat) and butter oil (99% fat). Non-fat milk solids, which include milk proteins, lactose and minerals, contribute to flavor and texture. The milk proteins in particular, support the development of texture by emulsifying the fat and the air, and by increasing the viscosity of the unfrozen serum (Goff and Hartel, 2013). Lactose is less sweet than sucrose and has a small effect on overall sweetness in the final product; but it is functional in lowering the freezing point of the mix along with the other sugars added. However, its low solubility may pose a problem if it crystalizes during storage, producing a sandy texture (Goff and Hartel, 2013). The slight salty taste of minerals in milk enhances the flavor profile of the final product, while also contributing to the depression of the freezing point (Goff and Hartel, 2013). Common sources of concentrated milk solids non-fat include dried milk, whey products such as whey concentrates or isolates, and condensed milk. Water is added either with fluid dairy ingredients, liquid sweeteners, or by adding potable water to balance the mix composition. Nutritive sweeteners are added to obtain the desired sweet flavor also decrease the freezing point of the mix as well as influence the perception of creaminess. The most common combination of sweeteners used in ice cream manufacturing is sucrose and corn syrup solids in an approximate ratio of 11 to 4 (Goff and Hartel, 2013). Stabilizers may be used to increase mix viscosity, a property which aids in the suspension of colloidal particles, as well as in reducing the rate of growth of ice and lactose crystals during storage (Goff and Hartel, 2013). Stabilizers can be proteins or high molecular weight carbohydrates that are obtained from bacteria, algae or plant extracts. Some examples include xanthan gum, guar gum, starch, gelatin and carboxymethylcellulose (CMC). Emulsifiers are amphiphilic molecules that aid in the formation of ice cream texture. They are added mainly to promote fat destabilization and to improve the whipping properties of the mix due to their interphase behavior. Commonly used emulsifiers include mono- and diglycerides and sorbitan esters, and they are often used in combination.

1.3 Manufacturing process

Figure 1-1 is a flow diagram for ice cream manufacture. The formulation of frozen desserts is variable depending on the type of product that is desired and the manufacturing equipment available. Table 1-1 presents an approximate composition for different ice cream categories. The CFR defines a reduced-fat food product as that with 25% less fat than the reference product; a low-fat food has less than 3 g of total fat per serving; and a fat-free product has less than 0.5 g of total fat per serving (21 CFR §101.62(b)). Usually, as milk-fat content increases in a product, the MSNF content decreases to avoid an increase in mix viscosity (Goff and Hartel, 2013).

Table 1-1. Approximate composition of ice cream, adapted from Goff and Hartel (2013).

	Composition (%)			
	Milk fat	**Milk solids non-fat**	**Sweeteners**	**Total solids**
Nonfat ice cream	<0.5	12-14	18-22	28-32
Low-fat ice cream	2-5	12-14	18-21	28-32
Reduced-fat ice cream	7-9	10-12	18-19	32-36
Economy ice cream	10	10-11	15-17	35-36
Standard ice cream	10-12	9-10	14-17	36-38
Premium ice cream	12-14	8-10	13-16	38-40
Super premium ice cream	14-18	5-8	14-17	40-42

Once the ingredients have been sourced and analyzed, a formula is used to calculate the recipe needed for production of a specific batch size. All liquid ingredients are measured and transferred into a blending tank. The solid ingredients are weighed and added to the liquid ingredients under agitation at a temperature below 50°C to favor dissolution of solid particles

(Goff and Hartel, 2013). It is important to control the agitation speed to avoid formation of foam that may produce problems in further operations. Once ingredients have been fully dispersed, the ice cream mix is homogenized to reduce the particle size of the milk fat globules. This process prevents creaming during the storage of the mix. As the particle size of the native fat globules is reduced, the native coat of phospholipids present in the milkfat globules is insufficient to cover the increased lipid-water interface. Amphiphilic molecules such as proteins and emulsifier cover the interfacial area to reduce the free energy associated with water-lipid contact. Homogenization pressures vary according to the amount of fat present in the ice cream mix: high fat mixes require lower pressures to limit an increase in viscosity that may affect the final structure (Goff and Hartel, 2013). Innocente et al. (2009) showed that increasing homogenization pressures from conventional (18MPa) to high pressure (100 MPa) produced a reduction in particle size of the fat globules of 70 to 95 nm, as well as a change in the rheological profile, where the dispersed phase accounted for the increase in viscosity and the continuous phase was responsible for the viscoelastic and gel behavior. A higher fat content presented a greater viscosity and dynamic moduli while high homogenization pressures produced stronger gels. Homogenization requires all fat present to be in a liquid state, thus the mix must be above 40°C before entering the homogenizer. This dictates the position of this operation in the process flow: if using a batch pasteurizer, homogenization often immediately follows pasteurization; if using a continuous pasteurizer, it can be placed after the regeneration section (Goff and Hartel, 2013).

Pasteurization is used to eliminate vegetative pathogenic microorganisms from the mix and to reduce the numbers of spoilage organisms present in the mix. The minimum time and temperature required for pasteurization of ice cream mix are 25 seconds at 80 °C when using a High Temperature Short Time (HTST), or 30 minutes at 68.3°C for a batch process (21 CFR §135.3). The heat treatment also aids in improving the dissolution of solid ingredients, in particular the hydrocolloids used as stabilizers.

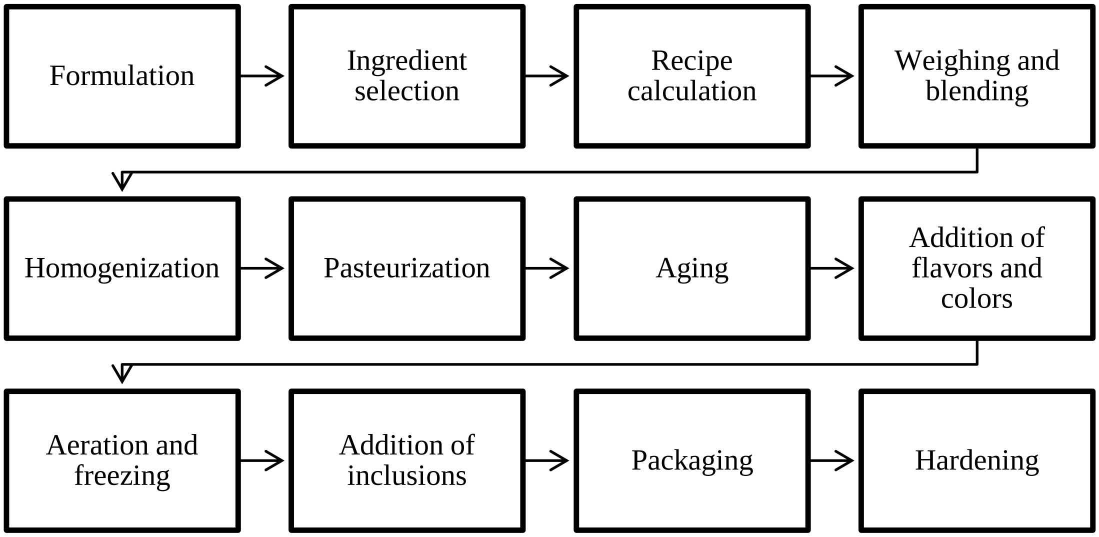

Figure 1-1. Flow diagram of typical ice cream production.

After pasteurization, the ice cream mix is cooled to refrigeration temperatures (<7°C) and aged between 4 to 24 hours. The fat globules, that were molten during pasteurization, partially crystalize during this aging time; while the emulsifiers, if present in the ice cream mix, displace some of the proteins at the lipid-water interphase. These two process will favor partial coalescence of milk fat globules that will help produce the final desired physical structure, a dry product at extrusion with good resistance to melting (Goff and Hartel, 2013). Prior to freezing, the ice cream mix may be flavored.

Fundamentally, ice cream freezers are scraped surface heat exchangers, consisting of a barrel with a rotational dasher equipped with scrapers blades (Figure 1-2) (Bolliger et al., 2000b). On the outside of the walls, a refrigerant flows. The walls of the freezer are the coldest point in the freezing cylinder and it is the nucleation spot for ice crystals. The ice crystals are removed from the walls by the scraper blades. In a batch style freezer, air is incorporated into the product by the agitation of the dasher that captures it from the environment. In a continuous operation, air is directly injected into the freezer allowing a more precise control of overrun in the final product. Due to the shear forces in the freezer, the milk fat particles collide with each other and partially coalesce causing the formation of a three dimensional network of fat globules. The cluster of fat globules formed due to this process, also known as fat destabilization, aids in the stabilization of the air in the final product (Goff et al., 1999). Once about half of the water present in the mix is frozen (T~-5°C depending on the composition of the mix), the ice cream is taken from the freezer and mixed with solid inclusions, if desired. Then, the product is packaged and sent to a hardening system, such as a forced-air convection freezer with temperatures below -30°C, where around 80% of the water present in the mix is frozen by the growth of the crystals (Goff and Hartel, 2013). The hardening step does not cause any more ice crystals to nucleate, but rather it allows existing crystals to grow in size.

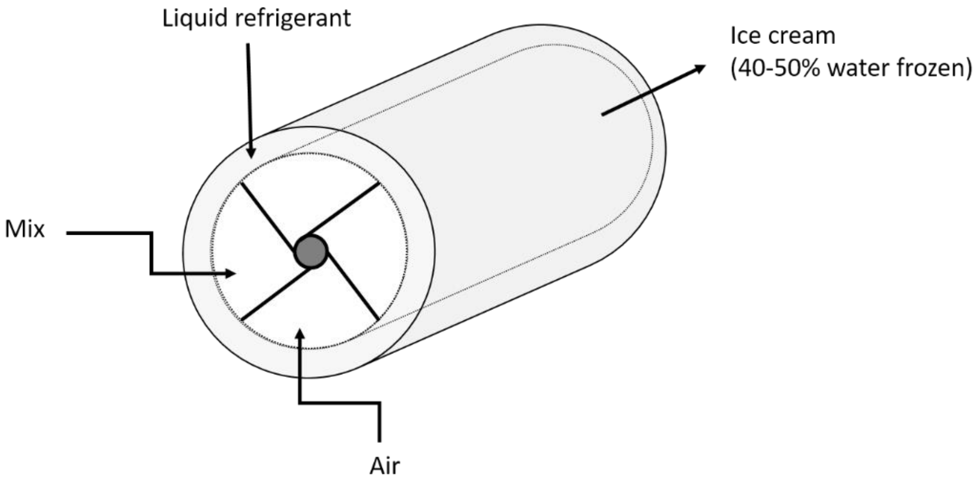

Figure 1-2. Diagram of an ice cream freezer barrel.

1.4 Ice cream structure

Ice cream is a complex food matrix with multiple phases that contribute its characteristic structure and sensory attributes (Goff and Hartel, 2013). Physically, it consists of water in the form of ice crystals; air whipped into small bubbles; fat in the form of partially destabilized clusters; casein micelles in a colloidal suspension; and a concentrated unfrozen aqueous solution of hydrophilic proteins, sugars, stabilizers and minerals. This structure is obtained by the combination of a correct formulation and balance of the initial mix as well as the manufacturing process, in particular the freezing conditions applied.

1.4.1 Water and ice crystal formation

The water present in the mix is converted into ice crystals during the first freezing stage of ice cream manufacturing. The number and size of these crystals has an effect on the final texture of ice cream, where crystals above 45 μm are perceived as a grainy or gritty (Buyck et al., 2011; Goff and Hartel, 2013). To achieve a correct texture, the dynamic freezing must be fast enough to produce many crystals of a size ranging from 15 to 30 μm (Goff and Hartel, 2013). The freezer is designed to remove heat from the mix, resulting in a rapid decrease in temperature below the freezing point, where the transition to solid state is favored (Adapa et al., 2000). Ice crystal nuclei are formed at the walls of the barrel, the coldest point of the freezer and grow as dendrites. The rotation of the dasher scrapes the crystals into the bulk of the mix where they ripen due to the higher temperatures to rounder shapes (Hartel, 1996; Adapa et al., 2000). By the end of the dynamic freezing about 50% of the water is frozen (Hartel, 1996), and the product contains the largest amount of ice crystals it will ever have.

During hardening, though existing crystals grow in size; no more crystals are formed. The water molecules present in the ice cream move to the existing ice crystals surface and crystalize, increasing their size (Adapa et al., 2000b). After hardening, about 75-80% of the water in the ice cream is frozen (Hartel, 1996).

Storage temperatures below -30°C help maintain ice crystals size, probably due to the proximity to glass transition temperatures (Adapa et al., 2000b). However, temperature fluctuations during storage and shipping may result in an increase in size of the crystals resulting in the grainy/icy defect. Ndoye and Alvarez (2015) studied the effects of storage temperature and temperature fluctuations on ice cream using focused beam reflectance measurements. They observed that higher storage temperatures and a higher temperature fluctuations produced an increase in the mean size of the ice crystals and a wider distribution of sizes. Common recrystallization mechanisms in ice cream include isomass rounding, accretion and Ostwald ripening. Isomass rounding involves a reorganization of the crystal that smooths the edges; while accretion refers to the coalescence of two crystals into a bigger one (Ndoye and Alvarez, 2015). Ostwald ripening is the mechanism were bigger crystals grow at the expense of the small ones, by migration of the water molecules from the surface of smaller to larger crystals (Coupland, 2014). Thus, the viscosity of the unfrozen serum plays an important role in the growth of ice crystals during hardening and storage. The presence of ice growth inhibitors such as stabilizers and propylene glycol monostearate (PGMS) can control the degree of crystal growth, by different mechanisms (Adapa et al., 2000; Aleong et al., 2008). The amount of fat influences the size of the ice crystals; a high fat content reduces the growth of the crystals by interfering with water diffusion (Adapa et al., 2000). Other factors that might increase the rate of recrystallization include low solids of the mix, low freezing point, high draw temperatures and defective scraper blades (Buyck et al., 2011).

1.4.2 Serum

The serum phase includes all the sugars, proteins, minerals and stabilizers in water. The proteins are present as a colloidal suspension while the solutes are dissolved in the water phase. The presence of low molecular weight solutes, such as minerals and sugars, decrease the mix freezing point from that of pure water. This parameter is of importance for the manufacture of ice cream since it will determine, along with the final freezing temperature, how much of the water present will be frozen at a given temperature (Adapa et al., 2000). The depression of the freezing point is dependent on the number of molecules of low molecular weight present in the mix. In ice cream, the main components that affect freezing point are the sugars and minerals (Adapa et al., 2000b). During freezing, water is removed from the solution due to the formation of ice crystals. The remaining unfrozen serum becomes more concentrated, producing a further depression of the freezing point which requires a lower temperature for the remaining water to become a solid. Between -23 and -43°C, depending on mix composition, the system transitions into the metastable glassy state (Goff et al., 1993). This is of particular importance during the storage of ice cream since, below the glass transition temperature (Tg), the system behaves like a solid, with restricted molecular movement that inhibits crystal growth (Goff and Hartel, 2013).

Stabilizers are added in low doses to the ice cream mix and they remain in the unfrozen phase. These compounds are hydrocolloids that can bind water increasing the viscosity of solutions. As ice is formed, they become concentrated and their effect on the overall viscosity is increased. Individual hydrocolloid molecules may also interact with one another due to the close proximity given by the concentration process, which further limits the diffusion of water and other solutes thus inhibiting recrystallization (Goff et al., 1993).

The concentration of dissolved lactose in the ice cream mix increases during freeze-concentration, but it remains in an amorphous state due to the fast speed of freezing. Lactose crystallization is possible with temperature fluctuations during storage, and it produces a textural defect often described as sandiness (Goff and Hartel, 2013).

1.4.3 Emulsion

After homogenization of the ice cream mix, milkfat is present in the form of distinct globules with a size of less than 2 µm (Goff and Hartel, 2013). Fat is the dispersed phase of an emulsion where the continuous phase is the serum. Emulsions are unstable systems that seek thermodynamic equilibrium by different mechanisms including flocculation and coalescence (Goff, 1997b). Flocculation refers to the process were the globules stick together while retaining their size and identity as an individual particle; while coalescence refers to the event where the particles come together and become one, losing their individual identity to become a bigger uniform globule (Goff, 1997b; Coupland, 2014). The presence of amphiphilic molecules, such as proteins and emulsifiers, reduce the surface tension of the lipid-water interface and stabilizes emulsions. During the steps prior to dynamic freezing, the mix is aged and kept at temperatures that induce the partial crystallization of the fat contained in the globules (Goff, 1997b), thus the fat globules at refrigeration temperature contain fat in liquid state and as solid crystals. The combination of the freezing and whipping process causes partial destabilization of fat droplets where the individual particles cluster in a three-dimensional structure. This process is thought to be due to partial coalescence (Méndez-Velasco and Goff, 2012). When two fat globules come close together, the presence of fat crystals inside the globules can break the interface, forming a solid bridge between the particles. The surrounding liquid oil present will wet the crystals reinforcing the union (Vanapalli and Coupland, 2001; Fredrick et al., 2010). The fat globules retain their original shape, but there is a connection between the contents of the particles (Goff, 1997b; Fredrick et al., 2010). As this events continues, an irregular arrangement of clusters forms, which increases the viscosity of the system and limits the movement of the continuous phase (Fredrick et al., 2010).

Fat destabilization is dependent on the amount of fat, the percentage of solid fat in the aged mix, the size of the fat droplet, the shear force applied in the freezing barrel and the arrangement of the fat crystals in the globule (Fredrick et al., 2010; Goff and Hartel, 2013). The type and nature of the surface active molecules also affects the behavior of the fat globules when placed under shear stress. Milk proteins, both casein and whey proteins, may be present at the interface. A stronger protective layer of protein, such as that formed by denatured whey proteins or casein, reduces the amount of partial coalescence caused by shear (Goff, 1997b). The amount of protein present in the ice cream mix will also affect the extent of fat destabilization, a high protein content will reduce this process (Daw and Hartel, 2015). Smaller surfactants molecules promote fat destabilization by competing with proteins and displacing them from the interface, causing a thinning of the surface which cannot prevent partial coalescence during whipping (Goff and Jordan, 1989; Goff, 1997b). The crystallization of water is needed, along with the shear action to favor partial coalescence in ice cream (Goff, 1997b). The formation of ice crystals during dynamic freezing forces the fat droplets to come into contact, increasing the rate of fat destabilization (Fredrick et al., 2010).

One of the primary effects of fat destabilization is its role in the formation of the microstructure of ice cream. Goff et al. (1999) observed, using electron microscopy, that as the degree of fat destabilization increases, a higher amount of fat clusters is present in the interphase of the air bubbles. They also showed areas in the bubble’s interphase with no fat coverage, which were thought to be covered by proteins or emulsifiers. This was supported by Koxholt et al. (2001) who investigated the effect of fat destabilization on ice cream meltdown and in the mechanism of foam stabilization. They concluded that, when the fat clusters reach a size bigger than the air lamella, a large amount of fat is retained at the interface of the air bubbles, limiting drainage and resulting in the observed reduction of melting rate.

1.4.4 Air phase

Air is the last ingredient introduced into ice cream during the dynamic freezing stage. It forms a foam that provides a smooth and foamy mouthfeel to the final product. Moreover, it retards the melting rate of ice cream due to the lower thermal conductivity of air which acts as an insulator (Xinyi et al., 2010). Overrun measurements are used to quantify the amount of air incorporated during freezing. It refers to the increase in volume after the dynamic freezing, compared to the volume of the mix (Goff and Hartel, 2013).

The amount of air added varies depending on the formulation of the mix as well as the type of freezer used. Batch freezers incorporate air directly from the environment though whipping, while continuous freezers inject air under pressure (Xinyi et al., 2010). The continuous whipping results in air cells with a wide range of sizes, from 1 to 100 μm (Goff and Hartel, 2013), but sizes ranging between 10-50 μm were found to be the most stable (Xinyi et al., 2010). A portion of the freezing process must be done in conjunction with the whipping to assure proper introduction of the air phase: the formation of the ice crystals and the resulting increase in viscosity of the serum phase aids in the stabilization of the air bubbles. Moreover, the presence of milk proteins, emulsifiers and partially destabilized fat clusters favor the stabilization of the air phase and prevent coalescence (Goff et al., 1999; Goff and Hartel, 2013). Foam destabilization at frozen temperatures, also known as shrinkage, may be due to changes in internal pressure of the air cells, which lead to rupture of the interphase and collapse the bubble (Xinyi et al., 2010).

1.5 Fat reduction in ice cream

Over the past decades, consumer demand has driven the food industry to decrease the amount of fat present in its products. High fat intake is considered a risk factor for energy overconsumption and weight gain which may lead to obesity (Schrauwen and Saris, 2006). Moreover, the development of obesity increases the risk of other metabolic illnesses such as type-2 diabetes (Schrauwen and Saris, 2006). The USDA 2015-2020 Dietary Guidelines recommend a daily consumption of fat equivalent to less than 35% of the total calories ingested (USDA, 2015). Fat reduction is often pursued as a strategy to reduce the overall caloric content of food, since it provides the highest amount of energy per gram when compared to the other macronutrients (McClements, 2015). Furthermore, considering the high cost of milk fat, manufacturers seek to decrease fat to reduce costs. Either the removal of fat or its replacement with an ingredient that costs less will result in overall lower production costs and higher profits for the manufacturer.

Ice cream is a complex food product, in which the removal of one ingredient may affect not only its physical structure but also the sensory characteristics that make it acceptable to consumers. Fat in particular plays a role as a structural agent; the destabilization of the fat globules and formation of a three dimensional network results in the stabilization of the air bubbles (Goff et al., 1999). This provides the characteristic smoothness, dryness and retarded melting rate that is expected from the product (Goff and Hartel, 2013). Moreover, fat acts as a flavor delivery system, in particular of molecules that are hydrophobic in nature. However, consumers tend to associate reduced-fat products with a lower sensory quality. da Silva et al. (2014) studied the perceptions of frequent consumers to several concepts of ice cream, including Traditional, Light, and Zero Fat by word association. They observed that traditional ice cream was related to appealing sensory descriptors and a high calorie intake, while Light and Zero Fat concepts were associated with a decrease in sensory quality and food restriction. A consumer panel used in a study on the effect of fat content on flavor perception of vanilla ice cream showed a greater preference for the high fat ice creams, even for those participants who self-declared to like reduced-fat products better (Li et al., 1997).

A strategy often used to reduce the fat content of frozen desserts, involves simply taking a percentage of the fat out of the formula and balancing the mix by adding water. By following this method, all components are diluted and the total solids are reduced. Previous research addressed the changes in physical properties, including rheology of the mix, and melting rate and hardness of the final ice cream; as well as changes in the sensory profile.

Rheology measurements are used to characterize the way a material flows (Coupland, 2014). Ice cream mix is a non-Newtonian, shear-thinning liquid (Innocente et al., 2009; Karaca et al., 2009; Mahdian and Karazhian, 2013). This type of flow is characterized by the decrease in apparent viscosity as shear rate increases (Singh and Heldman, 2014). The apparent viscosity of mixes was shown to increase with an increase in fat content (Specter and Setser, 1994; Li et al., 1997), due to the increase in the amount of the dispersed phase of the emulsion (Innocente et al., 2009).

Hardness and melting rate are often measured in ice creams due to their relationship with the structure of the product, as well as with consumer acceptability. Hardness is dependent on the freezing point of the mix , total solids, overrun and the stabilizer (Goff and Hartel, 2013). The removal of fat has been shown to have an inverse effect on hardness: as fat decreases, hardness tends to increase (Guinard et al., 1997; Roland et al., 1999a), due to dilution of the total solids by the addition of water as a balancing agent. The rate of melt has a strong influence on consumer acceptance, as it is desired to consume the product while still in the frozen state. The amount of air and fat affect the speed at which frozen product melts, as well as the freezing point (Goff and Hartel, 2013). An increase in fat content has been shown to produce ice creams with slow melting properties (Guinard et al., 1997; Prindiville et al., 1999; Roland et al., 1999a).

Descriptive analysis is a tool that allows researchers to create an objective depiction of products (Lawless and Heymann, 2010). For this purpose, 8 to 12 panelists are trained to select and rate the intensity of sensory attributes that are considered important to the product, such as sweetness, hardness and vanilla flavor. Quantitative Descriptive Analysis (QDA) is one method within descriptive analysis that has been frequently used to assess changes in the sensory profile of ice cream when reducing its fat content. Conforti (1994) prepared ice creams with 10, 13 and 16%, and found no significant difference in melting rate, vanilla intensity, flavor masking and sweetness between the samples. However, the sensory chewiness increased with the increase of fat content; while iciness decreased with increasing fat content. Stampanoni Koeferli et al. (1996) observed that the addition of fat from 3 to 12% increased firmness, mouth coating, buttery and creamy notes, while it decreased coldness, ice crystal perception and melting rate. Sweetness as well as the vanillin note were not modified by fat addition. Guinard et al. (1997) tested ice creams samples ranging from 8 to 18% fat and found that sweetness increased with fat content while vanilla flavor did not significantly change. In this study, the amount of fat did not generate an effect as strong as that of sugar variation on flavor or mouthfeel characteristics. Roland et al. (1999a), sought to identify and quantify the most important sensory and physical properties of vanilla ice cream, with the intent of understanding what characteristics should be considered when fat is removed from ice cream. They prepared samples containing 0.1, 3, 7 and 10% fat and formulated them to have the same freezing properties. The results obtained for the descriptive analysis of selected attributes are presented in Figure 1-3. The authors observed that, as fat content decreased, the texture and flavor attributes significantly decreased in intensity. However, melting rate decreased as fat content increased. In the conclusion they state that whenever fat needs to be removed from ice cream, an ingredient (or ingredients) must be used to replace the solids lost due to the fat-reduction. Moreover, this substitute must impart cohesiveness, moderate the coldness perception and slow the melting rate of the product. However, most of the studies cited above did not verify that the sensory changes noted by trained panelists can be also perceived by naïve consumers.

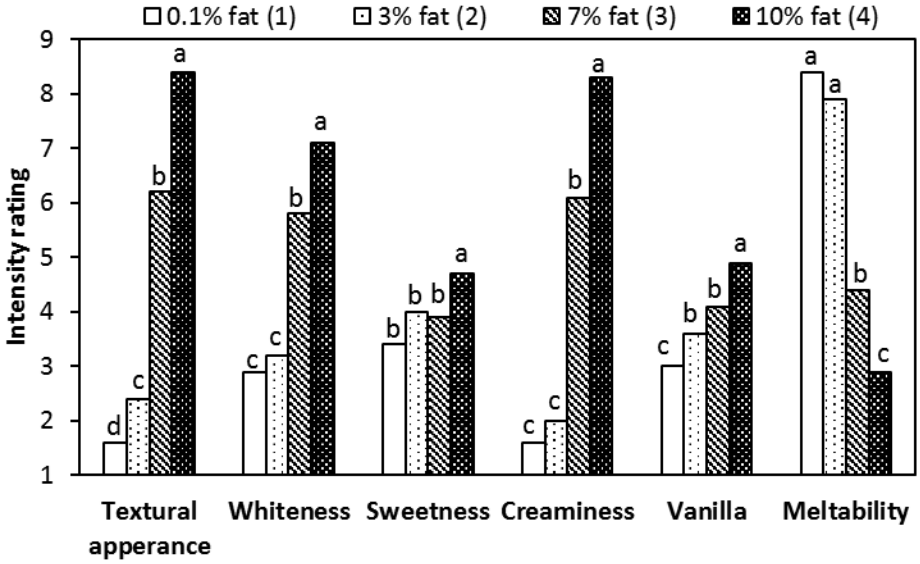

Figure 1-3. Descriptive analysis of vanilla ice cream with 0 to 10% fat content, adapted from Roland et al. (1999a). Different letters within the same descriptor represent significant differences at α=0.05. Ice creams were formulated to have similar freezing points and percentage of frozen water. All ice creams were formulated with 13.1% sugar, 4.5% CSS, 11.0% MSNF and 0.2% stabilizer; and an overrun of 90%.

(1) Composed of 0.1% fat and 28.7% total solids.
(2) Composed of 3% fat and 31.5% total solids.
(3) Composed of 7% fat and 35.2% total solids.
(4) Composed of 10% fat and 38.5% total solids.

Few authors have studied the effect of fat removal on consumer acceptability. Guinard et al. (1996), aimed to determine the concentrations of fat and sugar that would yield the highest acceptability score for vanilla ice cream. They observed a small effect from the fat levels, while the sugar content was found to be a more important determinant of acceptability; and declared the optimal formulation to contain 14.3% sugar and 14.8% fat. However, the effect of reducing the total solids in the ice cream samples might have had a bigger effect on the changes observed in consumer acceptability. Figure 1-4 was produced with data from Guinard et al. (1996) and shows a possible effect of the change in total solids to the consumer acceptability rating. Briefly, overall liking was plotted as a function of total solids content, and a polynomial regression was applied. The use of a higher order equation did not produce a higher coefficient of determination (R^2).

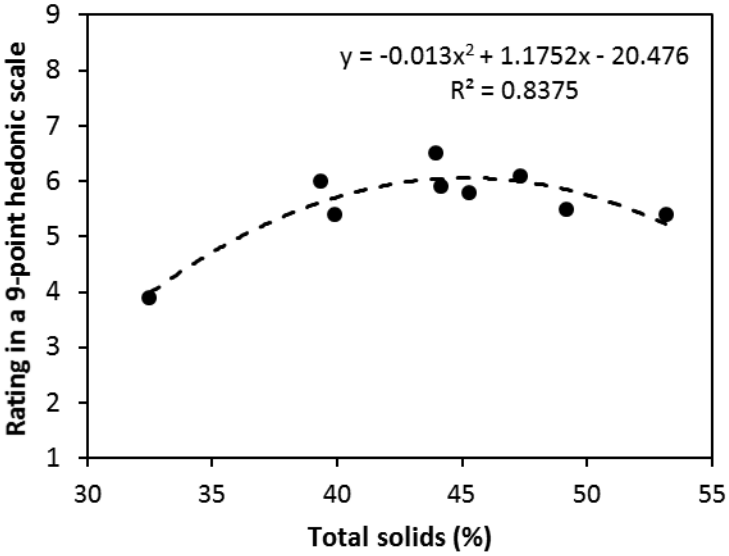

Figure 1-4. Possible effect of total solids on consumer acceptability. Adapted from Guinard et al. (1996), using the mean total solids and mean hedonic rating for each treatment; then applying quadratic trend line.

1.5.1 Use of fat replacers and bulking agents

The change in sensory properties due to the decrease in total solids when removing fat has led several research groups to study the use of fat replacers and bulking agents as an alternative strategy. While terminology varies widely in the literature, for the purpose of the present study, fat replacers are defined as compounds used to mimic the textural and sensorial properties of fat while bulking agents are ingredients used only to account for the loss in solids due to the removal of fat. Fat replacers can be lipids, proteins or carbohydrates in their chemical nature (Akoh, 1998). Carbohydrate and protein-based fat replacers are usually used due to their lower caloric content when compared to fat. In general these macromolecules adsorb a significant amount of water which produces a modification in viscosity and the perceived texture of the product (Akoh, 1998). However, they lack the ability to transport hydrophobic flavor molecules. Some of the protein-based fat replacers are produced by shear under heat, process known as microparticulation, to create a spherical deformable particle that can mimic the texture of fat; while others are modified to increase their water holding capacity or their emulsifier functionality (Akoh, 1998). Protein-based fat replacers are thought to produce reduced-fat ice cream with a more similar flavor profile to the full-fat version (Liou and Grün, 2007).

Physical characterization of ice cream with addition of an ingredient to replace the fat have included rheology, melting rate, and hardness measurements. The use of carbohydrate-based ingredients, such as maltodextrin, polydextrose and inulin, has been shown to increase the viscosity in fat-reduced ice creams when compared to the full-fat product (Schmidt et al., 1993; Aykan et al., 2008). The use of fat replacers often produces ice creams that melt faster than full-fat products (Ohmes et al.,1998; Roland et al., 1999b; Tiwari et al., 2015). However, Li et al. (1997) observed a reduction in melting rate when using polydextrose to reduce the fat content of vanilla flavored ice creams. Roland et al. (1999b) showed a decrease in hardness of non-fat ice creams with the addition of maltodextrin or polydextrose, when compared with a non-fat ice cream with lower solids concentration. Tiwari et al. (2015) observed an increase in hardness with the use of inulin as a fat replacer.

Descriptive sensory analysis has been used extensively to assess the changes produced in the sensory profile of reduced-fat ice cream. Schmidt et al. (1993) investigated the effects of protein and carbohydrate-based ingredients on 2% fat ice milk. In this work, the carbohydrate-based ingredient (maltodextrin) yielded ice creams with a higher viscosity than the other samples with lower whipping ability, measured as the amount of overrun over freezing time. The protein fat replacer (microparticulated whey protein) produced mixes with higher whipping ability, probably due to the surface properties of whey proteins. The authors conclude that the use of the protein-based replacer resulted in ice milk that was more similar to the 5% control than the use of a carbohydrate-based ingredient. In an extension of their previous study, Roland et al. (1999b) tried to identify a fat replacer to use in fat-free ice cream formulations that would provide the sensory and physical characteristics of a full-fat ice cream. They used maltodextrin (MD), polydextrose (PD) and milk protein concentrate (MPC) and formulated the ice creams with 0.1% fat to have the same freezing characteristics (freezing point and percentage of frozen water) and sweetness as a 10% fat ice cream. Figure 1-5 shows an adaptation of the results obtained for selected sensory descriptors. It can be seen that the use of maltodextrin on non-fat ice creams produced intensity ratings that are closer to those of the 10% fat control, though still significantly different.

Few studies investigated the effect of fat replacement on consumer acceptability. Prindiville et al. (1999) studied the effect of milk fat on sensory properties of chocolate ice cream, preparing samples that ranged in fat content from 0.5% to 10% fat with the addition of polydextrose or microparticulated whey protein isolate. Consumer acceptability did not differ across the samples, which the authors attribute to the use of the fat replacement strategies. However, Li et al. (1997) observed an increase in liking with increased fat content from 6 to 10%, when using polydextrose to maintain total solids constant.

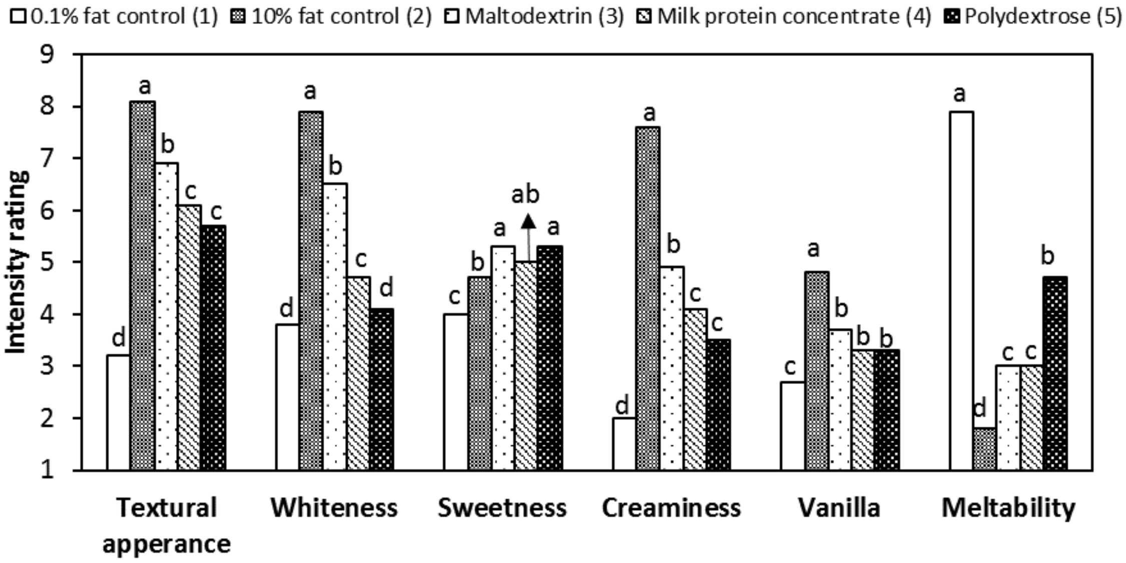

Figure 1-5. Effect of using fat replacers on descriptive sensory parameters, adapted from Roland et al. (1999b). All ice creams were manufactured to have a 90% overrun. Ice creams that included a fat replacer contained 0.1% fat and were formulated to have the same sweetness intensity and % of frozen water at -13°C as that of the 10% fat control.

(1) 0.1% fat ice cream was composed of 11.0% MSNF, 13.1% sugar, 4.5% CSS and 30.5% total solids.
(2) 10% fat ice cream was composed of 11.2% MSNF, 13.1% sugar, 4.5% CSS and 39.2% total solids.
(3) The maltodextrin treatment had the addition of 13.3% MD
(4) The milk protein concentrate treatment has the addition of 6% MD and 4.6% MPC.
(5) The polydextrose treatment had the addition of 5.3% MD and 10.12% PD.

This section aimed to review the strategies implemented when a reduction in fat content of ice cream is desired. The use of descriptive analysis showed changes in sensory attributes, in particular a decrease in those that are thought to be critical to ice cream liking, such as sweetness, vanilla flavor and creaminess when compared to a full-fat product. However, very few have looked into the consumer perspective of fat reduction in dairy frozen desserts. Moreover, when this technique was used, it was limited to a few samples of a wide range of fat content; or fat was not the only component of the ice creams that was tested. The question remains if the changes detected by trained panelists can be perceived by naïve consumers. Furthermore, the extent to which fat can be reduced and replaced with a single ingredient without changing liking has not been investigated. Regarding the physical structure of ice cream and the possible changes due to fat reduction, rheological properties have been studied as well as the hardness and melting rate of the products. Parameters related with the fat physical structure, such as particle size and the degree of destabilization after freezing, have often been overlooked. It is interesting to note that, while most studies included physical and sensory analysis, most of them failed to look for a possible relationship between these parameters, which could lead to the identification of possible drivers of liking of vanilla ice cream.

Chapter 2

Statement of the problem

Fat reduction is a strategy often pursued to decrease the overall energy density of food products. Fat is the most energy dense macronutrient, providing 9 kcal/g, when compared to proteins and carbohydrates (4 kcal/g). Moreover, fat sources are often among the most expensive ingredients, particularly in products like ice cream. However, consumers often perceive a lower sensory quality in reduced-fat products, when comparing them to the full fat version.

Ice cream is a very complex food matrix, with multiple coexisting physical phases including ice crystals, air bubbles, partially coalesced fat globules and a highly concentrated, unfrozen serum. Fat contributes to the texture of the product, by generating a smooth product with retarded melting rate; and also acts as a flavor delivery system. Furthermore, it is an important component of the characteristic creamy perception associated with these products.

Removal of fat from ice cream and its replacement with water has been shown to produce harder ice creams with a different sensory profile when compared to full-fat products, a lower mix viscosity and a faster melting rate. The use of bulking agents and fat replacers has shown to be a better alternative. However, the perfect replacement strategy has not been found, since the flavor and texture attributes of reduced-fat products do not fully match those of the full-fat versions. Descriptive analysis has been the main sensory technique used to evaluate the effect of fat reduction on ice cream. The use of maltodextrin, a polysaccharide produced by partial hydrolysis of starch, has shown promise as a bulking agent in non-fat ice cream. Moreover, there is a lack of information regarding the effect that fat reduction has on consumer acceptability and preference of vanilla ice cream.

Based on the available literature, **I hypothesize that replacement of fat with maltodextrin in vanilla ice cream will result in a change of the physical structure that will**

lead to a reduced consumer acceptability. This study aims to investigate the effect of fat reduction and the use of maltodextrin as a bulking agent on physical properties related to the structure of fat in ice cream, as well as its effect on consumer acceptability. The first objective is to evaluate the effect of fat replacement with maltodextrin on properties related to the physical structure of ice cream. Simultaneously, the fresh ice creams will be evaluated for consumer acceptability initially and after storage for 19 weeks at -18°C. The final objective is to determine if consumers are able to discriminate vanilla ice creams, based on their fat content.

Chapter 3

Effect of fat reduction on physical parameters and consumer acceptability of vanilla ice cream

3.1 Abstract

Fat reduction is often pursued as a way to reduce the overall energy density of food products. Ice cream is a complex food where removal of one ingredient may affect not only physical properties but also multiple sensory characteristics that are important to consumers. Fat, in particular, plays a role in structuring ice cream, contributing to the characteristic smoothness, dryness and melting rate. Removal of fat from ice cream without replacement of solids has been shown to decrease sensory quality indicators. Previous work evaluating fat removal strategies has focused on changes in key sensory descriptors, with surprisingly little information being collected on consumer acceptability of reduced-fat products. Here, we evaluated the effect of replacing fat with maltodextrin (MD) on consumer acceptability and on selected physical properties of ice cream simultaneously. Vanilla ice creams were formulated with 6, 8, 10, 12 and 14% fat and 8, 6, 4, 2, and 0% maltodextrin, respectively. A series of sensory tests were conducted in the Sensory Evaluation Center at Penn State, each with ~100 participants, to measure liking and perceived intensity of various sensory attributes. A triangle test was used to determine the difference in fat content that consumers are able to discriminate. Physical measures included fat particle size, fat destabilization, hardness and melting rate. The experiment was replicated three times. Data were analyzed using mixed model ANOVA and correlation to assess relationships between consumer acceptability, physical variables and sensory attributes. Additional sensory testing was conducted after 19 weeks of storage at -18°C. Fat particle size and fat destabilization significantly decreased

with fat reduction, but consumer acceptability did not significantly differ with fat content for fresh or stored ice cream. Overall liking was correlated with slower melting rate in fresh ice cream. Following storage, ice creams with 6, 12 and 14 % fat did not change in consumer acceptability compared to fresh ice cream. However, ice creams with 8 and 10% fat (and 6 and 4% MD), each showed a small though significant drop in liking score following storage. Consumers were not able to discriminate a 2% fat difference in ice creams that ranged in fat content from 6 to 12%, and had maltodextrin in the formulation. However, the 12 and 14% fat samples were discriminated, possibly due to the presence of maltodextrin in the lower fat sample. Collectively, the changes on the physical structure of ice cream caused by the reduction in fat from 14 to 6% did not show evidence of gross changes in consumer acceptability for either fresh or aged ice cream, although storage altered liking for some formulations but not others.

3.2 Introduction

Due to the risk of obesity and the consequences on human health that the overconsumption of calories may pose, the food industry has dedicated considerable efforts to reducing the caloric density of products (Schrauwen and Saris, 2006). Fat reduction is often pursued as a strategy to reduce the overall caloric content of food, since it provides the highest amount of energy per gram when compared to the other macronutrients (McClements, 2015). Reduced and low-fat products have been increasing in popularity, due to consumer’s desire to reduce their intake of fat and calories. However, consumers tend to associate reduced-fat products with a lower sensory quality (da Silva et al., 2014). Furthermore, considering the high cost of milk fat, manufacturers seek to decrease fat to reduce costs. Either the removal of fat or its replacement with an ingredient will result in lower production costs and higher profits for the manufacturer.

In ice cream, the reduction of fat results in multiple issues, due to its contribution to flavor and mouthfeel; while also acting as a structural agent. Previous researchers have used one of two strategies when reducing fat from ice cream - either simply removing fat or removing fat and replacing the solids with fat replacers or bulking agents. Previous work has focused on studying the effects of fat reduction by comparing the sensory profile of reduced-fat products to a full-fat version, using descriptive techniques (Conforti, 1994; Stampanoni Koeferli et al., 1996; Roland et al., 1999a). Studies that examined the consumer perspective often had experimental designs that could have cofounded the effect of the reduction in solids (Guinard et al., 1996), or did not have enough power (Aykan et al., 2008; Tiwari et al., 2015) to obtain representative results. In a study where fat was completely removed from vanilla ice cream, maltodextrin showed the closest descriptive sensory profile when compared to a full-fat version (Roland et al., 1999b), however significant differences were still found. Maltodextrins (MD) are polysaccharides produced by partial hydrolysis of starch, composed of D-glucose with an α-(→4) glyosidic bond (Sonwane and Hembade, 2014); the length of the chain varying from 2 to 20 residues depending on the degree of hydrolysis. Maltodextrins are classified by their dextrose equivalent (DE), the percentage of reducing sugars, measured as glucose, on dry basis (Marchal et al., 1999). Lower DE maltodextrin has a higher predisposition to forming gels, due to the prevalence of long chains (Dokic et al., 1998).This project aims to study the effect of replacing fat with maltodextrin on consumer acceptability and on physical parameters of ice cream, simultaneously. Moreover, it intends to investigate the effect of storage on consumer acceptability of reduced fat ice creams. Finally, it intends to determine if ice creams can be discriminated by their fat content.

3.3 Materials and methods

3.3.1 Ingredients

Pasteurized whole milk, pasteurized cream, sugar, 36 DE corn syrup solids (CSS) and non-fat dried milk (NFDM) were provided by the Berkey Creamery (University Park, PA). Maltodextrin 10 DE was kindly provided by Tate&Lyle (Star-dri® 100, Tate&Lye, London, UK). A stabilizer/ emulsifier blend (Grindsted® IcePro 2005 SH, DuPont, Wilmington, DE) was used, which is composed of propylene glycol mono esters, mono and diglycerides, cellulose gum, guar gum, carrageenan and silicon dioxide.

3.3.2 Formulation

Vanilla ice creams were formulated to contain 6 to 14% milkfat, in two percent increments. Maltodextrin 10 DE was added to account for the loss of solids. The level of milk solids non-fat, sugar, corn syrup solids and stabilizer/emulsifier (S/E) blend was kept constant throughout the treatments. The formulations for each treatment are presented in Table 3-1.

Table 3-1. Vanilla ice cream formulations with decreasing fat content and replacement with maltodextrin (MD).

	Treatments				
	6% fat; 8% MD.	**8% fat; 6% MD.**	**10% fat; 4% MD**	**12% fat; 2% MD**	**14% fat; 0% MD**
Milkfat	6.00	8.00	10.00	12.00	14.00
MSNF	10.50	10.50	10.50	10.50	10.50
Sucrose	12.96	12.96	12.96	12.96	12.96
Stabilizer/emulsifier	0.50	0.50	0.50	0.50	0.50
Corn syrup solids	3.70	3.70	3.70	3.70	3.70
Maltodextrin 10 DE	8.00	6.00	4.00	2.00	0.0
Total Solids	41.66	41.66	41.66	41.66	41.66

Once the composition of the milk and cream to be used for the production of the ice cream treatments was measured, all mixes were formulated using TechWizard ™ version 4 (Owl Software, Columbia, MO) to obtain the final recipe. This software was also used to provide an estimate of the freezing point of the ice cream samples, as well as the amount of water frozen at the draw temperature, based on the formulations.

3.3.3 Ice cream manufacture

Figure 3-1 shows the process flow diagram used for manufacture of ice cream. Wet (milk and cream) and dry (sugar, non-fat dried milk, corn syrup solids, maltodextrin and the stabilizer/emulsifier blend) ingredients were weighed separately and blended together, under low speed agitation for 20 minutes at room temperature, to allow for a complete dispersion of the solids. The treatments were pasteurized in a continuous HTST (APV Junior Pasteurizer, APV Invensys, Woodstock, GA) at 80°C for 25 seconds and homogenized (Gaulin, Lake Mills, WI) in a two-stage process applying a pressure of 10.3 and 3.5 MPa respectively. The pasteurized mix was cooled to 7°C, collected into milk cans and stored at refrigeration temperature (<7°C) for 48 hours, to allow complete hydration of the stabilizers and partial crystallization of the fat globules. After aging, samples were collected for physical and microbiological analysis of the mix. Before freezing, the mixes were flavored with two-fold vanilla extract (David Michael & Co, Philadelphia, PA) (4.45 ml/kg mix) and converted into ice cream, using a continuous freezer (Gram IF 600, Gram Equipment, Inc., Northvale, NJ) with overrun set at 65%. The resulting ice cream was packaged (Compact Single Line Rotary Filler, T.D. Sawvel Co. Inc., Maple Plain, MN) into 4-ounce cups, coded with a three-digit blinding number and kept in a -35 °C hardening room. Three days prior to the sensory test, the ice creams were allowed to temper in a -18°C freezer. All the ice creams were tested for total aerobic bacteria and High Sensitivity Coliform counts (Petrifilm™, 3M, Maplewood, MI) to assure their suitability for human consumption. Three batches of the ice cream treatment levels were manufactured between March, 2015 and October, 2015.

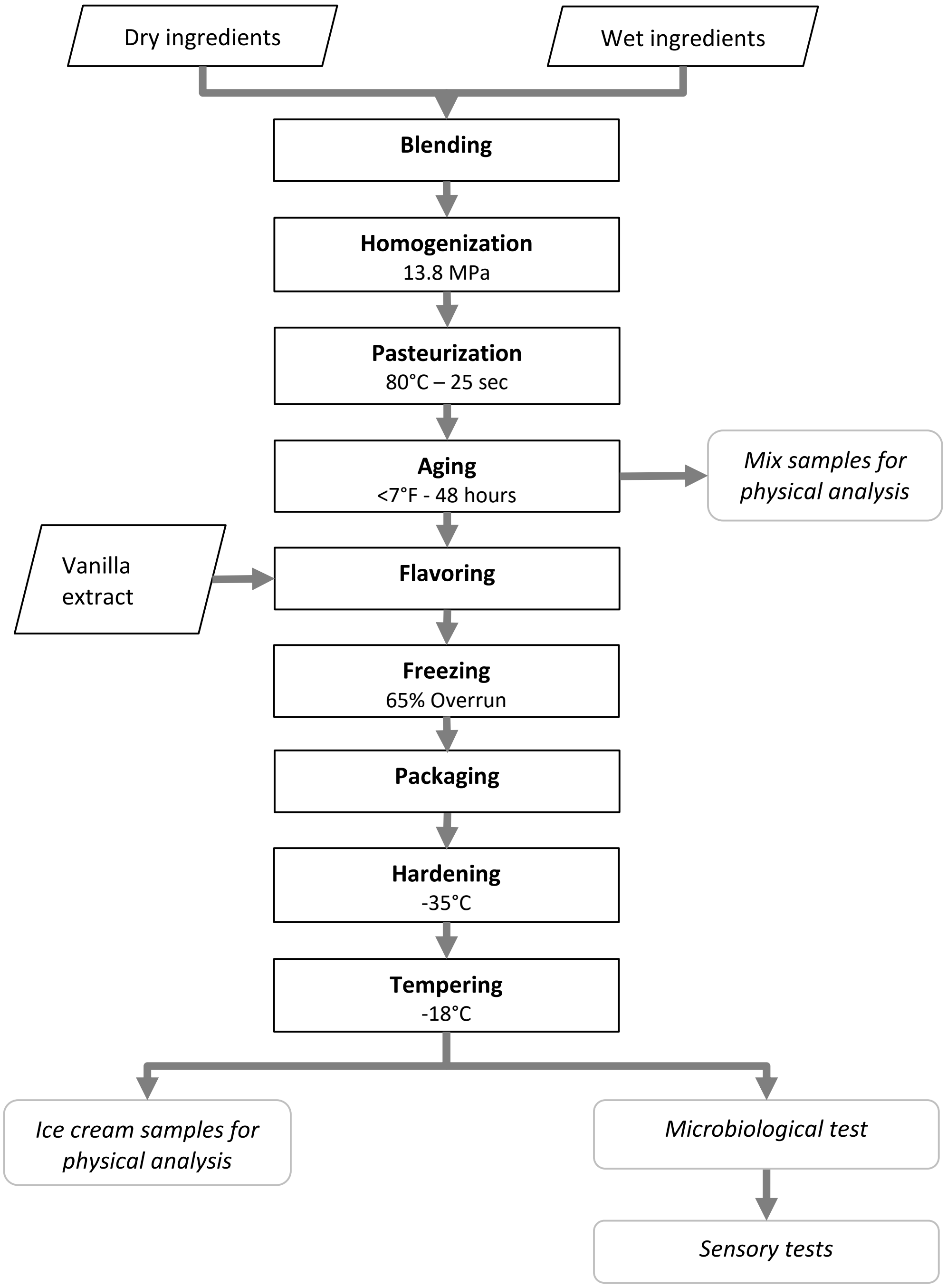

Figure 3-1. Flow diagram of ice cream manufacturing used for this project.

3.3.4 Physical analysis

3.3.4.1 Total solids and total fat

Total fat and solids content were measured using Smart Track (CEM Corporation, Matthews, NC). Cartwright et al. (2005) compared the performance of this equipment to standard methods used to test total solids and fat content in dairy products (Wehr and Frank, 2004), including ice cream. An aliquot of ice cream mix was loaded into sample pads and placed in the moisture/solids microwave chamber. The sample was dried until constant weight by microwave drying. The dried sample was then, rolled into a plastic tube and placed in the Nuclear Magnetic Resonance (NMR) chamber. Low Resolution time domain NMR (LR-NMR) was used on the dried samples to measure the total amount of fat present. Briefly, the sample is placed in a magnetic field and a pulse of radiofrequency energy is sent through the sample which generates a signal by the hydrogen protons (Cartwright et al., 2005). After drying, the food components with protons that can be excited by this energy are the proteins, carbohydrates and lipids. However, protein and carbohydrates relaxation times are fast, while the fat protons decay slowly, allowing for an accurate measurement. The intensity of the signal is proportional to the number of protons present in the fat, and the total fat content (Cartwright et al., 2005).

3.3.4.2 Density and kinematic viscosity.

The density of the mix was measured by filling a pint container and weighing its content (Goff and Hartel, 2013). An orifice type viscometer (Zahn cup #2, Boekel Scientific, Feasterville, PA) was used to quantify the kinematic viscosity of the mixes after aging (Sahin and Sumnu, 2006). The instrument consists of cup with a fixed volume of 44 ml, a handle and a calibrated orifice. The Zahn cup was completely immersed in sample mix, lifted to the air allowing the liquid to flow through the orifice, and the time from lifting the cup until the liquid column breaks was measured with a stopwatch (ASTM International, 2005). Kinematic viscosity was calculated with the appropriate formula for the size of cup used:

$$Kinematic\ viscosity\ (cSt) = 3.5 * (time - 14)$$

3.3.4.3 Draw temperature and overrun

Draw temperature was measured during ice cream production using a calibrated thermocouple. Overrun was measured by comparing the weight of a full pint of the ice cream and that of the mixes before freezing (Adapa et al., 2000a). The overrun of each ice cream treatment was calculated by using the following equation:

$$Overrun\ (\%) = \frac{weight\ mix - weight\ ice\ cream}{weight\ ice\ cream} * 100$$

3.3.4.4 Rheology

To characterize the flowing behavior of the ice cream mixes, a rheological test was performed. Aged mixes were analyzed with a rheometer (Discovery HR-3, TA Instruments, New Castle, DE) with a modification of the method used by Innocente et al. (2009). A 25 mm parallel plate geometry was used for the analysis; shear rates ranged from 0 to 80 s^{-1} and temperature was kept constant at 25°C. Flow curves were plotted with TRIOS Software (TA Instruments, New Castle DE) and the flow behavior was modeled using the Herschel Bulkley equation (Singh and Heldman, 2014), shown below. Apparent viscosity was calculated as the slope of the curve at 30 s^{-1}.

$$\tau = \tau_y + m\,(\dot{\gamma})^n$$

τ: shear stress (Pa)
τ_y: yield stress (Pa)
m: consistency index (Pa*s^n)
γ: shear rate (1/s)
n: flow index

3.3.4.5 Particle size

The particle size of the milk fat globules was assessed in the mix after aging and in the ice cream, using static light scattering (HORIBA LA-920, Horiba Scientific, Japan). This method is based on the scattering pattern obtained after a laser beam goes through a particle in a very dilute solution. The light intensity and angle relative to the incident beam are used to calculate particle size distributions based on light wavelength and optical properties of the particles (Coupland, 2014).

For these experiments, deionized water was used as the diluent; and the relative refractive index was set at 1.14, calculated as the refractive index of the particle (1.52 for milk fat) divided by the refractive index of the diluent (1.33 for water). Drops of aged mix or particles of frozen ice cream were added into the chamber until transmittance equilibrated between 70-95%. Temperature was kept between 40 to 45°C, to assure the milk fat was in liquid state. At this temperature all partially destabilized fat present in the ice cream samples fully coalesced. From the particle size distribution, the volume-weighted mean ($d_{4,3}$) was calculated as shown in the following equation, where n is the number of particles and d is the diameter.

$$d_{4,3} = \frac{\sum_i n_i d_i^4}{\sum_i n_i d_i^3}$$

3.3.4.6 Fat destabilization

The amount of fat destabilization was calculated by comparing the particle size of ice cream and aged mix using the equation presented below. This calculation indicates how the fat structure is affected by changing the total amount of fat and its replacement with the bulking agent.

$$Fat\ destabilization\ (\%) = \frac{Particle\ size\ ice\ cream - Particle\ size\ mix}{Particle\ size\ ice\ cream} * 100$$

3.3.4.7 Hardness

Hardness was measured as described by previous researchers (Karaca et al., 2009; Roland et al., 1999a). A texture analyzer (TA-XT2 Texture Analyzer, Texture Technologies, Hamilton, MA) equipped with a 25 mm acrylic cylindrical probe was used to compress the ice creams. The measurements were performed using pre- and post-test speed of 3.00 mm/s, test speed of 2.00 mm/s, a trigger force of 0.1 N and total distance of 20 mm. Hardness was determined as the peak compression force. After each measurement, the temperature of the sample was measured with a calibrated thermocouple to assure that any difference observed in hardness was not due to temperature differences between samples.

3.3.4.8 Melting rate

Melting rate was quantified following the method described by Goff and Hartel (2013). The content of a 4-ounce cup of ice cream (approximately 70 g) was placed over a metallic mesh inside a funnel and allowed to drain over a beaker, at room temperature (Figure 3-2). The amount of melted ice cream inside the beaker was weighed every ten minutes for two hours. A weight of the sample drained over time was plotted and melting rate was calculated as the slope of the linear portion of the curve.

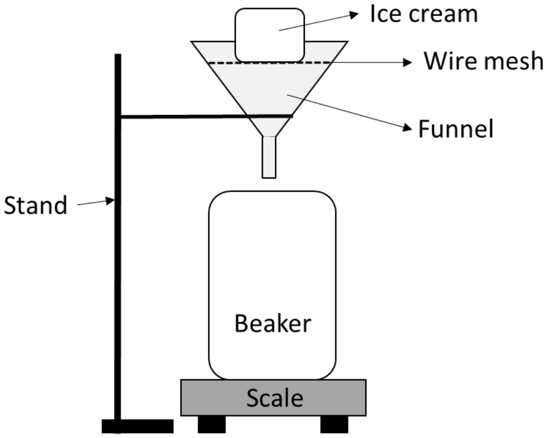

Figure 3-2. Melt rate apparatus.

3.3.5 Sensory analysis

3.3.5.1 Consumer test

For each batch of ice cream, a consumer sensory panel of approximately 100 people was assembled. Panelists were screened for food allergies and monthly consumption of vanilla ice cream in order to assure that they were regular consumers.

To measure the degree of liking a labeled affective magnitude scale (LAM) was used, which can be seen in Figure 3-3. The LAM scale was developed by Schutz and Cardello (2001) to assess liking/disliking of food products as an alternative to the traditional 9-point hedonic scale. Benefits of the LAM scale include the use of magnitude (ratio type) labels, instead of category labels in the hedonic scale; and the use of extreme anchors that allow panelists to rate liking in the same psychological continuum (Lawless and Heymann, 2010). The LAM scale has been compared to the 9-point hedonic scale, showing similar performance but a higher discrimination for well-liked products (Schutz and Cardello, 2001; El Dine and Olabi, 2009).

Panelists were also asked to rate intensity attributes of interest, including sweetness, vanilla flavor, creaminess, smoothness, mouth coating, hardness and melt rate of each ice cream treatment. Even though it is not traditional to ask intensity questions to untrained panelists (Lawless and Heymann, 2010), it is of interest to gather this information to identify reasons for any changes in liking observed.

Ice creams were presented one at a time (monadic sequential presentation) with 3-digit blinding codes in counter balanced order, using a Williams design (Williams, 1949). This was done to assure that all samples were tasted at the same temperature and to avoid comparison between treatments. Each panelist received a sample, answered the liking question and the intensity questions afterwards to avoid biasing the hedonic rating. Data was collected using Compusense Cloud (Compusense Inc., Guelph, ON, Canada).

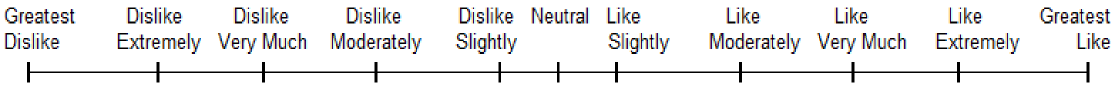

Figure 3-3. Labeled affective magnitude scale, as could be seen by the panelists. Adapted from Schutz and Cardello (2001).

3.3.5.2 Discrimination test

A discrimination test (O’Mahony and Rousseau, 2002) was used to determine if consumers were able to distinguish between differences in fat content in vanilla ice cream. The test was performed in two sessions: in session 1, panelists were asked to discriminate samples that differed by 2% fat; and in session 2, panelists were asked to discriminate ice creams samples with

4% fat difference. If a sample was effectively discriminated in session 1, it was not included during session 2.

In each session, panelists were presented with two triangle sets of vanilla ice cream, with a 5-minute resting period in between. Each triangle consisted on two samples of ice cream with the same fat level and a sample with a different fat content; panelists had to indicate which one was the different sample. A total of approximately 100 panelists tested each triangle. Data was collected using Compusense Cloud (Compusense Inc., Guelph, ON, Canada).

3.3.5.3 Storage test

After the initial sensory test, the ice creams were stored in a walk-in freezer (-18°C) for 19 weeks. A new consumer acceptability panel was used to measure the degree of liking and intensity of selected attributes of the stored ice creams, as described in section 3.3.5.1.

3.3.6 Statistical analysis

The entire experiment was replicated three times. All physical measurements were performed three times for each independent batch. SAS 9.4 (SAS Institute Inc., Cary, NC) was used to perform the statistical analysis of all data using the ANOVA mixed procedure (proc mixed), except where otherwise stated. Treatments were considered significantly different if $p<0.05$.

3.3.6.1 Physical analysis

One-way Analysis of Variance (ANOVA) (Fisher, 1932) was used to analyze the physical data. If significant differences were found, Tukey's test (Tukey, 1949) was applied to assign the treatments into groups.

3.3.6.2 Consumer test and storage stability analysis

The following mixed model ANOVA was used for the statistical analysis of all the sensory data obtained:

$$\begin{aligned}
&\boldsymbol{Sensory\ attribute}\\
&\quad = \boldsymbol{Treatment} + \boldsymbol{Batch} + \boldsymbol{Batch} * \boldsymbol{Treatment} + \boldsymbol{Panelist}(\boldsymbol{Batch})\\
&\quad + \boldsymbol{Serving\ position}(\boldsymbol{Batch}) + \boldsymbol{Residual}
\end{aligned}$$

Treatment was the fixed effect, while Batch, Batch*Treatment, Panelist and Position were considered as random effects. If significant differences were found, Tukey's test was used to compare the treatments.

To compare effect of fresh vs stored ice cream, the following mixed ANOVA model used was:

$$\begin{aligned}
&\boldsymbol{Sensory\ attribute}\\
&\quad = \boldsymbol{Treatment} + \boldsymbol{Batch} + \boldsymbol{State} + \boldsymbol{Test\ date} + \boldsymbol{Batch} * \boldsymbol{Treatment}\\
&\quad + \boldsymbol{Batch} * \boldsymbol{State} + \boldsymbol{Treatment} * \boldsymbol{State} + \boldsymbol{State} * \boldsymbol{Treatment} * \boldsymbol{Batch}\\
&\quad + \boldsymbol{Panelist}(\boldsymbol{Test\ date}) + \boldsymbol{Serving\ position}(\boldsymbol{Test\ date}) + \boldsymbol{Residual}
\end{aligned}$$

Treatment, State (either fresh or stored) and their interaction were considered fixed effects, the rest of the terms were random effects. If significant differences were found, Tukey's test was applied for the Treatment*State interaction term. For this analysis, the general linear model procedure (proc glm) was used in the SAS code since it is better than the mixed procedure when a large number of effects are included in the model (SAS/STAT® 12.4 User's Guide).

3.3.6.3 Discrimination test

For the discrimination tests, the use of a triangle test sets the chance level at 1/3. The number of participants that correctly identified the odd sample was computed as the proportion of correct answers. Based on Thurstonian modeling, d', the sensory difference, was calculated from the proportion of correct answers (Jesionka et al., 2014) with its associated p-value using Compusense Cloud (Compusense Inc., Guelph, ON, Canada).

3.3.6.4 Correlation analysis

The Pearson correlation analysis (Pearson, 1896) was used to compare the physical and sensory variables under study. The least square means from each batch were used to perform this analysis. To compare all the sensory attributes among themselves, raw data were used instead of group means.

3.4 Results and discussion

3.4.1 Physical analysis

Table 3-2 shows the results for total solids, total fat, overrun and draw temperature of the ice creams under study. Total solids, overrun and draw temperature did not significantly differ between treatments. While the fat content of all the treatments were significantly different from each other, the values were somewhat higher than expected based on the formulation. This may be due to the sequence in which the treatments were run in the pasteurizer, from high fat to low fat, which might have resulted in a carryover effect. The order of run in the HTST was chosen to avoid carryover of maltodextrin from one treatment to the other. Regardless, the different samples had systematically different fat contents allowing us to compare their properties and address the questions in the study. The actual difference in fat content was 2.09% between the 6 and 8% fat ice creams; 2.13% between the 8 and 10% fat ice creams, 2.11% between the 10 and 12% fat ice creams; and 1.28% between the 12 and 14% fat ice creams.

TechWizard ™ (Owl Software, Columbia, MO) was used to calculate an estimate of the freezing point, and the amount of water frozen at the draw temperature (using the overall mean -5.4±0.1), hardening temperature (-40°C) and storage temperature (-18°C) from the formulation. (Table 3-3). There is a difference in the freezing point of the samples of 0.18°C between the two extreme treatments, which in literature was considered not different (Roland et al, 1999a). However, the increase in freezing point due to the reduction of fat resulted in a slight, though no significant, reduction of the draw temperature.

Table 3-2. Compositional and manufacturing attributes of vanilla ice cream made with decreasing fat content and replacement with maltodextrin (MD).

	Treatment					**p-value**
	6% fat; 8% MD	**8% fat; 6% MD**	**10% fat; 4% MD**	**12% fat; 2% MD**	**14% fat; 0% MD**	
Total fat (%)	6.58±0.14^{e}	8.67±0.14^{d}	10.80±0.14^{c}	12.91±0.14^{b}	14.19±0.14^{a}	<0.01
Total solids (%)	41.46±0.16^{a}	41.72±0.16^{a}	41.79±0.16^{a}	41.81±0.16^{a}	41.29±0.16^{a}	0.18
Overrun (%)	66±2^{a}	63±2^{a}	63±2^{a}	65±2^{a}	63±2^{a}	0.72
Draw temperature (°C)	-5.7±0.2^{a}	-5.5±0.2^{a}	-5.5±0.2^{a}	-5.3±0.2^{a}	-5.1±0.2^{a}	0.47

Results are presented as least square mean ± standard error of the mean (n=3). The means for each batch of ice cream were calculated from three measurements, and the overall least squared means, presented here, were calculated using the means of each batch (Appendix C). The p-value was obtained from the one-way Analysis of Variance for the treatment effect. Different letters within the same row indicate significant differences at α=0.05.

Table 3-3. Calculated freezing point of vanilla ice cream made with decreasing fat content and replacement with maltodextrin (MD).

	Treatment				
	6% fat; 8% MD	**8% fat; 6% MD**	**10% fat; 4% MD**	**12% fat; 2% MD**	**14% fat; 0% MD**
Freezing point (°C)	-2.88	-2.82	-2.77	-2.72	-2.67
% Water frozen at Draw temperature (-5.4°C)	44.1	45.3	46.2	47.1	48.0
% Water frozen at hardening temperature (-40°C)	89.2	89.4	89.6	89.8	90.0
% Water frozen at storage temperature (-18°C)	80.3	80.6	80.9	81.2	81.5

Results were calculated from the mix formulations using TechWizard ™ (Owl Software, Columbia, MO).

The physical parameters measured on the aged mix and ice cream are shown in Table 3-4 with some also illustrated in Figure 3-4. Density and kinematic viscosity decreased with increased fat content which can be explained by the higher content of maltodextrin in the reduced-fat ice cream samples. An increase in viscosity with increasing concentrations of polysaccharides was also observed by Aykan et al. (2008) and by Schmidt et al. (1993) when using inulin and maltodextrin, respectively. All mixes exhibited shear thinning flow, with a flow index between 0 and 1 (Table 3-5), as is typical of ice cream mixes (Ohmes et al., 1998; Innocente et al., 2009; Mahdian and Karazhian, 2013).

Mix particle size increased with fat content as expected, since the homogenization pressure was constant for all treatment levels. During dynamic freezing, the milkfat globules underwent the process of partial coalescence, which explains the increase in size measured in the ice cream samples compared to the mix. In a study on the effects of increased protein content on fat destabilization, Daw and Hartel (2015) used particle size analysis to measure the degree of partial coalescence after ice cream freezing. They observed three distinct particle size distribution peaks: the first one (between 0.3 to 0.4 µm) corresponded to casein micelles; the second one (at approximately 1 µm) corresponded to homogenized fat globules; and a third one (above 10 µm) represented the destabilized fat clusters. In this study, only one distribution was observed in the ice cream samples and in the aged mixes; however, the distribution was broader for the ice creams indicating partial coalescence (data not shown). Since not all clusters have the same size, a wider distribution of particle sizes is observed. In our study, the treatments with the highest amount of fat exhibited a higher degree of fat destabilization and a larger increase in particle size. This can be explained by the higher probability of droplet collision at higher fat contents. Schmidt et al. (1993) did not observe a change in fat destabilization, when replacing approximately 3% fat with maltodextrin. Adapa et al. (2000a) observed a decrease in fat destabilization when reducing fat content from 12% to 6% without replacement of the solids; and a further decrease in fat destabilization in a 6% fat ice cream when using microcrystalline cellulose and guar gum as fat replacers that was attributed to the increase in mix viscosity.

Fat content of the ice creams did not significantly affect hardness. Ice creams with higher freezing points should be harder, due to the higher amount of ice crystals at any storage temperature however, the difference in freezing point in these samples was small (Table 3-3). Roland et al. (1999b) observed a decrease in hardness in fat-free ice creams with added maltodextrin or polydextrose, when compared to a fat-free ice cream with a lower solids content. However, the hardness of the ice cream with added maltodextrin was not significantly different from that of a 10% fat control ice cream.

Fat content did not affect the melting rate of the ice cream treatments under study. This trend was also observed with the use of maltodextrin to replace approximately 3% fat from an ice cream formula (Schmidt et al., 1993). However, Roland et al. (1999b) observed a faster melting rate when using maltodextrin, polydextrose or milk protein concentrate, compared to a 10% fat control ice cream. The use of inulin as a fat replacer increased the rate of melt of ice cream, which was explained by the lower heat transfer coefficient of milk fat when compared to the water phase of ice cream mixes (Tiwari et al., 2015).

Table 3-4. Physical characterization of vanilla ice cream made with decreasing fat content and replacement with maltodextrin (MD).

	Treatment					**p-value**
	6% fat; 8% MD	**8% fat; 6% MD**	**10% fat; 4% MD**	**12% fat; 2% MD**	**14% fat; 0% MD**	
Density (g/ml)	1.18±0.01^{a}	1.15±0.01^{ab}	1.15±0.01^{ab}	1.15±0.01^{ab}	1.13±0.01^{b}	0.02
Mix particle size $d_{4,3}$ (µm)	0.58±0.01^{c}	0.62±0.01^{bc}	0.66±0.01^{ab}	0.68±0.01^{ab}	0.71±0.01^{a}	<0.01
Kinematic viscosity (mm^{2}/s)	194±11^{a}	188±11^{a}	169±11^{ab}	134±11^{b}	117±2^{b}	<0.01
Apparent viscosity at 30 s^{-1} (Pa*s)	0.14±0.01^{ab}	0.15±0.01^{ab}	0.16±0.01^{a}	0.16±0.01^{ab}	0.13±0.01^{b}	0.03
Ice cream particle size $d_{4,3}$ (µm)	1.00±0.53^{c}	1.38±0.53^{bc}	2.74±0.53^{abc}	3.54±0.53^{ab}	4.48±0.53^{a}	<0.01
Fat destabilization (%)	34.5±6.9^{c}	45.5±6.9^{bc}	67.3±6.9^{ab}	69.0±6.9^{ab}	78.2±6.9^{a}	0.01
Hardness at -13.7±0.7°C (kg)	5.21±1.17^{a}	4.84±1.17^{a}	4.50±1.17^{a}	5.93±1.17^{a}	7.45±1.17^{a}	0.45
Melting rate at room temp. (˜20°C) (g/min)	1.35±0.10^{a}	1.32±0.10^{a}	1.16±0.10^{a}	0.97±0.10^{a}	1.09±0.10^{a}	0.09

Results are presented as least square mean ± standard error of the mean (n=3). The means for each batch of ice cream were calculated from three measurements, and the overall least squared means, presented here, were calculated using the means of each batch (Appendix C). The p-value was obtained from the one-way Analysis of Variance for the treatment effect. Different letters within the same row indicate significant differences at α=0.05.

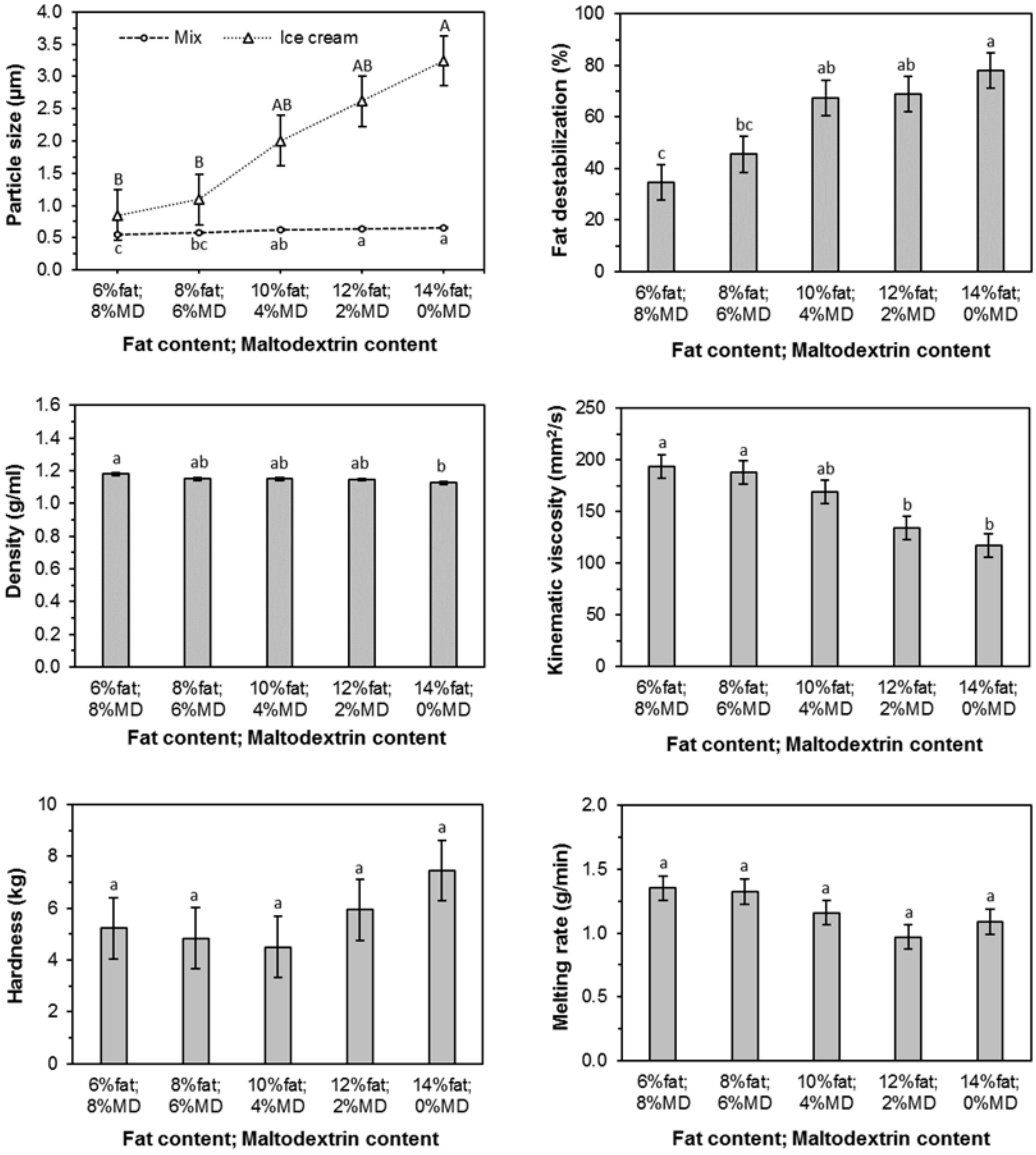

Figure 3-4. Particle size, fat destabilization, density, kinematic viscosity, hardness and melting rate of vanilla ice cream mixes with decreasing fat content and replacement with maltodextrin (MD). Results are presented as least square mean ± standard error of the mean (n=3). Different letters indicate significant differences at α=0.05.

Table 3-5. Rheology of ice cream mixes with decreasing fat content and replacement with maltodextrin (MD).

	Treatment					p-value
	6% fat; 8% MD	**8% fat; 6% MD**	**10% fat; 4% MD**	**12% fat; 2% MD**	**14% fat; 0% MD**	
Yield stress (Pa)	1.31±0.11^a	1.42±0.11^a	1.42±0.11^a	1.33±0.11^a	1.52±0.11^a	0.67
Consistency index -m (Pa*s^n)	0.16±0.03^a	0.20±0.03^a	0.24±0.03^a	0.16±0.03^a	0.14±0.03^a	0.18
Flow index -n	0.87±0.03^a	0.83±0.03^a	0.79±0.03^a	0.81±0.03^a	0.83±0.03^a	0.52

Results are presented as least square mean ± standard error of the mean (n=3). The means for each batch of ice cream were calculated from three measurements, and the overall least squared means, presented here, were calculated using the means of each batch (Appendix C). The p-value was obtained from the one-way Analysis of Variance for the treatment effect. Different letters within the same row indicate significant differences at α=0.05.

The correlation between all physical measurements is shown in Table 3-6. Most of these relationships can be explained by the effects of using maltodextrin to replace the solids lost due to fat reduction. Density negatively correlated with particle size, thus density decreased with an increase in fat content, or with a decrease in maltodextrin while particle size increased with fat content. A negative correlation between kinematic viscosity and particle size of both the mix and the ice cream was found. The decrease in fat content and use of maltodextrin to compensate for the loss in solids produced an increase in viscosity of the mixes. A lower fat content in the treatments resulted in a reduced particle size in both the mix and the final ice cream product. Fat destabilization negatively correlated with kinematic viscosity, thus as viscosity increases, fat destabilization decreases. The decrease in fat content and addition of maltodextrin resulted in an increase in viscosity of the mixes. A lower fat content lead to a lower extent of fat destabilization. Particle size of the mix and ice cream positively correlated with fat destabilization. This was expected since particle size measurements were used to calculate the percentage of fat that was destabilized during freezing (for details refer to section 3.3.4.6). Particle size of the ice creams and fat destabilization negatively correlated with melting rate, meaning that bigger particle sizes and a higher degree of fat destabilization are related to a slower melting rate. Koxholt et al. (2001) showed that the melting behavior of ice creams is highly dependent on fat destabilization, due to their stabilizing effect on the air phase. Particle size of ice creams positively correlated with hardness of the ice creams. Thus, samples with a higher fat content and its consequent bigger particle size are correlated with harder ice creams. Muse and Hartel (2004) were able to relate, through multiple regression analysis, an increase in hardness with an increase in fat destabilization, flow behavior index and consistency index.

The continuous freezer used to manufacture the ice cream samples freezes the product to constant viscosity. The reduction of fat, and consequent increase in maltodextrin, requires a lower temperature to maintain the viscosity of the ice cream. The way the freezer operates during freezing can explain the negative correlation between density and draw temperature; and the positive correlation between density and overrun. As fat decreases, and maltodextrin increases, the draw temperature decreases and the density increases.

Table 3-6. Correlation between physical variables.

		Mix					Ice cream					
		T. S.	Dens.	P. S. $d_{4,3}$	Kin. Visc.	App. Visc.	OR.	Draw Temp.	P. S. $d_{4,3}$	Fat destab.	Hard.	M. R.
Mix	Dens.	-0.029 0.917										
	P. S. $d_{4,3}$	0.044 0.876	**-0.783** **0.001**									
	Kin. Visc.	0.310 0.261	0.503 0.056	**-0.625** **0.013**								
	App. Visc	0.253 0.363	0.321 0.244	-0.382 0.160	**0.694** **0.004**							
Ice cream	OR.	-0.343 0.212	**0.686** **0.005**	-0.306 0.267	-0.018 0.949	0.160 0.568						
	Draw Temp.	-0.083 0.769	**-0.768** **0.001**	0.446 0.095	-0.433 0.107	-0.391 0.150	**-0.557** **0.031**					
	P. S $d_{4,3}$	0.031 0.914	-0.471 0.076	**0.705** **0.003**	**-0.782** **0.001**	-0.413 0.126	-0.006 0.983	0.210 0.453				
	Fat destab.	-0.005 0.986	-0.405 0.134	**0.687** **0.005**	**-0.751** **0.001**	-0.220 0.431	0.134 0.633	0.090 0.750	**0.945** **<0.001**			
	Hard.	-0.229 0.412	0.001 0.996	0.088 0.756	**-0.591** **0.020**	-0.289 0.297	0.295 0.286	0.071 0.802	**0.554** **0.032**	0.500 0.058		
	M. R.	-0.264 0.341	0.230 0.410	-0.473 0.075	**0.724** **0.002**	0.503 0.056	-0.085 0.762	-0.223 0.424	**-0.739** **0.002**	**-0.711** **0.003**	-0.494 0.061	

At the top of each cell is the Pearson correlation coefficient r and below is the p-value with a significance level of α=0.05. Bolded cells represent significant correlations. (n=15).

T. S.= Total Solids, Dens=Density, P. S.=Particle size, Kin. Visc=Kinematic Viscosity, App. Visc=Apparent Viscosity, OR=Overrun, Draw Temp.=Draw Temperature, Fat destab. =Fat destabilization, Hard. =Hardness, M. R.=Melt Rate.

3.4.2 Consumer test

A total of 292 consumers participated in the sensory evaluations of the ice creams. Of this total, 31.8% of the panelists were men and 55.1% were in their 20s and 30s. Consumers were asked to self-report their frequency of consumption of vanilla ice cream. Overall, 81.2% of the panelists reported that they consume vanilla ice cream at least 2 to 3 times per month.

The results obtained for overall liking of the ice creams are shown in Figure 3-5. The mean scores for the ice creams were between the "Like moderately" and "Like extremely" of the scale provided to the panelists.

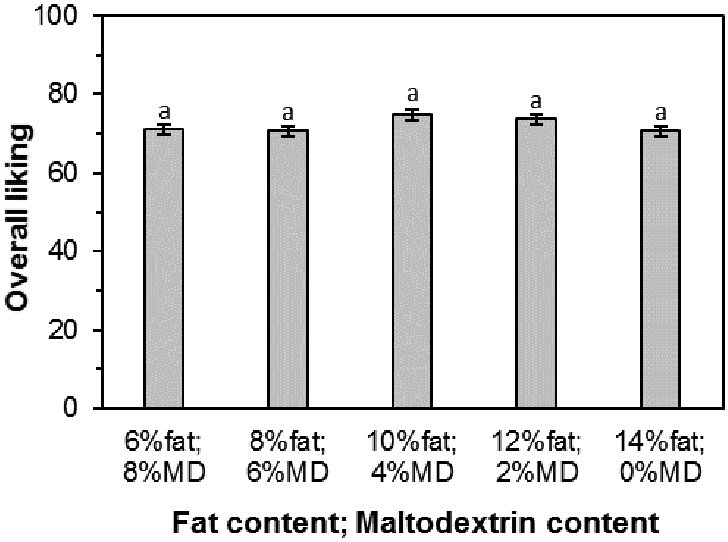

Figure 3-5. Overall liking of fresh vanilla ice cream. Results are presented as least square mean ± standard error of the mean (n=292). Different letters indicate significant differences at α=0.05.

Overall liking did not significantly change with the reduction in fat content, within the fat levels tested when total solids were constant. Li et al. (1997) observed that increasing the fat content from 0 to 10% in vanilla ice creams, by 2% fat increments, resulted in an increase of 0.5 to 0.6 units in consumer liking scores, using a 9-point hedonic scale. Guinard et al., (1996) also showed an increase in overall liking with fat content however, sugar content was a stronger determinant of liking than fat. However, Prindiville et al. (1999) found no significant difference in consumer acceptability of chocolate ice creams that differed in fat content between 0.5 and 9% milk fat. These authors assume the lack of difference to be due to the use of polydextrose and microparticulated whey proteins as fat replacers in their formulations. Nonetheless, the use of a 9-point hedonic scale may have masked differences in liking for a well-liked product such as ice cream. Other studies on consumer acceptability of reduced-fat ice creams did not have the necessary power to obtain representative results (Aykan et al., 2008; Tiwari et al., 2015).

The Fat Preference Questionnaire© (Ledikwe et al., 2007) was included at the end of the consumer test of the second and third trials, to measure the degree to which the panelists prefer the taste of high-fat food products and how often they consume them. Based on the scores obtained, panelists were segregated in groups, and the data was reanalyzed for differences in liking within groups (refer to Appendix B for the complete analysis). To summarize briefly, consumers with a high preference for the taste of full-fat products had a significant lower liking score for the 8% fat ice cream when compared to a 10% fat product. However, there was no significant difference between the 6, 10, 12 and 14% fat samples in their liking scores. The group of panelists that reported a higher frequency of consumption of high-fat products gave a higher rating to the high fat ice creams, where the reduced-fat ice creams (6 and 8%) had a lower liking rating. However, the 14% fat ice cream was not significantly different in liking than the reduced-fat ice creams.

Figure 3-6 shows the results obtained for the descriptive attributes assessed during the sensory test of the ice cream samples. Sweetness, vanilla flavor, hardness, mouth coating and melting rate did not significantly differ across treatment levels, following the same pattern as overall liking. The use of descriptive analysis has shown an increase in sweetness perception of reduced-fat ice creams when using maltodextrin, polydextrose or milk protein concentrate

(Roland et al., 1999b); as well as polydextrose or microparticulated whey proteins (Prindiville et al., 1999) to replace fat content in vanilla and chocolate ice creams, respectively. Regarding vanilla flavor, a high fat content has been shown to produce a retarded flavor perception when no bulking agents or fat replacers were added (Li et al., 1997; Frøst et al., 2005). However, the addition of whey-based fat replacers produced no change in vanilla intensity as assessed by a descriptive panel (Ohmes et al., 1998). Hardness was found to be higher in 10% fat ice creams when compared to a 4% fat product made without adding any ingredient to replace fat (Stampanoni Koeferli et al., 1996; Liou and Grün, 2007). However, the use of inulin as a fat replacer produced ice cream that were decreasing in hardness as fat content increased (Tiwari et al., 2015). Regarding melting rate as perceived during consumption, the use of fat replacers produced slower melting fat-reduced ice creams when using maltodextrin, polydextrose or milk protein concentrate (Roland et al., 1999b); or inulin (Tiwari et al., 2015).

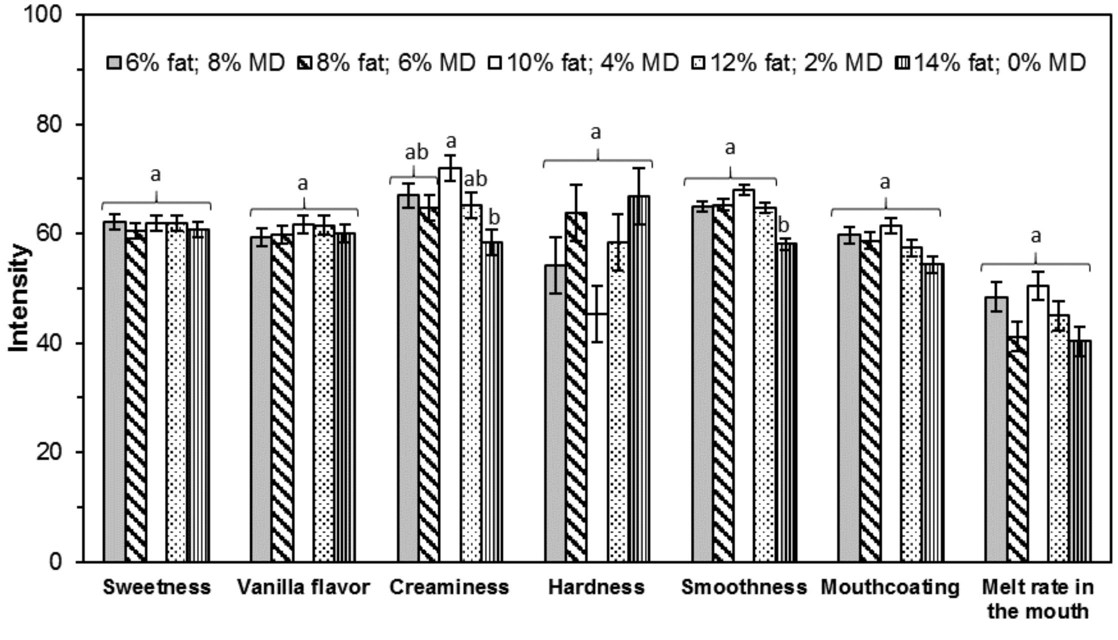

Figure 3-6. Intensity sensory variables of fresh vanilla ice cream with decreasing fat content and replacement with maltodextrin (MD). Results are presented as least square mean ± standard error of the mean (n=292). Different letters within the same descriptor indicate significant differences at α=0.05.

In the present study, creaminess and smoothness were significantly different across the treatment levels. Ice cream with 14% fat was significantly less smooth than the other treatments; and significantly less creamy than the 10% fat ice cream (Figure 3-6). Creaminess is a multimodal sensation: for a food product to be perceived as creamy, several sensory receptors need to be stimulated at the same time, including taste, texture and smell (Kilcast and Clegg, 2002; Jervis et al., 2014). This attribute has been shown to have a positive correlation with acceptance ratings of dairy products (Frøst and Janhøj, 2007; Jervis et al., 2014). Fat replacers often used in the food industry tend to mimic only one aspect of the creamy sensation, which results in a lower rating by consumers (Jervis et al., 2014). Using a descriptive panel, creaminess and smoothness were found to be higher in 10% fat ice creams when compared to a 4% fat version without replacement (Liou and Grün, 2007). Roland et al. (1999a) observed an increase in creamy flavor with an increase in fat content and no fat replacement. The use of maltodextrin and polydextrose in a fat-free ice cream produced a higher creamy perception (Hyvönen et al., 2003), which is consistent with our results.

It is important to recall that, within this study, consumers were not given any definition to rate the descriptive attributes of the ice creams. Moreover, the sample portion was not standardized for the perceived melting rate. It is likely that each panelist chose a unique definition and used it to measure and rate the intensity they perceived. This could have affected our results as well as increased the variability within the measurement. Furthermore, due to the phase transition during consumption of ice cream, from solid to liquid, most of the attributes, including flavor release, melting rate and hardness, change over time. A time-intensity sensory method would have been more useful to understand the changes that the reduction of fat generates on these particular attributes.

Correlation analysis was used to detect relationships between sensory attributes. Results are presented in Table 3-7, with significant correlations presented in bold. Most of the attributes measured were correlated with each other. Since the panelists were not trained and the attributes not defined, this could be an indication of how the panelists rated the intensity attributes. It is possible that consumers based the rating of the intensity attributes based on how much they liked the particular samples they were tasting.

Table 3-7. Correlation between sensory variables.

	O. L.	Sweet.	Vanilla	Cream.	Sens. H.	Smooth.	Mouthc.
Sweet.	**0.377** **<0.001**						
Vanilla	**0.557** **<0.001**	**0.617** **<0.001**					
Cream.	**0.502** **<0.001**	**0.447** **<0.001**	**0.541** **<0.001**				
Sens. H.	-0.025 0.338	**0.123** **<0.001**	**0.105** **<0.001**	**-0.145** **<0.001**			
Smooth.	**0.433** **<0.001**	**0.379** **<0.001**	**0.458** **<0.001**	**0.704** **<0.001**	0.018 0.506		
Mouthc.	**0.254** **<0.001**	**0.271** **<0.001**	**0.313** **<0.001**	**0.473** **<0.001**	**0.055** **0.004**	**0.490** **<0.001**	
M. R. M.	**0.120** **<0.001**	**0.145** **<0.001**	**0.099** **<0.001**	**0.256** **<0.001**	**-0.296** **<0.01**	**0.231** **<0.001**	**0.260** **<0.001**

At the top of each cell is the Pearson correlation coefficient r and below is the p-value with a significance level of $\alpha=0.05$. Bolded cells represent significant correlations. (n=292).
OL=Overall Liking, Sweet. =Sweetness, Vanilla =Vanilla flavor, Cream. =Creaminess, Sens. H.=Sensory hardness, Smooth. =Smoothness, Mouthc. =Mouth coating, M. R. M.=Melt rate in the mouth.

3.4.3 Correlation between sensory and physical variables

Table 3-8 shows the correlation analysis between the sensory attributes and the physical measurements done in the mix and ice creams. Remarkably few were significantly correlated, 3 out of 40 possible combinations when comparing sensory to physical measurements of the mix and 5 out of 48 possible combinations when comparing sensory to physical measurements of the ice cream. This is little more than would be expected by random chance and may reflect the relatively small differences in physical and sensory properties between the samples despite the large differences in composition. However, some of the correlations make physical sense.

Within the correlations between sensory attributes and the physical data of the mixes, density was positively correlated with smoothness. This relationship may be due to the higher amount of maltodextrin present in the lower fat samples, which increased the viscosity and hence the smoothness rating. Similarly, sensory measurements of mouth coating were also positively correlated to kinematic and apparent viscosity. Samples with a higher viscosity, those that contained more maltodextrin, could have produced a longer retention in the mouth.

Table 3-8. Correlation between physical and sensory variables.

		Sensory							
		OL	Sweet.	Vanilla	Cream.	Sens. H.	Smooth.	Mouthc.	M. R. M.
Mix	T. S.	0.511	0.285	0.270	0.421	-0.115	0.495	0.326	0.117
		0.052	0.303	0.331	0.118	0.684	0.061	0.236	0.677
	Dens.	0.007	0.339	0.035	0.335	-0.154	**0.541**	0.367	0.451
		0.979	0.216	0.902	0.223	0.583	**0.037**	0.179	0.091
	P. S. $d_{4,3}$	0.168	-0.098	0.199	-0.232	0.082	-0.445	-0.348	-0.224
		0.549	0.727	0.478	0.406	0.772	0.097	0.204	0.422
	Kin. Visc.	-0.238	-0.058	-0.285	0.373	-0.169	0.454	**0.565**	0.120
		0.392	0.836	0.304	0.170	0.547	0.089	**0.028**	0.699
	App. Visc.	-0.031	-0.175	-0.295	0.331	-0.098	0.510	**0.603**	0.123
		0.912	0.532	0.285	0.228	0.727	0.052	**0.017**	0.664
Ice cream	OR.	-0.024	0.163	-0.012	0.045	0.020	0.283	0.131	0.357
		0.932	0.561	0.965	0.873	0.943	0.307	0.642	0.191
	Draw Temp.	-0.132	**-0.574**	-0.418	-0.489	0.157	**-0.555**	**-0.575**	-0.472
		0.638	**0.025**	0.121	0.064	0.575	**0.032**	**0.025**	0.076
	P. S $d_{4,3}$	0.275	0.237	0.330	-0.255	0.234	-0.373	-0.339	-0.062
		0.321	0.395	0.230	0.359	0.401	0.170	0.217	0.826
	Fat destab.	0.324	0.170	0.349	-0.165	0.174	-0.212	-0.227	0.001
		0.238	0.546	0.202	0.558	0.535	0.448	0.416	0.998
	Hard.	0.174	0.173	0.026	-0.509	**0.560**	-0.373	-0.471	-0.235
		0.535	0.537	0.927	0.052	**0.030**	0.171	0.076	0.398
	M. R.	**-0.573**	-0.247	-0.424	0.067	-0.057	0.016	0.369	-0.101
		0.026	0.375	0.115	0.813	0.841	0.955	0.176	0.721

At the top of each cell is the Pearson correlation coefficient r and below is the p-value with a significance level of $\alpha=0.05$. Bolded cells represent significant correlations. (n=15).
T. S.= Total Solids, Dens=Density, P. S.=Particle size, Kin. Visc=Kinematic Viscosity, App. Visc.= Apparent Viscosity, OR=Overrun, Draw Temp.=Draw Temperature, Fat destab. =Fat destabilization, Hard. =Hardness, M. R.=Melt Rate, OL=Overall Liking, Sweet. =Sweetness, Vanilla=Vanilla flavor, Cream. =Creaminess, Sens. H.=Sensory hardness, Smooth. =Smoothness, Mouthc. =Mouth coating, M. R. M=Melt rate in the mouth.

Within the correlations between sensory attributes and the physical data of the ice creams, draw temperature negatively correlated with sweetness, smoothness and mouth coating.

Thus, as draw temperature decreased, the ice creams were perceived as sweeter, smoother and more mouth coating. To maintain a constant viscosity during freezing, samples with slightly lower freezing point (i.e. those with less fat and more maltodextrin) were automatically drawn at lower temperatures. The higher content of maltodextrin appears to have been perceived as sweeter, more smooth and more mouth coating. Maltodextrin 10 DE is less sweet than sucrose (Goff and Hartel, 2013), which could explain this relationship. Moreover, ice creams with higher maltodextrin content were significantly more viscous (Table 3-4), that may affect the smooth and mouth coating perception. Sensory hardness positively correlated to the instrumental measurement of harness. Finally, overall liking negatively correlated to melting rate at room temperature, regardless that neither overall liking or melting rate were affected by fat content. Linear regression was later applied to the data, which showed a significant linear relationship ($\beta_1 \neq 0$) between melting rate and overall liking (Figure 3-7).

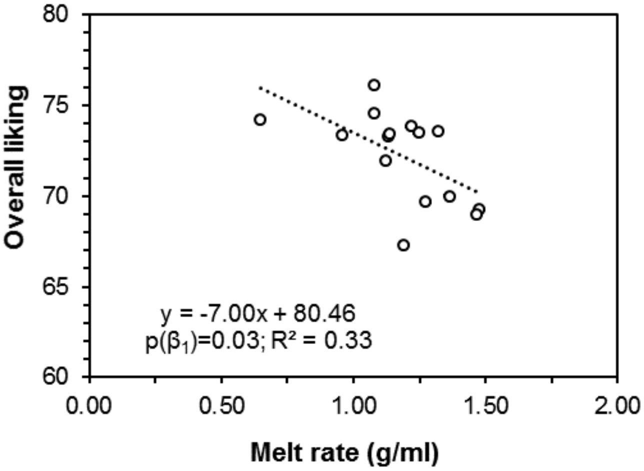

Figure 3-7. Regression analysis of overall liking vs melting rate. Dots represent least square mean values for all samples (n=15).

3.4.4 Discrimination test

Discrimination tests are used in psychophysics to measure differences in sensitivities to a stimuli (O’Mahony and Rousseau, 2002). The application of this type of sensory tests is extensively used in the food industry, particularly when a product is reformulated (Lawless and Heymann, 2010). Since no significant differences were observed in overall liking of the samples, a discrimination test was conducted to determine if consumers were able to differentiate ice creams with small reductions in fat content.

A new set of samples were prepared for this analysis, with the formulations presented in Table 3-1. Total solids, fat content, mix density, overrun and draw temperature were measured to verify formulation and manufacturing conditions. The results are presented in Table 3-9. Total solids and draw temperature were not significantly different across treatment levels, while total fat was significantly different across samples. Density decreased with an increase in fat content, consistently with the previous experiment. Overrun however, significantly decreased with fat content, which was not expected during the manufacturing process and may affect the sensory results.

The first discrimination test consisted of triangle comparisons of all ice creams with 2% fat difference. Results are presented in Table 3-10. Panelists were unable to differentiate between all ice creams that contained some maltodextrin added to the formulation. In contrast, consumers could differentiate between the 12 and 14% fat samples, with a difference in fat of 1.78%. This may be because there was no maltodextrin in the 14% fat samples, which might contribute some additional sweetness and a characteristic flavor to the 12% fat ice cream.

Table 3-9. Characteristics of ice creams made for the discrimination test.

	Treatment					p-value
	6% fat; 8% MD	**8% fat; 6% MD**	**10% fat; 4% MD**	**12% fat; 2% MS**	**14% fat; 0% MD**	
Total fat (%)	6.33±0.01^{e}	8.41±0.01^{d}	10.41±0.00^{c}	12.43±0.01^{b}	14.21±0.04^{a}	<0.01
Total solids (%)	41.48±0.05^{a}	41.76±0.04^{a}	41.47±0.08^{a}	41.46±0.24^{a}	41.27±0.09^{a}	0.16
Density (g/ml)	1.20±0.01^{a}	1.18±0.00^{b}	1.15±0.00^{d}	1.16±0.00^{c}	1.16±0.00^{cd}	<0.01
Overrun (%)	69.0±0.4^{a}	68.2±0.2^{ab}	63.8±0.7^{c}	64.4±0.6^{c}	65.4±1.1^{bc}	<0.01
Draw temperature (°C)	-6.0±0.0^{a}	-5.9±0.1^{a}	-5.9±0.1^{a}	-5.9±0.1^{a}	-5.8±0.2^{a}	0.67

Results are presented as least square mean ± standard error of the mean (n=3). The p-value was obtained from the one-way Analysis of Variance for the treatment effect. Different letters within the same row indicate significant differences at α=0.05.

In a second discrimination testing session, samples with a 4% fat differences and with maltodextrin in the formulation were compared. The 14% fat sample was excluded from this session since it was discriminated in the previous test when the fat difference was less than 2%. Results are shown in Table 3-11. Consumers were not able to discriminate between 4% fat difference between the 8 and 12% fat ice creams. However, samples with 6 and 10% fat content were effectively discriminated in this test. This could have been the result of a difference in overrun between these two samples (Table 3-9), or by a change in flavor profile of the samples due to the increased maltodextrin content in the lower fat sample. The reduction of fat, combined with a 4% increase in maltodextrin could have modified the flavor profile of the samples that allowed consumers to discriminate them. However, a thorough descriptive analysis would be useful to understand the underlying differences in the sensory profile of the ice creams with different fat and maltodextrin content.

Table 3-10. Results for the discrimination of ice creams with 2% fat difference.

	Comparisons			
	6% vs 8%	**8% vs 10%**	**10% vs 12%**	**12% vs 14%**
Actual fat content difference (%)	2.08	2.00	2.02	1.78
Number of panelists	99	102	99	101
Proportion of correct answers	0.36	0.27	0.32	0.43
d’	0.58	0.00	0.00	1.05
p-value	0.29	0.92	0.67	0.03

Triangle test sets the chance level at 1/3. d’ is the sensory difference, calculated from the proportion of correct answers using Thrustonian modeling.

Table 3-11. Results for the discrimination of ice creams with 4% fat difference.

	Comparisons	
	6% vs 10%	**8% vs 12%**
Actual fat content difference (%)	4.08	4.02
Number of panelists	93	93
Proportion of correct answers	0.42	0.23
d’	1.01	0.00
p-value	0.05	0.98

Triangle test sets the chance level at 1/3. d’ is the sensory difference, calculated from the proportion of correct answers using Thrustonian modeling.

3.4.5 Storage stability

The quality of ice cream may be affected during storage. Temperature fluctuations during storage and shipping may lead to an increase in size of the ice crystals; above the sensory threshold (>45µm) consumers may be able to detect the presence of ice crystals (Goff and Hartel, 2013). Moreover, changes in air bubble size and lactose crystallization are also important parameters to consider, since it leads to defects known as shrinkage and sandiness, respectively

(Goff and Hartel, 2013). Past research has focused on the effects of storage temperature and temperature fluctuations in ice crystal growth in ice cream (Donhowe and Hartel, 1996a; b; Park et al., 2015), viscoelastic behavior (Tsevdou et al, 2015) as well as in sensory quality, using descriptive panels (Conforti, 1994; Buyck et al., 2011). However, few studies (Tsevdou et al., 2015) investigated changes in consumer acceptability of ice cream after storage.

In this study, the ice cream samples were re-evaluated for consumer acceptability after 19 weeks of storage at approximately -18°. A total of 282 consumers tested the samples. Of this total, 39.7% of the panelists were men and 54.2% were in their 20s and 30s. 78.7% of the panelists self-reported a consumption of vanilla ice cream of 2 to 3 times per month.

Figure 3-8 shows the comparison between the fresh and the stored ice creams sensory evaluations. All mean ratings for the storage test were between the “Like moderately” and “Like very much” labels of the LAM scale. After storage, there was no significant difference in liking across treatment levels, however, all storage ratings were slightly lower than those obtained when the ice creams were tested fresh. Only the 8% and 10% fat aged samples were statistically significantly different when compared to the fresh sample evaluation. A decrease in overall liking of ice cream after storage was observed by Abd El-Rahman et al. (1997) in a study on the effect of different milk fat sources on sensory quality of frozen desserts. Using a trained panel (n=10), Tsevdou et al. (2015) observed a decrease in acceptability of ice cream over time as well as a storage temperature dependence.

During the evaluation of the stored ice cream samples, panelists were asked to rate the perceived intensity of descriptive attributes as was done previously in fresh ice cream. Sweetness, vanilla flavor, creaminess, smoothness and mouth coating were not significantly different across treatment levels in the aged ice cream. However, for perceived hardness, the 12% fat aged ice cream had the lowest intensity score and was significantly different from the aged ice creams with 8, 10 and 14% fat. As for melting rate, the 8% fat aged ice cream had the lowest score and was significantly different from the 12% fat aged ice cream. Using a trained sensory panel, Buyck et al. (2011) observed that light ice cream (5.2% fat) was perceived as less creamy, icier and colder when compared to a full-fat product (10.3% fat) at storage temperatures ranging from -23.3 to -45.6°C. Moreover, the ice crystal size was significantly bigger in light ice cream, after 19 weeks of storage at any temperature tested. Sweetness, vanilla flavor and mouth coating ratings were lower after storage, when compared to the fresh samples, but the difference was not significant. Using a descriptive panel, Conforti (1994) observed a reduction in sweetness and vanilla intensity ratings in ice creams with fat content ranging from 10 to 16% fat after a heat shock treatment. In the present study, the 10% fat aged ice cream was perceived as significantly less creamy and smooth; significantly harder and presented a slower melting rate when compared to the evaluation done on fresh ice cream. The 12% fat ice cream was significantly less hard and had a faster melting rate after storage, compared to the fresh ice cream ratings.

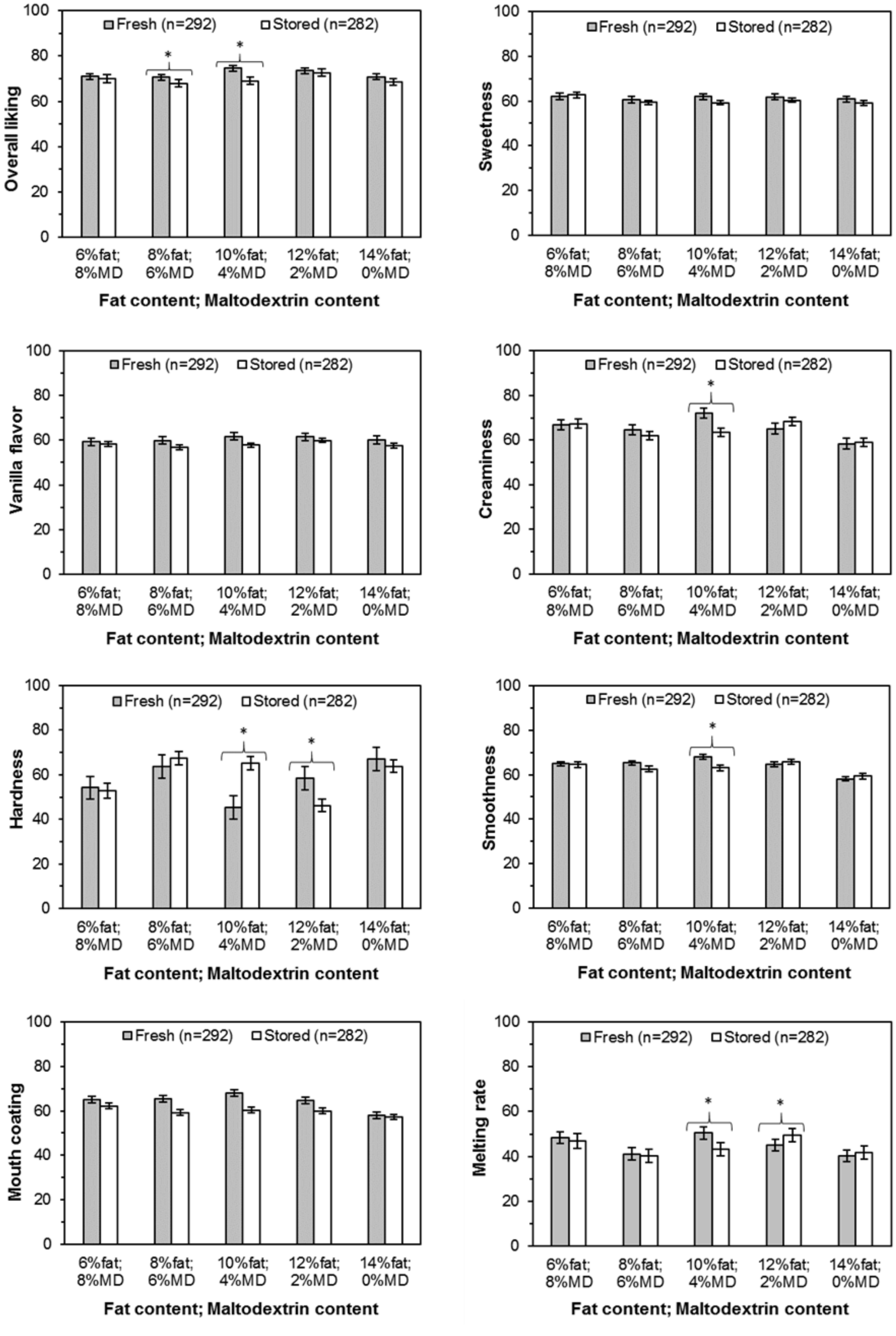

Figure 3-8. Overall liking and sensory attributes of fresh and stored ice creams. Results are presented as least square mean ± standard error of the mean. Asterisks within the same treatment level indicate significant differences in the state*treatment effect at α=0.05.

3.5 Conclusions

The reduction of fat and use of maltodextrin to compensate for the loss of solids resulted in ice cream mixes with higher density and kinematic viscosity. This was due to the use of a carbohydrate with water binding properties to compensate for the loss of solids when removing fat. After freezing, particle size decreased as fat content decreased, due to a lower extent of fat destabilization. However, this did not result in a significant difference in hardness or melting rate at room temperature. The ice creams manufactured with fat contents from 6 to 14% fat did not differ significantly in overall liking, based on the sensory analysis. Moreover, sweetness, vanilla flavor, hardness, mouth coating and melting rate in the mouth did not differ significantly across the treatment levels tested. However, creaminess and smoothness were significantly different across treatment levels, possibly due to the inability of untrained consumers to isolate these complex attributes. Consumers were not able to discriminate between treatments containing maltodextrin with a 2% fat difference. Further testing revealed that consumers were unable to distinguish a 4% fat difference in ice creams with 8 and 12%; but were able to discriminate this difference in fat in ice creams with 6 and 10% fat. Moreover, consumers were able to distinguish ice cream with 12% fat + 2% MD from the 14% fat+0% MD. Thus, it is possible that maltodextrin is adding a flavor attribute to the ice creams that leads consumers to differentiate the samples. Storage for 19 weeks at -18°C did not result in a change in consumer acceptability across the treatments included in this study. However, when compared to fresh ice cream only the 8% and 10% fat ice creams were significantly less liked after storage. The correlation analysis between sensory attributes and physical measurements resulted in remarkably few relationships within the data. This may be a reflection of the relatively small differences in physical and sensory properties despite the large compositional difference. The most interesting correlation was between overall liking and melting rate, meaning that consumers may have a greater liking for ice creams with a slower melting rate.

Overall, this study showed that while reducing fat content from 14 to 6% and adding maltodextrin to compensate for the loss in solids affected the physical properties of the ice creams, it did not produce a difference in overall liking when tasted fresh or after a storage period. Moreover, consumers were not able to distinguish a 2% fat difference in samples that contained maltodextrin, or a 4% fat difference between 8 and 12% fat ice creams. The use of maltodextrin as a bulking agent could be a feasible alternative to reduce the energy density of vanilla ice cream, as well as a way to reduce production costs. However, manufacturers should evaluate this alternative within their own formulations, as well as test the effect this change may cause to the brand image.

3.6 Suggestions for future research

The reduction of fat content and the use of maltodextrin did not result in a significant difference in consumer acceptability. This still leaves the question of how much fat can be removed from frozen desserts without observing a change in liking. Moreover, other bulking agents could be tested to determine if there is the same effect as that obtained for maltodextrin. Furthermore, the use of a forced choice test might be interesting to examine if there is a preference for a particular fat content.

When a discrimination task was used, panelists could not segregate samples which contained the bulking agent with a 2% difference, but samples were distinguished when there was a 4% fat difference on the samples with the lowest fat content in this study. However, samples that varied in fat content by 1.78% fat and one had no addition of maltodextrin, samples were discriminated. It would be interesting to further investigate what is causing the discrimination, if it is the flavor profile of the maltodextrin or a change in texture.

The changes in physical structure of ice creams due to fat reduction could be further explored using cryo-microscopy imaging. It would be interesting to observe if the changes in physical parameters measured in this study produced a visible modification of ice cream microstructure.

Appendix A

Effect of stabilizer/emulsifier blend on physical properties and consumer acceptability of vanilla ice cream

A.1 Introduction

Stabilizers and emulsifiers are optional ingredients used in the production of ice cream to improve functionality. Stabilizer systems are composed of hydrocolloids, to improve texture and retard the rate of growth of ice crystals (Goff and Hartel, 2013). Hydrocolloids interact with water, resulting in an increase in the viscosity of solutions. Emulsifiers are amphiphilic molecules, used to improve whipping and to promote fat destabilization (Goff and Jordan, 1989). To use in ice cream, both ingredients are often combined in proprietary blends to deliver a specific functionality for a specific formula. Previous research has focused on the effect of specific stabilizers and emulsifiers in rheology, ice crystal growth and fat destabilization (Goff and Jordan, 1989; Bolliger et al., 2000a; Flores and Goff, 1999). Few studies have explored the effect of stabilizers and emulsifiers on sensory properties (Soukoulis et al., 2008; Varela et al., 2014), especially after a prolonged storage. This study aims to investigate the effect of the concentration of a stabilizer/emulsifier blend in physical properties and consumer acceptability of fresh and stored vanilla ice cream.

A.2 Materials and methods

A.2.1 Ingredients and formulations

To test the effect of the level of addition of a stabilizer/emulsifiers (S/E) blend, vanilla ice creams with 14% fat were formulated with three concentration levels: a sample with high concentration (0.5%), a low concentration (0.25%) and a sample without any addition of stabilizer/emulsifier. The formulations can be seen in Table A-1.

Table A-1. Vanilla ice cream formulations with varying stabilizer/emulsifier (S/E) concentration.

	Treatments		
	0% S/E	**0.26% S/E**	**0.50% S/E**
Milkfat	14.00	14.00	14.00
MSNF	10.50	10.50	10.50
Sucrose	12.96	12.96	12.96
S/E	0.00	0.26	0.50
Corn syrup solids	3.70	3.70	3.70
Total Solids	41.16	41.42	41.66

All ingredients used during the manufacturing of the ice creams were obtained from the same sources as those described in section 3.3.1. The stabilizer/emulsifier blend (Grindsted® IcePro 2005 SH, DuPont, Wilmington, DE) is composed of propylene glycol mono esters, mono and diglycerides, cellulose gum, guar gum, carrageenan and silicon dioxide. The manufacturing process of the ice cream samples is described in detail in section 3.3.3.

A.2.2 Physical, sensory and statistical methods

Physical measurements of total solids, fat, overrun, draw temperature, apparent viscosity, kinematic viscosity, mix density, particle size, fat destabilization, hardness and melting rate were performed as described in section 3.3.4. A consumer sensory test was used to evaluate the overall liking and the intensity of attributes of interest, following the protocol in section 3.3.5.1. A storage test was applied for this experiment after 19 weeks at -18°C, according to section 3.3.5.4. Physical data was statistically analyzed using a one-way ANOVA (details are in section 3.3.6.1).

Data collected from the consumer sensory tests of fresh and stored ice cream were analyzed using a mixed-model ANOVA, as described in section 3.3.6.2.

A.3 Results and discussion

A.3.1 Physical analysis

The ice creams made with varying content of the stabilizer/emulsifier blend were analyzed for fat and solids composition, as well as overrun and draw temperature, to verify formulation and manufacturing conditions. The results are presented in Table A-2. As expected, there were no significant differences across treatment levels.

Table A-2. Composition and manufacturing attributes of vanilla ice cream made with increasing staiblizer/emulsifier concentration.

	Treatment			**p-value**
	0% S/E	**0.26% S/E**	**0.5% S/E**	
Total fat (%)	14.04±0.13^a	13.97±0.13^a	14.01±0.13^a	0.91
Total solids (%)	41.32±0.16^a	41.24±0.16^a	41.15±0.16^a	0.77
Overrun (%)	60±1^a	61±1^a	64±1^a	0.17
Draw temperature (°C)	-5.3±0.3^a	-5.1±0.3^a	-5.2±0.3^a	0.85

Results are presented as least square mean ± standard error of the mean (n=3). The means for each batch of ice cream were calculated from three measurements, and the overall least squared means, presented here, were calculated using the means of each batch (Appendix C). The p-value was obtained from the one-way Analysis of Variance for the treatment effect. Different letters within the same row indicate significant differences at α=0.05.

A change in concentration of stabilizer and emulsifier does not affect the freezing point of the mixes, due to the high molecular weight of the hydrocolloids (Flores and Goff, 1999). The calculated freezing point of the samples, as well as the amount of water frozen at draw, hardening and tempering temperatures is presented in Table A-3.

Table A-3. Calculated freezing point for ice cream samples, calculated by TechWizard.

	Treatment		
	0% S/E	**0.26% S/E**	**0.5% S/E**
Freezing point (°C)	-2.67	-2.68	-2.69
% Water frozen at Draw temperature (-5.2°C)	46.3	46.1	45.9
% Water frozen at hardening temperature (-40°C)	90.0	90.0	90.0
% Water frozen at storage temperature (-18°C)	81.6	81.5	81.4

Results were calculated from the mix formulations using TechWizard ™ (Owl Software, Columbia, MO).

The results from physical analysis of the ice cream mix and the final product are presented in Table A-4; the results from the rheological analysis are presented in Table A-5. In the mix, density and particle size did not significantly differ across treatment levels. However, the viscosity of the mix as well as the consistency index increased with the addition of the stabilizer/emulsifier blend. This was due to the increasing content of hydrocolloids present in the stabilizer system. These macromolecules can interact with water, modifying the rheological properties of solutions (Goff and Hartel, 2013). Cottrell et al. (1980) observed a non-linear increase in apparent viscosity of ice cream mix with increasing concentrations of hydrocolloids, including CMC, locus bean gum and guar gum.

In the present study, none of the physical properties measured in the final ice cream, including fat particle size, fat destabilization, hardness and melting rate significantly differ across the treatment levels in this study. Fat destabilization was expected to increase with increasing content of emulsifiers. These amphiphilic molecules are added to ice cream mix to promote partial coalescence of fat globules by competition and displacement of proteins from the globule interface (Goff and Jordan, 1989; Goff, 1997a). It is possible that the dissolution of ingredients at room temperature during the blending step of ice cream manufacturing was not complete and the emulsifiers were separated in the balance tank of the HTST. Bolliger et al. (2000) observed an increase in fat destabilization and a decrease in the rate of melt with increasing concentrations of emulsifiers. Soukoulis et al. (2008) observed an increase in hardness and a decrease in melting rate with increased concentrations of hydrocolloids.

Table A-4. Physical measurements of mix and ice cream made with increasing stabilizer/emulsifier concentration.

	Treatment			**p-value**
	0% S/E	**0.26% S/E**	**0.5% S/E**	
Density (g/ml)	1.12±0.01^{a}	1.14±0.01^{a}	1.12±0.01^{a}	0.23
Mix particle size $d_{4,3}$ (µm)	0.69±0.02^{a}	0.67±0.02^{a}	0.70±0.02^{a}	0.54
Kinematic viscosity (mm^{2}/s)	23±11^{b}	50±11^{b}	117±11^{a}	<0.01
Apparent viscosity at 30 s^{-1} (Pa*s)	0.06±0.01^{b}	0.08±0.01^{b}	0.12±0.01^{a}	<0.01
Ice cream particle size $d_{4,3}$ (µm)	3.87±0.46^{a}	3.68±0.46^{a}	3.62±0.46^{a}	0.92
Fat destabilization (%)	74.6±3.5^{a}	73.2±3.5^{a}	72.8±3.5^{a}	0.93
Hardness at -13.5±0.1°C (kg)	8.29±1.32^{a}	8.06±1.32^{a}	7.35±1.32^{a}	0.88
Melting rate at room temperature (g/min)	1.02±0.10^{a}	1.03±0.10^{a}	1.18±0.10^{a}	0.51

Results are presented as least square mean ± standard error of the mean (n=3). The means for each batch of ice cream were calculated from three measurements, and the overall least squared means, presented here, were calculated using the means of each batch (Appendix C). The p-value was obtained from the one-way Analysis of Variance for the treatment effect. Different letters within the same row indicate significant differences at $\alpha=0.05$.

Table A-5. Rheology of ice cream mixes with increasing stabilizer/emulsifier concentration.

	Treatment			**p-value**
	0% S/E	**0.26% S/E**	**0.5% S/E**	
Yield stress (Pa)	1.06±0.13^a	1.10±0.13^a	1.49±0.13^a	0.11
Consistency index -m (Pa*s^n)	0.04±0.02^b	0.10±0.02^{ab}	0.12±0.02^a	0.03
Flow index - n	0.92±0.03^a	0.81±0.03^a	0.84±0.03^a	0.13

Results are presented as least square mean ± standard error of the mean (n=3). The means for each batch of ice cream were calculated from three measurements, and the overall least squared means, presented here, were calculated using the means of each batch (Appendix C). The p-value was obtained from the one-way Analysis of Variance for the treatment effect. Different letters within the same row indicate significant differences at α=0.05.

Table A-6 shows the correlation analysis for all the physical measurements performed in the mix and the ice cream. Remarkably few correlations (4 out of 55 possible combinations) resulted significant, a proportion that is lower than expected by random chance. Moreover, these correlations do not seem to be related with the compositional differences of the treatments under study. However, some make physical sense. Apparent viscosity positively correlated with kinematic viscosity, which is expected since both measurements are related to the flow behavior of the mixes. Overrun positively correlated with apparent viscosity, thus an increase in viscosity relates to a higher air incorporation. This is in disagreement with the general assumption that a high viscosity relates to a low overrun (Goff and Hartel, 2013). However, the increased content of emulsifiers may favor air incorporation due to the amphiphilic nature of these small surfactant molecules. Particle size of the ice cream positively correlated with fat destabilization. This was expected since particle size measurements were used to calculate the percentage of fat that was destabilized during freezing (for details refer to section 3.3.4.6).

Table A-6. Correlation between physical variables.

		Mix					Ice cream				
		T. S.	Dens.	P. S. $d_{4,3}$	Kin. Visc.	App. Visc.	OR.	Draw Temp.	P. S, $d_{4,3}$	Fat destab.	Hard.
Mix	Dens.	-0.357 0.346									
	P. S. $d_{4,3}$	0.335 0.378	-0.226 0.558								
	Kin. Visc.	-0.226 0.489	0.198 0.610	0.297 0.437							
	App. Visc	-0.365 0.333	0.152 0.697	0.375 0.321	**0.941** **<0.001**						
Ice cream	OR.	-0.409 0.274	0.169 0.665	0.485 0.186	0.662 0.052	**0.742** **0.022**					
	Draw Temp.	-0.041 0.916	-0.427 0.251	-0.059 0.881	-0.157 0.686	0.084 0.829	**-0.152** **0.696**				
	P. S $d_{4,3}$	0.548 0.126	-0.014 0.916	0.512 0.159	-0.018 0.963	-0.095 0.808	0.096 0.805	-0.077 0.844			
	Fat destab.	0.490 0.181	-0.014 0.971	0.359 0.343	0.015 0.970	-0.097 0.805	0.008 0.984	-0.031 0.984	**0.966** **<0.001**		
	Hard.	-0.320 0.402	0.469 0.202	-0.616 0.077	-0.077 0.845	-0.271 0.480	-0.325 0.393	-0.635 0.066	-0.513 0.158	-0.423 0.257	
	M. R.	-0.245 0.525	-0.404 0.281	0.023 0.953	0.249 0.518	0.429 0.249	0.180 0.642	0.532 0.141	-0.651 0.058	-0.636 0.066	-0.221 0.567

At the top of each cell is the Pearson correlation coefficient r and below is the p-value with a significance level of α=0.05. Bolded cells represent significant correlations. (n=9).

T. S.= Total Solids, Dens=Density, P. S.=Particle size, Kin. Visc=Kinematic Viscosity, App. Visc=Apparent Viscosity, OR=Overrun, Draw Temp.=Draw Temperature, Fat destab. =Fat destabilization, Hard. =Hardness, M. R.=Melt Rate.

A.3.2 Consumer test

A total of 383 consumers participated in the sensory evaluations of the ice creams. Of this total, 38.1% of the panelists were men and 53.3% were in their 20s and 30s. Figure A-1 shows the results for overall liking of the ice creams with increasing content of the stabilizer/emulsifier blend. Overall liking significantly decreased from the sample with no stabilizer system to the sample with the highest concentration of added stabilizer/emulsifier blend. This could be due to the higher viscosity of the mix, that may be perceived while eating the sample with the highest amount of stabilizer/emulsifier. A key quality attribute for the acceptability of ice creams is the texture perceived in the mouth (Varela et al., 2014). Sweetness, vanilla flavor, creaminess, hardness, smoothness, mouth coating and melting rate did not significantly differ across treatment levels (Figure A-2). Ideally, stabilizers and emulsifiers should not provide or modify the flavor profile of ice creams (Goff and Hartel, 2013).

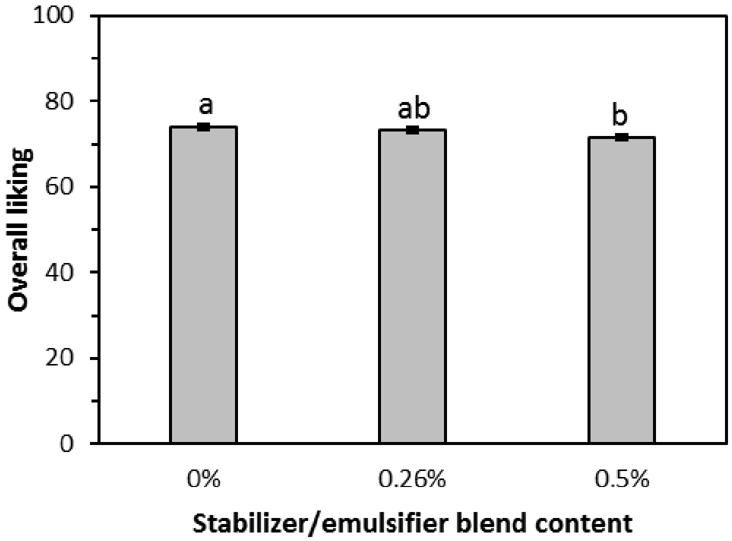

Figure A-1. Overall liking of fresh vanilla ice cream with varying content of stabilizer/emulsifier blend. Results are presented as least square mean ± standard error of the mean (n=383). Different letters indicate significant differences at $\alpha=0.05$.

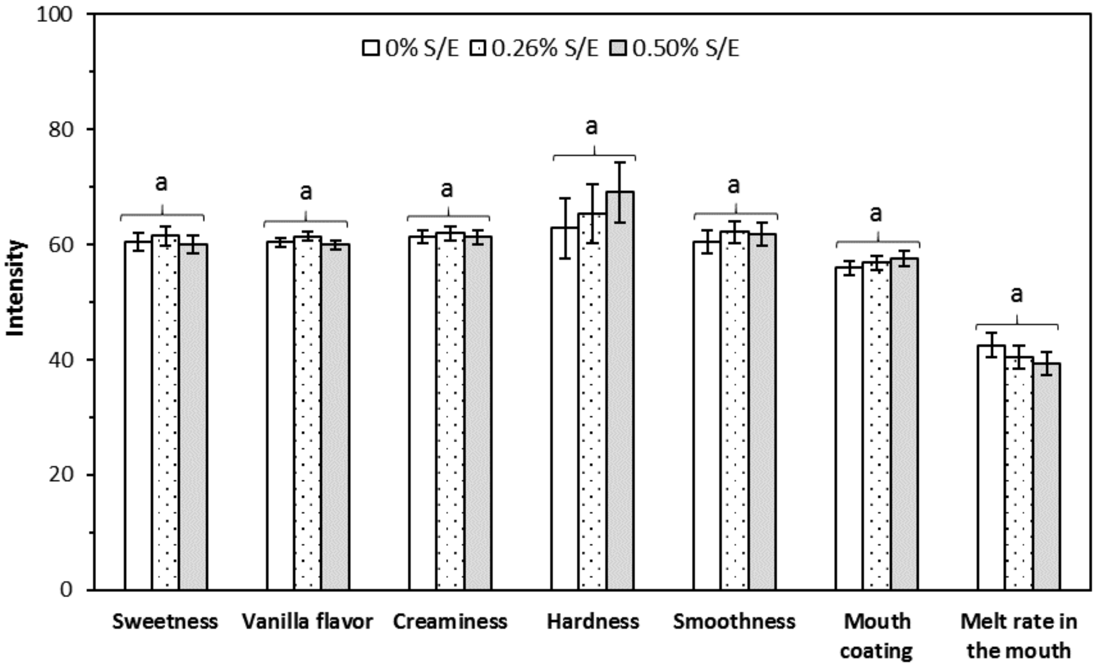

Figure A-2. Intensity sensory attributes of fresh vanilla ice cream. Results are presented as least square mean ± standard error of the mean (n=383). Different letters within the same descriptor indicate significant differences at α=0.05.

Correlation analysis was used to detect relationships between sensory attributes. Results are presented in Table A-7, with significant correlations presented in bold. Most of the attributes measured were correlated with each other. Since the panelists were not trained and the attributes not defined, this could be an indication of how the panelists rated the intensity attributes. It is possible that consumers based the rating of the intensity attributes based on how much they liked the particular samples they were tasting.

Table A-7. Correlation between sensory variables.

	O. L.	Sweet.	Vanilla	Cream.	Sens. H.	Smooth.	Mouthc.
Sweet.	**0.419** **<0.001**						
Vanilla	**0.551** **<0.001**	**0.648** **<0.001**					
Cream.	**0.510** **<0.001**	**0.474** **<0.001**	**0.545** **<0.001**				
Sens. H.	-0.054 0.068	**0.158** **<0.001**	**0.104** **<0.001**	**-0.066** **0.026**			
Smooth.	**0.473** **<0.001**	**0.428** **<0.001**	**0.445** **<0.001**	**0.666** **<0.001**	**0.090** **0.002**		
Mouthc.	**0.322** **<0.001**	**0.430** **<0.001**	**0.406** **<0.001**	**0.529** **<0.001**	**0.136** **<0.001**	**0.513** **<0.001**	
M. R. M.	**0.097** **0.001**	**0.069** **0.020**	0.043 0.150	**0.189** **<0.001**	**-0.344** **<0.001**	**0.128** **<0.001**	**0.171** **<0.001**

At the top of each cell is the Pearson correlation coefficient r and below is the p-value with a significance level of $\alpha=0.05$. Bolded cells represent significant correlations. (n=383).
OL=Overall Liking, Sweet. =Sweetness, Vanilla =Vanilla flavor, Cream. =Creaminess, Sens. H.=Sensory hardness, Smooth. =Smoothness, Mouthc. =Mouth coating, M. R. M=Melt rate in the mouth.

A.3.3 Correlation between sensory and physical variables

Table A-8 shows the correlation results of sensory and physical data obtained. When comparing physical properties of the mix with the sensory attributes measured, only 2 out of 40 relationships were found. Density was found to positively correlate with perceived vanilla flavor; overall liking negatively correlated with apparent viscosity.

The comparison between sensory and the physical attributes measured on the final ice cream produced 11 out of 48 possible correlations. This is little more than would be expected by random chance and may reflect the relatively small differences in physical and sensory properties between the samples despite differences in composition. However, the negative correlation between overall liking and apparent viscosity may explain the differences observed in Figure A-1. Overall liking also negatively correlated with melting rate, meaning that liking increases with a slower melting rate. This last correlation was also observed in the experiments involving fat reduction (Section 3.4.3). Linear regression analysis was used to assess the relationship between overall liking and viscosity; and overall liking with melting rate. Both resulted in significant relationships ($\beta_1 \neq 0$) (Figure A-3).

Table A-8. Correlation between physical and sensory variables.

		Sensory							
		OL	Sweet.	Vanilla	Cream.	Sens. H.	Smooth.	Mouthc.	M. R. M.
Mix	T. S.	0.373 0.323	0.206 0.596	0.099 0.800	0.035 0.929	0.165 0.671	0.063 0.872	-0.223 0.565	-0.244 0.527
	Dens.	0.221 0.568	0.574 0.106	**0.709** **0.032**	0.425 0.255	0.523 0.148	0.275 0.473	0.403 0.283	-0.483 0.188
	P. S. $d_{4,3}$	0.000 0.999	-0.032 0.934	0.226 0.559	0.389 0.301	0.220 0.569	0.577 0.104	0.319 0.402	-0.339 0.372
	Kin. Visc.	-0.528 0.144	0.144 0.713	0.092 0.814	0.182 0.639	0.576 0.105	0.266 0.489	0.578 0.103	-0.608 0.082
	App. Visc	**-0.681** **0.044**	-0.046 0.812	-0.046 0.907	0.140 0.720	0.355 0.348	0.326 0.392	0.497 0.173	-0.463 0.209
Ice cream	OR.	-0.197 0.612	-0.024 0.951	0.203 0.600	0.341 0.370	0.159 0.683	0.505 0.165	0.520 0.152	-0.118 0.762
	Draw Temp.	-0.558 0.119	-0.660 0.053	**-0.742** **0.022**	-0.183 0.637	**-0.723** **0.028**	-0.014 0.973	**-0.297** **0.437**	0.448 0.227
	P. S. $d_{4,3}$	0.524 0.148	0.547 0.127	0.474 0.198	**0.816** **0.007**	0.137 0.725	**0.748** **0.021**	0.534 0.139	-0.193 0.620
	Fat destab.	0.493 0.178	0.558 0.118	0.399 0.287	**0.811** **0.008**	0.154 0.692	0.647 0.060	0.525 0.147	-0.207 0.594
	Hard.	0.227 0.556	0.327 0.391	0.274 0.475	-0.281 0.464	**0.418** **0.263**	-0.552 0.123	-0.116 0.766	-0.181 0.642
	M. R.	**-0.771** **0.015**	**-0.891** **<0.001**	**-0.800** **0.010**	**-0.689** **0.040**	-0.298 0.436	-0.492 0.179	-0.532 0.141	0.176 0.651

At the top of each cell is the Pearson correlation coefficient r and below is the p-value with a significance level of $\alpha=0.05$. Bolded cells represent significant correlations. (n=15).

T. S.= Total Solids, Dens=Density, P. S.=Particle size, Kin. Visc=Kinematic Viscosity, App. Visc=Apparent Viscosity, OR=Overrun, Draw Temp.=Draw Temperature, Fat destab. =Fat destabilization, Hard. =Hardness, M. R.=Melt Rate, OL=Overall Liking, Sweet. =Sweetness, Vanilla=Vanilla flavor, Cream. =Creaminess, Sens. H.=Sensory hardness, Smooth. =Smoothness, Mouthc. =Mouth coating, M. R. M=Melt rate in the mouth.

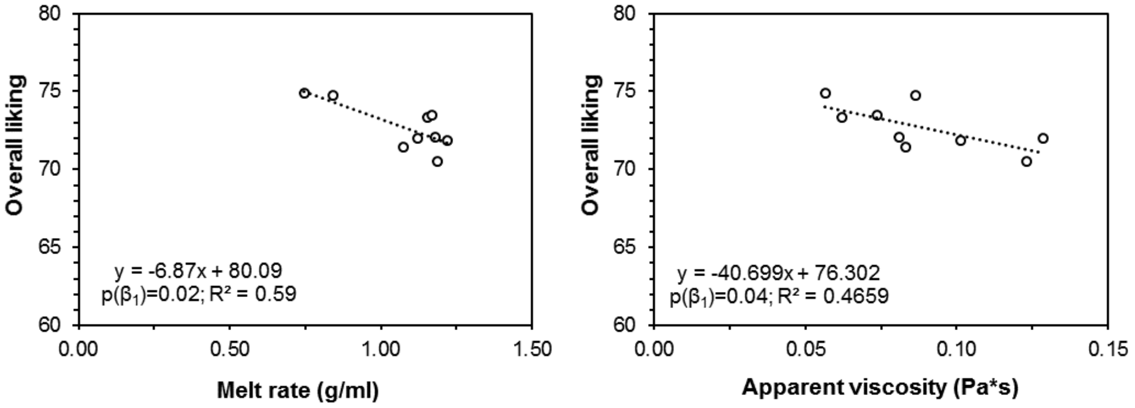

Figure A-3. Regression analysis of overall liking vs melting rate and overall liking vs apparent viscosity. Dots represent least square mean values for all samples (n=9).

A.3.4 Storage stability

The quality of ice cream may be affected during storage, due to ice crystal growth, lactose recrystallization and changes in the air phase (Goff and Hartel, 2013). The major role of stabilizers in ice cream occurs during storage. The water holding capacity of hydrocolloids greatly increases the viscosity of the unfrozen serum phase, limiting the rate of growth of ice and lactose crystals (Flores and Goff, 1999). Past research has focused on the effects of storage temperature and temperature fluctuations in ice crystal growth in ice cream (Flores and Goff, 1999). Descriptive sensory evaluation after storage with different type and concentration of hydrocolloids as also been studied (Soukoulis et al., 2008). However, the effect of storage in ice creams with different concentrations a stabilizers/emulsifier blend has not been explored, thus far. In this study, ice creams were stored for approximately 19 weeks at -18°C before performing a consumer test to assess the degree of liking of the samples. The panel consisted of 289 people in total, of which 39.8% were men and 58.1% were within their 20s and 30s.

The results for the sensory analysis of stored ice creams are presented in Figure A-4. There was no significant difference in overall liking across treatment levels after storage.

However, when comparing between the fresh and stored ice cream liking data, there is a significant difference in liking only in the ice creams that has no addition of stabilizer emulsifier. This sample had a lower rating after the storage period. This could be due to the growth of ice crystals during storage, process that is more favorable when no hydrocolloids are added to limit the movement of water. The stabilizer/emulsifier blend used in this study contains propyl glycol mono esters, which has been shown to decrease the rate of growth of ice crystals (Aleong et al., 2008). Flores and Goff (1999) showed that storage of ice cream at -16°C produced the increase ice crystals. However, the presence of stabilizers did not inhibit crystal growth.

Sweetness, vanilla flavor, hardness, smoothness and melting rate did not significantly differ across treatment levels after storage. Creaminess perception in aged ice cream increased significantly with increasing content of stabilizer/emulsifier blend. When comparing between fresh and stored data, the samples that contained any amount of stabilizer/emulsifier were perceived as less hard and slower melting by consumers after the storage period. Samples without any stabilizer/emulsifier added, were perceived less smooth and less creamy after storage, when compared to the results of the fresh ice cream. Mouth coating perception increased with addition of the stabilizer emulsifier system. However, there were no significant differences when comparing the fresh and stored data.

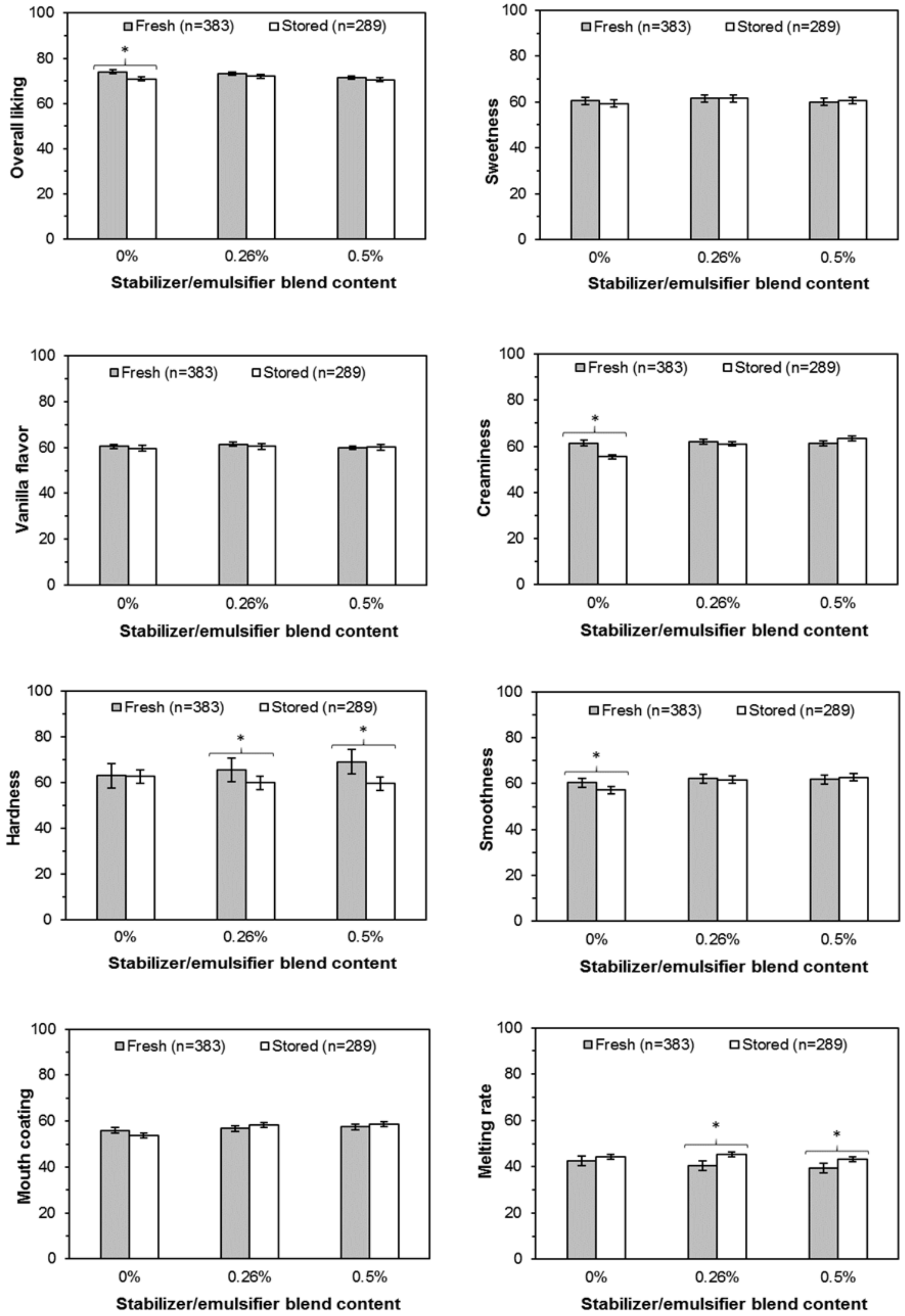

Figure A-4. Overall liking and sensory attributes of fresh and stored ice creams. Results are presented as least square mean ± standard error of the mean. Asterisks within the same treatment level indicate significant differences in the state*treatment effect at α=0.05.

A.4 Conclusions

Changing the amount of stabilizer/emulsifier in an ice cream mix containing 14% fat did not produce an effect in most of the physical parameters measured. The only exception was the increased in viscosity with increase concentration of stabilizer, which was due to the increase in the concentration of hydrocolloids. Overall linking of fresh ice cream increased with a decrease in stabilizer/emulsifier. This could be due to the perception of a more viscous solution during eating. Moreover, a significant negative correlation between apparent viscosity and overall liking was found, as well as a negative correlation between overall liking and melting rate. As for the other sensory attributes that consumers were asked to rate, there was no significant differences across treatment levels. However, prolonged storage for 19 weeks at -18°C equilibrated the liking for all treatment levels tested, which was probably due to the increase in size of ice crystals. However, ice crystal size was not measured in this study.

Appendix B

Use of the Fat Preference Questionnaire©

B.1 Introduction

The Fat Preference Questionnaire© is a survey designed to assess the degree to which individuals prefer the taste of high fat foods, as well as the frequency of consumption of foods that are high in fat. The scores obtained from this tool, have been correlated with fat and calorie intake (Ledikwe et al., 2007).

In this study, the small difference observed in overall liking during the first trial, led to the inclusion of the questionnaire, at the end of the second and third consumer test. The aim was to segregate participants by their degree of preference for high fat food products, and re-analyze the hedonic data.

B.2 Method

The use of the questionnaire involves 19 food sets with each at least one containing full-fat, reduced-fat and no-fat options. Table B-1 presents each food set and the options presented to panelists. Participants answered whether they consume the products in each food set, which one they consume more often and which one they like the most. With the answers produced by the survey, three scores were calculated: TASTE that indicates how much a consumer prefers the taste of high fat food products; FREQ which indicates how often the person will consume a high fat product; and DIFF, the subtraction of FREQ from TASTE which indicates a measure of restrain from consuming high fat products (Ledikwe et al., 2007).

Table B-1. Food sets and choice options included on the Fat Preference Questionnaire© (Ledikwe et al., 2007).

Food set	**High-fat options**	**Reduced-fat or low-fat options**
1. Candy	Chocolate candy	Hard candy
2. Bagel spreads	Regular cream cheese, butter or margarine.	Reduced-fat cream cheese, butter, or margarine or no spread (plain bagel)
3. Potato	French fries or baked potato with regular sour cream or butter	Baked potato with reduced-fat topping or no topping
4. Ice cream	Full-fat ice cream	Reduced fat ice cream
5. Soup	Cream soup	Clear soup
6. Vegetables	Sautéed or fried vegetables	Plain steamed vegetables
7. Sandwich spreads	Regular mayonnaise	Reduced-fat mayonnaise or no mayonnaise
8. Cheese	Full-fat cheese	Reduced-fat cheese
9. Pancake spread	Regular butter or margarine	Reduced-fat butter or margarine, or no butter or margarine
10. Fish	Fried fish	Baked, broiled or grilled fish
11. Burger	Hamburger	Grilled chicken sandwich
12. Salad dressing	Full-fat dressing	Reduced-fat dressing
13. Pasta sauce	Cream sauce	Tomato sauce
14. Pizza	Pizza with extra cheese or meat	Regular cheese pizza
15. Vegetable dip	Full-fat dip	Reduced-fat dip or no dip (plain vegetables)
16. Cookies	Full-fat cookies	Reduced-fat cookies
17. Chicken	Fried chicken	Baked, broiled or grilled chicken
18. Potato chips	Full-fat potato chips	Reduced-fat potato chips
19. Milk	Whole milk	2% or 1% or skim milk.

TASTE and FREQ were calculated as the percentage of food sets where the panelist reported that a high-fat option tasted better or is consumed more often, respectively. A high TASTE score indicates that the consumer reported a preference for the taste of high fat food products. Similarly, a high FREQ score indicated that the consumer eats higher fat products more frequently. DIFF was calculated as the difference of TASTE and FREQ, and represents how much a consumer avoids eating high fat foods, a measure of restraint from consuming high-fat products. After calculating the three scores, the panelists were segregated into groups (High, Medium or Low) for TASTE, FREQ and DIFF. Panelists with scores below 33% were classified as Low, between 33% and 66% as medium and above 66% as High. For each group, a mixed model ANOVA was used to evaluate significant differences in their liking scores for the ice creams.

$$\begin{aligned}\boldsymbol{Overall\ liking} \\ &= \boldsymbol{Treatment} + \boldsymbol{Batch} + \boldsymbol{Batch} * \boldsymbol{Treatment} + \boldsymbol{Panelist}(\boldsymbol{Batch}) \\ &+ \boldsymbol{Serving\ position}(\boldsymbol{Batch}) + \boldsymbol{Residual}\end{aligned}$$

Treatment is a fixed effect and the rest are random effects. If significant differences were found at a 95% confidence level, Tukey’s test was used to compare the treatments within the fat preference group.

B.3 Results

The Fat Preference Questionnaire© was included at the end of the consumer test to measure the degree to which the panelists prefer the taste of high-fat food products and how often they consume high-fat products. Based on their TASTE, FREQ and DIFF scores, panelists were segregated in groups, and the data was reanalyzed to check for differences in liking. Table B-2 shows the results obtained, also illustrated in Figures B-1 through B-3.

Table B-2. Overall liking results segregated by Fat Preference Questionnaire© scores.

	Group	**Treatments**				
		6% fat; 8% MD.	**8% fat; 6% MD.**	**10% fat; 4% MD**	**12% fat; 2% MD**	**14% fat; 0% MD**
TASTE	High (n=131)	71.8±1.3^{ab}	69.7±1.3^{b}	76.0±1.3^{a}	74.2±1.3^{ab}	73.0±1.3^{ab}
	Medium (n=53)	70.4±1.8^{a}	70.5±1.8^{a}	73.2±1.8^{a}	72.3±1.8^{a}	71.5±1.8^{a}
FREQ	High (n=60)	72.2±1.0^{c}	70.6±1.1^{c}	79.6±1.1^{a}	76.2±1.1^{ab}	73.3±1.1^{bc}
	Medium (n=85)	73.3±1.3^{a}	70.5±1.3^{a}	75.1±1.3^{a}	72.8±1.3^{a}	73.5±1.3^{a}
	Low (n=43)	67.4±1.9^{a}	64.9±1.9^{a}	69.9±1.9^{a}	71.7±1.9^{a}	69.8±1.9^{a}
DIFF	Medium (n=36)	72.1±3.4^{a}	67.0±3.4^{a}	71.0±3.4^{a}	70.9±3.4^{a}	70.6±3.4^{a}
	Low (n=151)	71.4±1.0^{ab}	70.1±1.0^{b}	76.5±1.0^{a}	74.4±1.0^{ab}	73.1±1.0^{ab}

Results are presented as least square mean ± standard error of the mean. Different letters within the same row indicate significant differences at $\alpha=0.05$.

Figure B-1 shows the results for the analysis of the overall liking data when consumers were segregated based on their TASTE score. The High group self-reports a preference for the taste of high-fat products, the Low group reported to not prefer the taste of high fat products and the Medium group fell in between. Due to the low number of panelists in the Low group (n=4), the analysis was not performed for this group. For the High fat group, the 8% was less liked than the 10%. However, for the 6, 10, 12 and 14% there was no significant difference in their liking ratings. For the panelists that fell in the Medium group, there was no significant difference in their liking scores for the treatment levels under this study. However, the analysis of the Medium group had a lower power, due to the small number of panelists.

Figure B-2 shows the results for the analysis of the liking data when panelists were separated based on their FREQ group. Panelists in the High group self-reported higher consumption of high-fat products; those in the Low group self-reported lower consumption of low-fat products; and those in the Medium group fell in between. The group of panelists that reported a higher consumption of high-fat products gave a higher rating to the high fat ice creams, where the reduced-fat ice creams (6 and 8%) had a lower liking rating. Moreover, the 10% fat ice cream was rated with the highest liking intensity. However, the 14% fat ice cream is not significantly different in liking that the reduced-fat ice creams. The Medium and Low groups did not show a significant difference in liking for the ice cream treatment levels, which could be due to the small number of panelists included in these groups, resulting in a lower power in the analysis.

Figure B-3 shows the results for the analysis of the overall liking data when consumers were segregated based on their DIFF score, which represents a measure of dietary restraint for the consumption of high-fat products. For example, if a consumer reports that they prefer the taste of high fat products (high TASTE score) and reports that they often consume it (high FREQ score) this would result in a low restraint for consumption of fat products (low DIFF score). A low DIFF score would also be obtained if a panelist reported that they do not like the taste of high-fat products and that they do not consume them (low TASTE and low FREQ). The High group represents consumers with a high restraint from consuming high-fat products, the Low group represents the panelists with a low restraint from consuming high-fat products and the Medium group fell in between. Due to the small number of panelists in the High group (n=1), the analysis was not performed for this group. For the Low group, the 8% was less liked than the 10% fat sample, following the same trend as that shown for consumers with a high TASTE score. However, for the 6, 10, 12 and 14% fat ice cream samples there was no significant difference in their liking ratings. Analysis of the data from panelists that fell in the Medium group, there was no significant difference in their liking scores for the treatment levels under this study, which could be due to the small number of panelists included in this group, resulting in a lower power in the analysis.

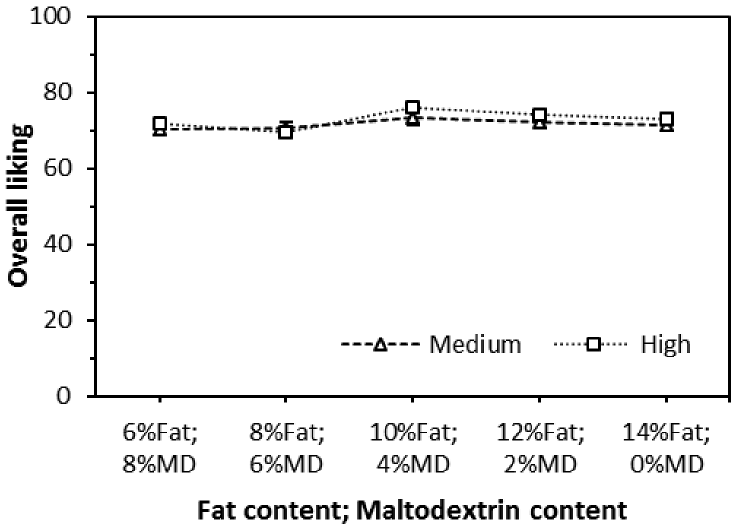

Figure B-1. Overall liking for Fat Preference TASTE score groups. Results are presented as least square mean ± standard error of the mean.

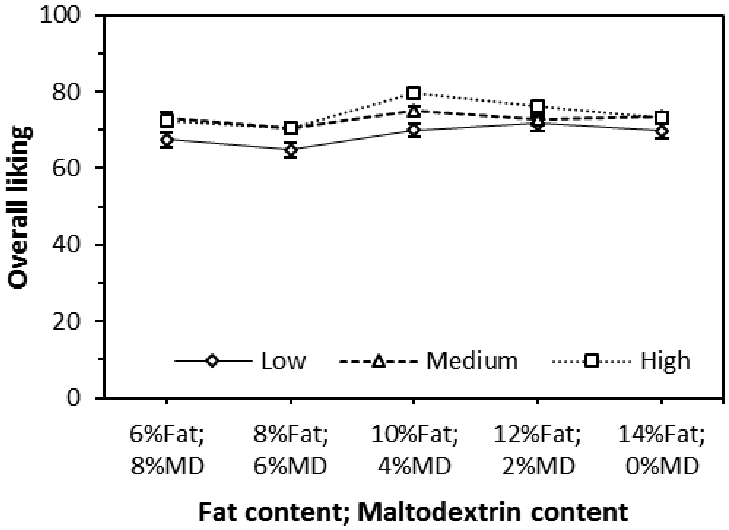

Figure B-2. Overall liking for Fat Preference FREQ score groups. Results are presented as least square mean ± standard error of the mean.

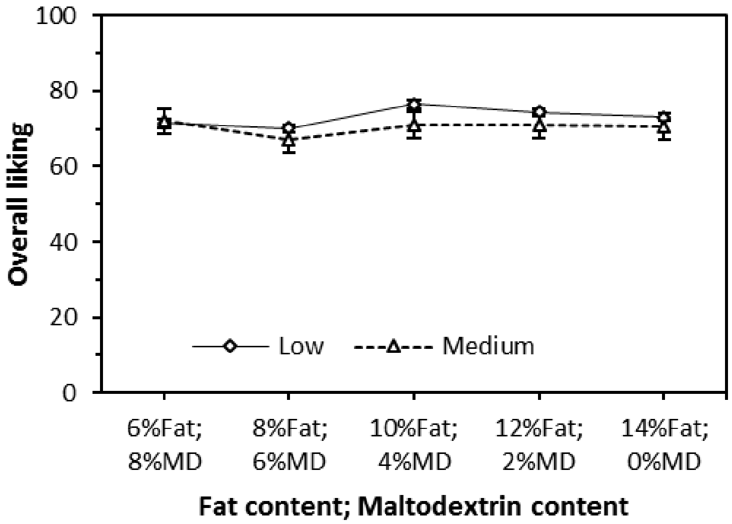

Figure B-3. Overall liking for Fat Preference DIFF score groups. Results are presented as least square mean ± standard error of the mean.

B.4 Conclusions

The use of the Fat Preference Questionnaire© showed that panelists with increased preference for the taste of high-fat products, and with higher frequency of consumption of high-fat foods, resulted in significant differences in overall liking of vanilla ice cream that vary in fat content. For these consumers, the 10% fat sample was the most liked, showing an optimum level of fat in vanilla ice creams.

Appendix C

Raw physical data

C.1 Effect of fat reduction on parameters related to physical structure and consumer acceptability of vanilla ice cream.

Table C-1. Mean data from physical analysis by batch of ice cream mix with increasing fat content.

Batch	**Treatment**	**Total Solids (%)**	**Fat (%)**	**Density (g/ml)**	**Mix Particle Size $d_{4,3}$ (µm)**	**Kinematic viscosity (mm^2/s)**	**Apparent viscosity at 30 s-1 (Pa*s)**
1	06%Fat	41.78	6.62	1.16	0.60	204	0.14
	08%Fat	41.88	8.55	1.13	0.63	184	0.14
	10%Fat	41.93	10.81	1.13	0.67	195	0.18
	12%Fat	41.54	12.42	1.14	0.68	126	0.11
	14%Fat	40.82	14.03	1.12	0.70	107	0.12
2	06%Fat	41.47	6.45	1.19	0.59	215	0.15
	08%Fat	41.80	8.58	1.16	0.62	194	0.15
	10%Fat	41.67	10.61	1.16	0.66	162	0.15
	12%Fat	41.86	13.12	1.14	0.70	146	0.14
	14%Fat	41.45	14.25	1.13	0.75	141	0.13
3	06%Fat	41.13	6.66	1.19	0.56	163	0.14
	08%Fat	41.47	8.89	1.16	0.60	185	0.17
	10%Fat	41.78	10.98	1.16	0.66	149	0.15
	12%Fat	42.03	13.19	1.16	0.67	131	0.13
	14%Fat	41.61	14.28	1.13	0.67	104	0.12

Presented as the mean of three measurements.

Table C-2. Mean data from physical analysis by batch of ice cream with increasing fat content.

Batch	**Treatment**	**Overrun (%)**	**Draw T (°C)**	**Ice Cream Particle Size $d_{4,3}$ (µm)**	**Fat destabilization (%)**	**Hardness (kg)**	**Melt rate (g/min)**
1	06%Fat	62	-5.2	0.85	24.4	3.00	1.36
	08%Fat	59	-5.0	1.06	33.3	4.43	1.24
	10%Fat	61	-5.0	1.91	57.1	3.75	1.32
	12%Fat	62	-5.1	1.61	46.5	4.56	1.13
	14%Fat	65	-4.6	3.73	74.1	5.66	1.19
2	06%Fat	66	-5.9	0.96	33.3	5.34	1.48
	08%Fat	64	-5.9	1.62	52.0	2.94	1.27
	10%Fat	64	-5.9	3.32	74.1	3.69	1.08
	12%Fat	65	-5.6	4.60	79.9	4.95	1.13
	14%Fat	64	-5.5	4.24	76.7	6.69	1.12
3	06%Fat	70	-5.9	1.21	45.9	7.32	1.22
	08%Fat	66	-5.7	1.47	51.2	7.15	1.46
	10%Fat	66	-5.7	2.98	70.7	6.06	1.08
	12%Fat	67	-5.2	4.41	80.7	8.29	0.65
	14%Fat	60	-5.1	5.45	83.7	10.01	0.95

Presented as the mean of three measurements.

C.2 Effect of stabilizer/emulsifier addition on parameters related to physical structure and consumer acceptability of vanilla ice cream.

Table C-3. Mean data from physical analysis by batch of ice cream mix with increasing stabilizer/emulsifier content.

Batch	Treatment	Total Solids (%)	Fat (%)	Density (g/ml)	Mix Particle Size $d_{4,3}$ (µm)	Kinematic viscosity (mm^2/s)	Apparent viscosity at 30 s-1 (Pa*s)
1	0%SE	41.53	14.14	1.11	0.68	20	0.06
	0.26%SE	41.48	14.19	1.12	0.70	23	0.08
	0.5%SE	40.82	14.03	1.12	0.70	107	0.12
2	0%SE	41.48	14.19	1.12	0.70	23	0.06
	0.26%SE	41.16	13.89	1.15	0.67	69	0.09
	0.5%SE	41.45	14.25	1.13	0.75	141	0.13
3	0%SE	40.96	13.80	1.13	0.69	25	0.07
	0.26%SE	41.09	13.82	1.14	0.64	57	0.08
	0.5%SE	41.19	13.76	1.12	0.66	103	0.10

Presented as the mean of three measurements.

Table C-4. Mean data from physical analysis by batch of ice cream mix with increasing stabilizer/emulsifier content.

Batch	**Treatment**	**Overrun (%)**	**Draw Temperature (°C)**	**Ice Cream Particle Size $d_{4,3}$ (µm)**	**Fat destabilization (%)**	**Hardness (kg)**	**Melt rate (g/min)**
1	0%SE	58	-4.7	4.11	78.5	6.74	1.15
	0.26%SE	61	-4.6	3.73	71.3	4.87	1.18
	0.5%SE	65	-4.6	3.73	74.1	5.66	1.19
2	0%SE	60	-5.7	4.63	79.3	8.42	0.75
	0.26%SE	63	-5.5	4.43	79.6	8.44	0.84
	0.5%SE	64	-5.5	4.24	76.7	6.69	1.12
3	0%SE	62	-5.5	2.87	66.0	9.69	1.17
	0.26%SE	57	-5.1	2.88	68.7	10.87	1.07
	0.5%SE	62	-5.5	2.87	67.5	9.69	1.22

Presented as the mean of three measurements.

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