DEVELOPMENT OF MODIFIED FAT ICE CREAM PRODUCTS USING INULIN AS A FAT REPLACER

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Thesis

Entitled

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ABTRACT

Nowadays, the trend of ice cream consumption in Thailand is increasing, especially for low-fat products. However, the reduction of fat content in ice cream products is known to reduce the quality of ice cream. The improvement of these qualities could be done by adding a fat replacer. Typically, fat replacers have been bulking agents, which are based on carbohydrates and dietary fiber such as cellulose, gum starch, pectin, maltodextrin and polydextrose. Theses ingredients are currently used in low fat formulations. One of the dietary fibers is inulin, which has health benefit and is also considered to have functional properties such as the ability to act as a fat or sugar replacer without adversely affecting food flavor. The aim of this study was to develop non-fat, low-fat, light and reduced-fat ice cream products using inulin as a fat replacer and to study the influence of inulin on the quality of the product. Inulin was used as a fat replacer at the concentration of 5, 7 and 9% in non-fat, low-fat, light and reduced-fat ice cream. All samples were analyzed for sensory properties and physical properties including viscosity, overrun, melting rate, color, texture (hardness), fat destabilization, and air cell size. The samples with highest score of sensory evaluation were chosen to test for stability during storage and nutritional value.

The results showed that increasing inulin concentration in the samples significantly increased ($p<0.05$) the values of viscosity, meltdown rate, and fat destabilization (%), whereas the overrun value, and air cell size decreased. Varying concentration of inulin in the samples did not affect the qualities ($p\geq0.05$) in hardness and sensory properties. The sensory scores of low, light and reduced-fat ice cream products with added inulin were similar ($p\geq0.05$) to the score of the full-fat sample. However, replacing all milk fat with inulin in the non-fat (0.5%fat) ice cream significantly lowered the sensory scores when compared to the control sample. The chosen formulas contained 5% inulin addition in each type of ice cream. According to the results of sensory test during storage, an unacceptable score (less than 5) was found in the overall acceptability only in non-fat ice cream with 5% inulin formula at the 3rd week. Increasing storage time significantly increased the hardness value ($p<0.05$). Whereas air cell size was not affected by storage time. Hence, it was possible to use inulin as a fat raplacer in modified fat ice cream products, starting at 5% by weight.

KEYWORDS: INULIN/ ICE CREAM/ FAT REPLACER

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การพัฒนาไอศกรีมดัดแปลงไขมันโดยใช้อินนูลินเป็นสารทดแทนไขมัน
(DEVELOPMENT OF MODIFIED FAT ICE CREAM PRODUCTS USING INULIN AS A FAT REPLACER)

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บทคัดย่อ

ปัจจุบันนี้ การบริโภคไอศกรีมในประเทศไทยมีแนวโน้มสูงขึ้นโดยเฉพาะในไอศกรีมที่มีการลดไขมัน อย่างไรก็ตามการลดไขมันในไอศกรีมส่งผลให้คุณภาพของไอศกรีมด้อยลง การปรับปรุงคุณภาพที่ด้อยลงของไอศกรีมลดไขมันอาจทำได้โดยการเติมสารทดแทนไขมันลงไปในผลิตภัณฑ์ สารทดแทนไขมันที่ใช้ในปัจจุบันจัดอยู่ในกลุ่มของคาร์โบไฮเดรตและใยอาหาร เช่น cellulose, gum starch, pectin เป็นต้น อินนูลิน เป็นใยอาหารประเภทหนึ่งที่ทราบกันดีว่ามีประโยชน์ต่อร่างกายและอาจมีคุณสมบัติในการเป็นสารทดแทนไขมันหรือน้ำตาลได้โดยปราศจากผลกระทบต่อกลิ่น-รสของผลิตภัณฑ์ จุดประสงค์ของการทดลองนี้เพื่อการพัฒนาไอศกรีมลดไขมันชนิดต่างๆ (non-fat, low-fat, light, and reduced-fat ice cream) โดยใช้อินนูลินเป็นสารทดแทนไขมัน และศึกษาถึงผลกระทบจากการใช้อินนูลินเป็นสารทดแทนไขมันต่อคุณภาพด้านต่างๆของไอศกรีม โดยใช้อินนูลินทดแทนไขมันในไอศกรีมสูตรต่างๆในอัตราส่วนร้อยละ 5, 7 และ 9 ไอศกรีมดัดแปลงไขมันจะถูกนำไปวัดคุณภาพทั้งทางด้านกายภาพ (ความหนืด การขึ้นฟู อัตราการละลาย สี เนื้อสัมผัส ดัชนีการรวมตัวกันของอนุภาคไขมันในไอศกรีม ขนาดเซลล์อากาศในไอศกรีม) และประสาทสัมผัส ผลิตภัณฑ์ที่ได้รับความยอมรับในการทดสอบทางประสาทสัมผัสมากที่สุดในแต่ละชนิดของไอศกรีมจะถูกเลือกไปทดสอบความคงตัวของผลิตภัณฑ์ระหว่างการเก็บรักษาและคุณค่าทางโภชนาการ

ผลการทดลองพบว่าการเพิ่มขึ้นของปริมาณอินนูลินในไอศกรีมแต่ละชนิดส่งผลให้ค่าความหนืด อัตราการละลาย และดัชนีการรวมตัวกันของอนุภาคไขมันมีค่าเพิ่มขึ้นอย่างมีนัยสำคัญ ($p<0.05$) ในขณะที่ค่าการขึ้นฟูและขนาดเซลล์อากาศในไอศกรีมมีค่าลดลงอย่างมีนัยสำคัญ ($p<0.05$) เมื่อเพิ่มปริมาณอินนูลินในไอศกรีมแต่ละชนิด ในส่วนของเนื้อสัมผัสและการทดสอบทางประสาทสัมผัสพบว่าการเติมอินนูลินในปริมาณที่แตกต่างกันไม่ส่งผลต่อคุณสมบัติเหล่านี้อย่างมีนัยสำคัญ ($p\geq0.05$) โดยเฉพาะในไอศกรีมชนิด light, low และ reduced-fat ice cream เมื่อเติมอินนูลินให้ผลทางประสาทสัมผัสไม่ต่างอย่างมีนัยสำคัญ ($p\geq0.05$) จากไอศกรีมสูตรไขมันเต็มในขณะที่ไอศกรีมชนิด non-fat การเติมอินนูลินทำให้คะแนนการประเมินผลทางประสาทสัมผัสลดต่ำกว่าไอศกรีมสูตรไขมันเต็มอย่างมีนัยสำคัญ ($p<0.05$) สำหรับการทดสอบความคงตัวของผลิตภัณฑ์ระหว่างการเก็บรักษาในไอศกรีมที่เติมอินนูลินที่ปริมาณร้อยละ 5 ในไอศกรีมแต่ละชนิดพบว่าการเพิ่มระยะเวลาเก็บรักษาส่งผลให้มีการแข็งขึ้นของเนื้อสัมผัส ($p<0.05$) แต่ไม่มีผลกระทบต่อขนาดเซลล์อากาศในไอศกรีม ดังนั้นจะเห็นได้ว่าสามารถใช้อินนูลินเป็นสารทดแทนไขมันในผลิตภัณฑ์ไอศกรีมัดแปรงไขมันโดยเริ่มต้นจากร้อยละ 5 โดยน้ำหนัก

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LIST OF ABBREVIATIONS

ANOVA	analysis of variance
Ca	calcium
CMC	carboxy-methylcellulose
cP	centipoises
CRB	completely randomized block
ºC	degree Celsius
d	day
DE	dextrose equivalence
DP	degree of polymerization
Fe	iron
FOS	frutrooligosaccharide
g	gram
h	hour
HTST	high temperature short time
kcal	kilocalorie
kg	kilogram
kJ	kilojoules
L	liter
Mg	magnesium
mg	milligram
min	minute
mL	milliliter
mm	millimeter
nm	nanometer
NMS	non-fat milk solid
no.	Number

LIST OF ABBREVIATIONS (cont.)

rpm	rotation per minute
sec	second
%t	% torque
μm	micrometer
w/w	weight by weight

CHAPTER I
INTRODUCTION

Ice cream is a frozen mixture of a combination of component of milk, sweetener, stabilizers, emulsifiers and flavoring agent (Marshall and Arbuckle 1996). Ice cream has been a favorite dessert in many countries, such as, the United State, Canada, and Western Europe (Anonymous 2003). In Thailand, ice cream is also popular. According to the Market Research, the market for ice cream is growing at an average annual rate of 3.4% during 2001-2006 (Anonymous 2007). Ice cream and other frozen desserts are consumed by more than 90% of household in the United State, and children are one of the primary consumer groups. Traditionally, a commercial regular ice cream should contain about 10% to 12% fat and 18% to 27% sugar. The caloric value of ice cream is about 9.6-11 KJ/g which makes it a high calorie product (Zhang and Wang 1999). Generally, high dietary fat intake is associated with an increase in a risk of many diseases, such as obesity, some types of cancer, high blood cholesterol and coronary heart disease (William and Rothstein 2006). Hence, recent surveys showed that low-fat ice creams are driving the growth while regular ice creams are decreasing in popularity (Anonymous 2005a). This market trend is seen in most developed countries because of consumers concern about the impact of diet on health (Yackel and Cox 1992; Buisoon 2006). In the United States, the demand for calorie-reduced foods by consumers is now greater than ever because most adults are overweight. As a consequence, the dairy industry has developed a variety of low-fat or fat-free ice cream products in order to cater to this tendency. Meanwhile, consumer’s perception of low-fat foods depends not only on the nutritional image but also the acceptable sensory qualities of appearance, texture and flavor (Shamil and Kilcast 1992). Consumers prefer the taste of high fat products due to better product quality, compared with the similar low-fat or fat-free products.

Previous studies showed fat reduction in frozen dairy desserts generally contributes to less positive flavor, texture, or overall acceptability ratings compared with higher-fat products (Prindiville *et al* 2000). It is evident that consumers want healthier ice cream but are not yet satisfied with the taste of the products being offered (Anonymous 1997)

Jiménez-Flores *et al* (1992) suggested the properties of milk fat in ice cream to include imparting a pleasing body and mouthfeel, sensation of richness, and pleasing flavor. The primary difficulties to be overcome in low-fat or fat-free products include improving the mouthfeel and flavor perception to resemble that of full-fat products. To meet this challenge, use of fat replacer is necessary to maintain the function of milk fat. Fat replacers have been used to replace fat in food systems due to their properties and the improvement of texture quality of such foods (Akoh 1998). Typically, fat replacers currently used in low-fat formulation have been bulking agents based on carbohydrates, such as cellulose, gum, starch, pectin, maltodextrin and polydextrose (Roland *et al* 1999). In addition many studies reported that increasing proportions of fiber in foods are known to reduce the risk of colon cancer, obesity, cardiovascular diseases and several other disorders. Several dietary fibers have been used in dairy products not only to provide their possible beneficial effects on health but also as potential fat substitutes. Some components of dietary fiber are classified as inulin.

Inulin, a nondigestible carbohydrate containing naturally occurring fructo-oligosaccharides, possesses some characteristics of dietary fibers (Flamm *et al* 2001), stimulates the selective growth of beneficial bifidobacteria, increases the absorption of calcium by the body and reduces the triglyceride content of the serum and in the liver (Kaur and Gupta 2002). Alongside its health benefits, inulin is also considered to have functional properties such as the ability to act as a fat or sugar replacer without adversely affecting flavor (Tungland 2002). Its properties as a fat mimetic have been attributed to its ability to bind water molecules and form a particle gel network (Franck 2002). Nevertheless, relatively little research has focused on inulin as a fat replacer in frozen desserts. El-Nagar *et al* (2002) found that addition of inulin to low fat yoghurt-ice cream increased viscosity of the yoghurt-ice cream mix and increased hardness of the resulting yogurt-ice cream. Akin *et al* (2007) studied the use of inulin as a prebiotic in probiotic ice cream. He also reported that the addition of inulin improved viscosity, first dripping and complete melting times, while it had no effect on the sensory properties. Therefore, limited information exists on the application of inulin particularly to the full range of modified fat ice creams.

Dairy products, such as ice cream, can provide major opportunities for the development of functional foods. Although the demand may be increasing for functional foods, their acceptability by the consumer is still based on satisfactory textural and sensory attributes. Therefore, it is essential to understand the technological impact of incorporation of inulin into ice cream and its potential function as a fat replacer in such product.

CHAPTER II
OBJECTIVES

General objective:

To develop non-fat, low-fat, light, and reduced-fat ice cream products using inulin as a fat replacer and to study the influence of inulin on the quality of product.

Specific objectives:

1. To develop non-fat, low-fat, light, and reduced-fat ice cream products using inulin as a fat replacer and evaluate the sensory acceptability of these products.
2. To determine the physical properties including apparent viscosity, color, texture, melting rate, development of air cell, fat destabilization and overrun of these products.
3. To determine the nutritional values of these products.
4. To examine product stability and shelf life.

CHAPTER III
LITERATURE REVIEW

3.1 Ice cream

3.1.1 Definition & classification

Ice cream is a frozen mixture of a combination of component of milk, sweeteners, stabilizers, emulsifiers and flavoring. Other ingredients such as egg products, coloring, and starch hydrolysates also may be added. This mixture, called a mix, is pasteurized and homogenized before freezing. Freezing involves rapid removal of heat while agitating vigorously to incorporate air, thus imparting the desirable smoothness and softness of the frozen product.

According to U.S. Federal Regulations (21CFR135.110), ice cream is a frozen food made from a mixture of dairy ingredients, containing at least 10% milk fat before the addition of bulk ingredients, such as flavorings and sweeteners (Marshall *et al* 2003).

Alexander (1997) demonstrated that typical ice creams contain about 10%-12% fat, while some premium products contain 16%-18% fat. Another composition standard for ice cream proposed by the International Ice Cream Association (ICA) was described as follows: non-fat products <0.8 % fat, low-fat 2-4 % fat, reduced-fat 7-9 % fat and full-fat 10-12 % (Farooq 1997). In other words reduced-fat ice cream is a product of at least 25% lower in total fat than typical ice creams; light ice cream is defined as a product of at least 50%lower in total fat or 33% fewer calories than the referenced products; low-fat ice cream contains a maximum of 3 g of total fat per serving (1/2 cup), and non-fat ice cream is a product of less than 0.5 g of total fat per serving (Klahorst 1997; Pszczola 2002; Miraglio 2006). Examples of the composition of some typical ice creams are shown in Table 3-1 (Klahorst 1997).

Table 3-1 The composition of some typical ice creams

Ingredients / Product	Milk fat (%)	NMS (%)	Sweeteners (%)	Stabilizers (%)	Total Solids (%)
Nonfat ice cream (hard)	<0.8	12-14	18-22	1.0	35-37
Low-fat ice cream (hard)	2-4	12-14	18-21	0.8	35-38
Light ice cream (hard)	5-6	11-12	18-20	0.5	35-38
Reduced-fat ice cream	7-9	10-11	18-19	0.4	36-39
Economy ice cream	10-12	10-11	15	0.3	35-37
Premium ice cream	18-20	6-7.5	16-17	0-0.2	42-45
Super-premium ice cream	20	5-6	14-17	0.25	46

NMS – Non fat milk solid
(Modified from Klahorst 1997)

3.1.2 Composition and quality factor

Ice cream is composed of a mixture of milk products, sweetening materials, stabilizers, flavors and egg products, which are referred to as ingredients. Most of these ingredients in ice cream are multifunctional, contributing to different aspects of ice cream manufacture, product quality and stability.

Non-fat milk solids

Non-fat milk Solids (NMS) are the solids of skim milk, and consist of approximately 55% lactose, 37% protein, 8% minerals and others, such as vitamins, acids and enzymes. These solids are high in food value, inexpensive, and while not adding high flavor notes to the ice cream, enhance its palatability. Lactose adds slightly to the sweet taste, largely produced by added sugar, and minerals have a slightly salty taste, which rounds out the flavor of finished product. The proteins in NMS help to make the ice cream more compact and smooth, and thus tend to prevent a weak body and coarse texture. Nevertheless, an excess of NMS may result in a salty, overcooked, or condensed-milk flavor and increase the risk of lactose crystallization during storage.

NMS increase viscosity and resistance to melting, but also lower the freezing point. Variations over the usual range of concentration have no pronounced effect on whipping ability, but variations in the quality of NMS do have an important influence on it.

Stampanoni Koeferli and others (1996) indicated that NMS can cause a decrease in coldness, ice crystal and melting rate perception and an increase in creaminess and mouth coating. In addition, it can increase attainable overrun without producing poor texture and strengthen resistance to heat shock and shrinkage (Goff *et al* 1989; Goff 1995). Lactose in NMS causes a lower freezing point, and milk protein provides a slight flavor, water holding and also affects the formation of air cells in ice cream (Campbell and Marshall 1975; Dahlberg 1931).

NMS can come from several sources, such as skim milk, condensed whole milk and buttermilk. Buttermilk solids can be a superior substitute for NMS, especially in mixes made with butter, butter oil or anhydrous milkfat as the source of fat. Buttermilk contains a higher concentration of fat globule membrane phospholipids than does skim milk (Marshall and Goff 2003; Marshall *et al* 2003).

Milk fat

Milk fat is an ingredient of major importance in ice cream. The use of correct percentage is essential not only to balance the mix properly, but also to satisfy legal standard (Marshall 1991; Goff 1995). The effect of milk fat in ice cream is dependent on several factors including the type and level of fat, the amount of non-fat milk solids and sugar, as well as variety of flavor compounds used in ice cream (Marshall and Arbuckle 1996).

Studies consistently show that fat globules concentrate at the surface of air cell during the freezing of ice cream. This accounts, in part, for milk fat imparting rich characteristic to ice cream flavor. Increasing of milk fat in ice cream decreases the ice crystal by interrupting the space in which they have to form. Milk fat, because it does not dissolve, dose not lowers the freezing point. It tends to retard the rate of whipping (Marshall and Arbuckle 1996).

The best source of milk fat is fresh cream, and provides the desirable flavors and aids in good melting properties and in decreasing the size of ice crystals (Hyde 2001). Furthermore, milk fat also affects textural attributes such as viscosity, tenderness, elasticity, emulsification, ice crystallization and other desirable attributes such as richness, smoothness (Marshall and Arbuckle 1996; Yackinous and Guinard 2000; Hyde 2001). The possible mechanism of milk fat contributing necessary structure and texture of ice cream is due to trapped water, creating an oil-in-water emulsion with the interaction of stabilizers and emulsifier during whipping (Hyde 2001).

During the freezing process, milk fat globules concentrate toward the surface of air cells to support the air cell structure as air is incorporated into the mix and are surrounded by casein subunits absorbed at the fat-water interface (Goff 1995; Koxholt *et al* 2001; Marshall and Goff 2003). Milk fat coalesces partially during freezing to form and stabilize the ice cream structure and to give body to the ice cream (Goff 1995). Stampanoni Koeferli *et al* (1996) showed that, within the 3% to 12% range, fat increased primarily buttery, creamy, and mouth coating characteristics of ice cream and lowered its melting rate, coldness and ice crystal perception, whereas sugar increased sweetness, caramel and vanillin notes and lowered milky flavor. Excessive milk fat decreases whipping ability and results in excessive richness as well as high caloric value (Goff 1995).

The fat content of commercial ice cream is usually 10-12%. When the fat percentage is lower than 10%, a descriptor (reduced-fat, light, low-fat and non-fat or fat-free) must be use in the label.

Sweeteners

Sweetness control in ice cream is very important in order to achieve maximum consumer acceptance and minimum production cost (Wilson-Walker 1982). For most ice cream formulation the sweetener can be either sucrose (cane or beet sugar) alone or sucrose in combination with some products of hydrolyzed corn starch. The sugar may be used in dry or liquid form.

The amount of sweeteners added to ice cream is very important. Besides creating desirable flavor properties, sweeteners are also the major ingredients to lower the freezing point, which is one of the influential factors for quality of the ice cream mixes (Baer and Baldwin 1984). When sweetener content is about 16% or higher, ice cream tends to become too soft or too dense and chewy, depending on the type of sweeteners used in excess, due to lower freezing point. In other words, hardness of ice cream is dependent upon the sugars and other materials (Baer and Baldwin 1984; Grotta 1994). If a mix with a lower freezing point causes less water to be frozen as the ice cream exits the freezer, the storage life of ice cream is shortened due to it being more susceptible to an increase in ice crystal size during temperature fluctuations (Schaller-Povolny and Smith 1999). Furthermore, as sweetener concentration is increased, viscosity of the mix and firmness of the ice cream increase.

Monosaccharides, such as fructose and glucose, equally lower the freezing point of the mix, although they do it to a greater degree than disaccharides. High molecular weight sugars, such as corn syrup, do not depress the freezing point as much as disaccharides on a weight to weight basis (Bodyfelt *et al* 1988).

Sweeteners and various flavorings are added to dairy products to improve flavor balance (Haschke *et al* 1988) and to partially mask acetaldehyde flavor (Kagan1985). In general, approximately 45% of the sucrose can be replaced with corn syrup for economic, handling or storage reasons. However, corn syrup with low to medium dextrose equivalents (DE) may impart off-flavors and should constitute no more than about one-third of the total sweetener solids. In fact, low DE sweeteners, made by hydrolysis of starches, do not contribute much sweetness, but they provide great water binding properties (Goff 1995).

The percentage of the sweetening agents obtained from different sources added to the ice cream mix is influenced mainly by the desired (1) concentration of sugar in the mix (2) total solids content of the mix (3) effect on the properties of the mix (4) concentration of sweeteners other than sugar and (5) relative inherent sweetening power of the sweeteners other than sucrose (Marshall *et al* 2003).

Emulsifiers

Emulsifiers are used in the manufacture of ice cream to produce a finished product with a smoother texture and stiffer body and to reduce whipping time. Mono-, diacylglycerides and sorbitan esters, especially polysorbate 80, are usually used in ice cream as the emulsifiers (Marshall and Goff 2003).

The normal requirements in ice cream ingredients for emulsifiers are between 0.1%- 0.5 % (Clark 1994; Marshall and Goff 2003). The excessive use of emulsifiers may result in slow melting, and body and texture defects.

Emulsifiers added to ice cream have several important functions, including that they

(1) Lower the fat and water interfacial tension in the ice cream mix so that they cause protein displacement from the fat globule surface, which in turn reduces the stability of the fat globule causing it to partial coalesce during the whipping and freezing process (Goff *et al* 1989);

(2) Promote nucleation of fat during aging of mixes, thus reducing the time needed to age mixes before freezing (Goff 1995);

(3) Decrease tendencies for shrinkage and lower the rate of melting (Bodyfelt *et al* 1988);

(4) Cause a high amount of agglomeration of the fat during freezing. Therefore, the surfaces of the fat globules must have a relatively high concentration of emulsifier (Goff 1995).

Stabilizer

Stabilizers are used to prevent the formation of objectionable large ice crystals in ice cream and are used in such small amounts as to have negligible influence on food value and flavor.

They are of three general types: (1) gelatin stabilizers, which come form animal sources (such as calf skin, pig skin, and bones); (2) vegetable stabilizers, such as sodium alginate, carrageenan, agar, and CMC (catboxy-methylcellulose); (3) gum, such as guar, locust bean, tragacanth, and oat.

The stabilizer contributes several functions in ice cream. It can increase the viscosity of products while decreasing water migration, maintain homogeneity and control ice crystal growth during the freezing process (Hagiwara and Hartel 1996; Flores and Goff 1999). Stabilizers in ice cream cause a slight increase in melting rate (Arbuckle 1986). During storage, stabilizers play a role in resisting structural changes during “heat shock”, which is the inevitable temperature-cycling during storage that creates ice crystal growth and other types of deterioration due to structural changes (Goff 1995). During consumption, stabilizers provide uniform meltdown, mouthfeel and texture. Stabilizers can also contribute to a smoother and more resistant body and texture (Arbuckle 1986).

However, too much stabilizer can make the mix too viscous, making the ice cream heavy and soggy. In short, stabilizer added to ice cream is to control ice crystal growth during hardening and storage, especially during temperature fluctuations, to give body and stiffness during freezing for air corporation and to impart smoothness in body and texture (Arbukle 1986; Marshall *et al* 2003). The sensory quality and overall acceptability of ice cream with various stabilizers has been reported (Minhas *et al* 1997, Minhas *et al* 2002).

The amount of stabilizer to use varies with its properties, with the solids content of the mix, with the type of processing equipment, and with other factors. The amount used in regular ice creams may be in the range 0-0.5%, but generally is from 0.2-0.3% (Bo-Kang Lion 2006). When fat content is reduced, stabilizers content is increased with cellulosic products being added (Mashall and Arbuckle 1996).

Flavorings

Flavor is the most important positive attribute of ice cream. Vanilla, chocolate and strawberry flavor are among the most preferred ice cream products (Marshall *et al* 2003). The type and intensity of flavor in ice cream are the two important flavor characteristics. Flavors should only be intense enough to be recognized easily and to present a delicate pleasing taste. Too much or too little flavoring, unnatural or atypical flavoring, and too much or too little sweetness could cause important defects in ice cream (Li *et al* 1997; Marshall *et al* 2003).

Some factors, including mix composition, ingredient quality, process variables, freezing and storage conditions, age of product, temperature of consumption, pH, fat content, sweetness level, stabilizers, incorporation of air and flavorings added, affect the overall flavoring of ice cream (Marshall *et al* 2003). For example, the higher the content of non-fat solid in ice cream, the more flavoring will be added (Hyde 2001). In addition, temperature, hydration, surface area, enzyme saliva and binding phase inversion also affect flavor release during eating (Marshall and Arbuckle 1996).

The procedure for adding flavorings to ice cream usually depends on the type of flavoring used, such as liquid, syrup, semisolid, and solid forms, and the type of freezer. Other than liquid forms, flavorings are added to the batch freezer prior to completion of the freezing process in most situations (Marshall *et al* 2003). Liquid flavorings are added to ice cream mixes prior to freezing. In addition, the performance and type of the freezer also is a critical factor in the use of the mix composition and flavor. For example, ice cream mixes with added chocolate flavor, whip more slowly than mixes of most other flavors (Marshall *et al* 2003). The amount of flavoring added to ice creams needs to be high enough to ensure good impact at the low temperatures of consumption and also to be balanced with sweetness (Marshall *et al* 2003). The typical consumption temperature of ice cream is between -20°C and -5°C. The lower the temperature, the lower the flavor impact perceived.

3.1.3 Manufacturing

The basic steps in the manufacturing of ice cream generally consist of two distinct stages: mix manufacture and freezing operations. Mix manufacture consists of combining and blending of ingredients, batch and continuous pasteurization, homogenization and mix aging. Freezing operations usually include a two-step process: under high shear and under quiescent conditions (Caldwell *et al* 1992; Marshall and Goff 2003).

Pasteurization

The main purpose of pasteurization, the biological control point, in ice cream is to destroy the pathogenic bacteria. In addition, most hydrolytic enzymes, even the natural ones of raw milk, which could damage flavor and texture, are destroyed by pasteurization. Pasteurization adds little additional expense, because it is necessary to heat mix to dissolve or hydrate dry ingredients. Furthermore, homogenization can be best accomplished at temperatures near those of pasteurization.

Both batch pasteurization and continuous high temperature short time (HTST) method are generally used in the manufacture of ice cream (Goff 1995). Batch pasteurization may be accomplished by heating either to 65.5 ºC for not less than 30 min followed by quick cooling to about 4 °C or to 71.1 ºC for 15-20 sec, which is the legal minimum for ice cream in a batch pasteurization system (Hyde 2001). The batch method is more suited to smaller manufacturers who will mix their ice cream and pasteurize it in the same vessel. One advantage of batch pasteurization is that it produces a better mouth feel of the ice cream, due to more of the whey proteins being denatured. HTST is more fit for larger manufacturers who use a plate heat exchanger, which heat-treats a continuous stream of product. The pasteurization temperature for ice cream is higher than that for milk because the sugar added to ice creams coats the bacterial cells and helps to protect them (Goff 1995; Marshall and Goff 2003).

Homogenization

The main purpose of homogenization is to make a stable and uniform suspension of the fat by breaking down or reducing the size of the fat globules found in milk or cream to less than 2 μm. The resulting mix has a smooth texture and can be whipped more easily during the freezing process, although not all ice cream manufacturers use a homogenizer in the production process line (Goff 1995; Marshall *et al* 2003).

Homogenization provides some functions in ice cream manufacture, including (1) size reduction of fat globules (2) increasing surface area (3) membrane formation to make a smoother ice cream (4) creating greater apparent richness and palatability (5) better whipping ability (6) decreasing the danger of churning the fat (7) enabling the use of butter, frozen cream, etc., and (8) increasing resistance to melting (Goff 1995; Marshall *et al* 2003). The mix should be homogenized in a two-step homogenizer with the pressure of the first stage between 2000-2500 pounds and between 500-1000 pounds for the second stage (Goff 1995). The higher the fat and total solids in the mix, the lower should be the pressure of the homogenizer. By doing a two-step homogenization, clumping or clustering of the fat is reduced, which produces a thinner more rapidly whipped mix, and melt-down is also improved (Goff 1995; Marshall *et al* 2003).

Aging

The aging process of ice cream mix is performed overnight in insulated and refrigerated storage tanks at a temperature maintained as low as possible without freezing (Hyde 2001). In the process, the fat cools down and crystallizes. However, the mix is not ready to freeze at that point in the process. Crystallization of the fat, adsorption of proteins and emulsifier to the fat globules, and hydration of the protein and stabilizers need to continue for a few hours, especially if gelatin is used as the stabilizers. Sodium carboxy-methylcellulose and guar gum, commonly used stabilizers, hydrate well during the processing of most mixes. However, hydration proceeds slowly for the amount of carrageenan that is usually added with these stabilizers to prevent whey separation on long-term storage.

Aging provides some essential functions including that it (1) improves whipping qualities of the mix (2) improves the body and texture of the ice cream (3) causes the reduction in stabilization of the fat globule (4) causes fat crystallization and (5) increases viscosity (Goff 1995; Marshall *et al* 2003).

Freezing and Hardening

Freezing the mix is one of the most important operations in making ice cream, for upon it depends the quality, palatability and yield of finished product.

Freezing consists of two parts: (1) the mix is frozen quickly while being agitated to incorporate air and to limit the size of ice crystals formed; and (2) the partially frozen product is hardened without agitation in a special low-temperature environment designed to remove heat rapidly.

The flavor and color is usually added to the aged ice cream mix before operating the freezing process because off-flavors do not occur once the ice cream mix has been aged. Freezing ice cream mix is a dynamic process that freezes a portion of the water and whips air into the frozen mix by the operation of a freezer pump, resulting in an ice cream that has a consistency close to that of soft-serve ice cream (Goff 1995). If a soft-serve ice cream is made, a horizontal batch freezer specifically designed to dispense the ice cream is used, because the ice cream has a higher solids content. The longer dwell time and lower overrun results in a product with a higher proportion of unfrozen water and consequently there is a greater risk of larger ice crystals to occur (Goff 1995). If the product is going to be sold in liter containers, small tubs or being destined for scooping, one of two types of freezer, batch freezer and continuous freezer may be used. Continuous freezers are more efficient with a shorter dwell time, higher level of air incorporation is possible and a lower proportion of unfrozen water in the product is achieved (Bo-Kang Lion 2006). Ice cream contains a considerable quantity of air, up to half of its volume. This air is referred to as overrun. This gives the product its characteristic lightness. Without air, ice cream would be similar to a frozen ice cube. The batch type of freezer produces ice creams with a low overrun and is better with recipes which contain about 30-32% total solids (Bo-Kang Lion 2006).

After the ice cream has been partially frozen, inclusions, such as nuts, candy or fruit, are added, and the freezing process is continued by subsequent hardening. The ice cream usually is packaged and is placed into a blast freezer at -30°C to -40°C where most of the remainder of the water is frozen. Some of the important factors affecting hardening rate are size and shape of package, air temperature, air circulation, positioning within the freezer room, drawing temperature from the freezer, composition of the mix and percentage of air incorporated. Quickly freezing the ice cream avoids the formation of large ice crystals. Below about -25°C, ice cream is stable for indefinite periods without danger of ice crystal growth; however, above this temperature, ice crystal growth is possible and the rate of crystal growth is dependent upon the temperature of storage. This limits the shelf life of the ice cream (Goff 1995; Marshall and others 2003).

3.1.4 Shelf life

The shelf life of ice cream is mainly dependent on the storage conditions. Ice cream can last as long as one year, or as little as two weeks. The finished product will have a shelf life of about 12-18 months if kept at around -20°C to -25°C. In order to maintain shelf life, some factors must be taken into consideration, including (1) proper formulation of the ice cream, such as the addition of stabilizer and sugar (2) freezing the ice cream quickly (3) hardening the ice cream rapidly and (4) avoiding temperature fluctuations during storage and distribution (Goff 1995; Marshall *et al* 2003; Lee *et al* 2005).

3.1.5 Ice cream defect

Ice cream defects can be classified into several categories including flavor defects, body and texture defects, melting quality characteristics, color defects and shrinkage defects (Goff 1995).

The ideal product should possess a typical, fresh, clean, pleasant, and delicate flavor; have close, smooth texture; melt slowly into the liquid with the appearance of the original mix; have a natural color, have any particulates, ripples or other inclusions evenly and liberally distributed; and have a low bacterial count.

Defects in flavor of frozen desserts are conveniently placed in the following categories: (1) dairy ingredients of poor quality-sour (acid), oxidized, stale, lipolyzed, unclean, and excessively cooked or scorched; (2) sweeteners-unnatural, excessive, or deficient; (3) flavoring- unnatural, excessive, or deficient; (4) blend- unpleasant balance of ingredients; (5) storage-stale or absorbed flavor.

The sweetener system is considered to be defect if the product is too sweet or lacks sweetness. However, the most commonly encountered defect in the flavor assessment of ice cream is the dairy ingredient defect.

Body and texture defect primarily includes coarse, icy texture (Goff 1996). Lower stabilizer or emulsifier, lower total solids or coarse air cells could cause a flaky, snowy quality or a crumbly body in ice cream (Lee *et al* 2005). However, the incorporation of large amounts of air as large air cells with low total solids or low stabilizer could produce a fluffy or spongy defect in ice cream (Lee *et al* 2005). A sandy texture is the easiest to detect and is caused by lactose crystals (Goff 1995).

Shrinkage is a very serious defect in ice cream. The defect shows up in hardened ice cream and manifests itself in reduced volumes of ice cream, usually pulling away from the top or sides of the container. Structurally, it is caused by a loss of air bubbles and formation of continuous air channels. Some factors including (1) freezing and hardening at low temperature (2) type of container (3) emulsifiers (4) methods of handling in the grocery store and (5) low and high storage temperatures are believed to be associated with the defect (Goff 1995).

3.2 Fat replacer

3.2.1 Introduction

The term "fat replacer", which can be divided into two categories: fat substitutes and fat minetics, is defined as a fats, proteins, or carbohydrates base compound that replaces one or more of the functions of fat in order to reduce calories in foods (Schmidt *et al* 1993; Drake *et al* 1996; Hatchwell 1996; Akoh 1998). Fat substitutes are macromolecules that physically and chemically resemble triglycerides (conventional fats and oils) and which can theoretically replace the fat in foods on a one-to-one, gram-for-gram basis (Akoh 1998; Jones 1996). Fat mimetics are substances that imitate organoleptic or physical properties of triglycerides but which cannot replace fat on a one-to-one, gram-for-gram basis. Fat mimetics, often called protein- or carbohydrate- based fat replacers, are common food constituents, e.g., starch and cellulose, but may be chemically or physically modified to mimic the function of fat. The caloric value of fat mimetics ranges from 0–4 kcal/g (Akoh 1998; Jones 1996).

According to their chemical functional properties, fat replacers are classified into ten general categories, including synthetic fat substitutes, emulsifiers or surface active agent, starch derivatives, maltodextrins, hemicellulose, β-glucans, soluble bulking agents, microparticulates, composites and functional blends (Gilksman 1991; Clark 1994; Jones 1996).

Fat provides flavor, mouth feel, texture, structure, process performance, shelf life and appearance so fat mimetics should also provide those characteristics in low fat or fat-free products (Clark 1994; Kuntz 1996; Akoh 1998). However, many studies found that the use of fat mimetics is difficult for mimicking the rheological effects of fats in some product categories (Jones 1996). In other words, none of the fat mimetics would fit all applications, and blends of ingredients may be required to fulfill all of the requirements of any one application (Kailasapathy and Songvanish 1998).

Fats and oils cannot simply be taken out of a food product and replaced with fat mimetics and water. Hence, reformulation of low fat foods is required to achieve all the taste and mouth feel characteristics which consumers want and expect (Anonymous 1992). Many products, such as baked goods, dressings, meat products, sauces, gravies and frozen desserts, have been successfully reformulated with fat mimetics (Yackel and Cox 1992). Low-fat ice cream, in which a certain amount of fat has been replaced with fat mimetics, should taste creamy and not develop ice crystals upon heat shock and possess proper hardness when taken from the freezer (LaBarge 1988; Yackel and Cox 1992; Giese 1996).

Matching a low-fat prototype to a full-fat product can be a difficult task in many instances because added fat mimetics change many sensory attributes, such as flavor release, sweetness, saltiness, aftertaste, mouth feel and melting properties, physical properties, such as viscosity, texture and appearance, and the microbiological stability, in these products (Yackel and Cox 1992). Screening and evaluating the appropriate fat mimetics in the development of low-fat food products have become a significant goal for food developers and ultimately to business (Yackel and Cox 1992). Fat mimetics, such as polydextrose and maltodextrin, as bodying agents in the fat-free ice creams significantly increase flavor release, fattiness, creaminess, and melting rate of the ice cream (Hyvönen *et al* 2003). Incorporation of fat mimetics may be more helpful in increasing the viscous properties than the elastic properties in a dairy-based system (Adapa *et al* 2000). For example, microparticulated protein may provide a dispersed phase, which uniformly distributes bound water throughout the product matrix. Gums or modified starches provide viscosity and control free water and emulsifiers keep the remaining fat compatible with the large amounts of water present (Clark 1994).

3.2.2 Category of fat mimetics

Carbohydrate-based fat mimetics

Carbohydrates have been used in some foods for several years to partially or totally replace fat. Digestible carbohydrates such as modified starches and dextrins provide 4 kcal/g, while nondigestible complex carbohydrates provide fewer calories.
Many carbohydrates serve as thickeners or gelling agents in foods. Gums, starches, pectin, cellulose, and other carbohydrate ingredients provide some of the functions of fat in foods by binding water. They usually function as bulking agents or water holding matrices, which give moistness to the food as well as provide texture, mouthfeel and opacity (Giese 1996). For example, many fat-free and reduced-fat cookies have used corn syrups, syrup solids, and high-fructose corn syrups as fat mimetics to control water activity (Akoh 1998). Polyols such as sorbitol and maltitol as well as fructooligosaccharides may also be used to control water activity (Akoh 1998).

Several carbohydrates are promoted and used for partial or total fat replacement, including (1) gums or hydrocolloids (2) polydextrose or Litesse® (Pfizer Chemical Division, NY) (Pfizer, Inc. 1991) (3) cornstarch maltodextrin or Maltrin® M040 (Grain Processing Corporation, IA) (4) tapioca dextrins (N-Oil®) or tapioca maltodextrin (N-Oil® II, National Starch and Chemical Corporation) (5) potato starch maltodextrin, passelli SA2 (Avebe America Inc. NJ) (6) modified potato starch, Staslim® (Duxbury 1991).

However, the use of carbohydrate-based fat mimetics in reduced-fat ice creams caused mixes to have higher viscosities, which can prevent air incorporation and results in limited whipping ability (Marshall and Arbuckle 1996; Adapa *et al* 2000). Studies showed that ice cream mixes with carbohydrate-based fat mimetics incorporated less air than control mixes and mixes with protein-based fat mimetics (Schmidt *et al* 1993). Functionally, carbohydrate-based fat mimetics cause stabilization and emulsification of food products (Alexander 1997).

Protein-based fat mimetics

Protein-based fat mimetics are derived from a variety of protein sources, including egg, milk, whey, soy, gelatin, and wheat gluten. They are digestible and metabolizable (Artz and Hansen 1994). These fat replacers provide1 kcal/g to 4 kcal/g.

Some of these protein-based fat mimetics are microparticulated (sheared under heat). Microparticulated protein products are tiny, spherical particles, which can provide a creamy mouth feel similar to fats. They often incorporate water and may be usable in amounts less than fat, for example, 1 g of protein-based fat mimetics can replace 3 g of fat in cream.

Protein-based fat mimetics are not suitable for use in fried foods but can be used in dairy products, such as fat-free ice creams, frozen desserts, and milkshakes, reduced-fat versions of butter, sour cream, low-fat cheese, yogurt, low-fat baked goods, salad dressing, margarine, mayonnaise, coffee creamers, soups, and sauces. One of these mimetics, *Simplesse®,* is manufactured from whey protein concentrate by a patented microparticulation process. Developed by the NutraSweet Kelco Co. (a unit of Monsanto Co., San Diego, CA), Simplesse® was affirmed as GRAS (21 CFR 184.1498) in 1990 for use in frozen dessert products and in 1994 for use in yogurt, cheese spreads, cream cheese, and sour cream. Simplesse® is suitable for use in additional products that do not require frying, such as baked goods, dips, frostings, salad dressing, mayonnaise, margarine, sauces, and soups. The caloric value of Simplesse®, on a dry basis, is 4 kcal/g. Formulation with hydrated gel forms, however, enables calorie reduction; for example, a 25% gel provides 1 kcal/g. Simplesse® provides fat-like creaminess in high-moisture applications, but like other proteins it tends to mask flavor. Simplesse® retains the biological value of the protein used and, hence, any antigenic/allergenic properties of the protein (Gershoff, 1995).

Protein blends, another group of protein-based fat mimetics that combine animal or vegetable protein, gums, food starch, and water, are used in frozen desserts and baked goods. A combination of protein, starches, and hydrocolloids has been suggested to have synergistic effects for lowering fat and retaining textural characteristics of the products.

Fat-based substitutes

Fat-based substitutes, which may include chemical alterations of fatty acids to provide fewer calories or no calories, have also been developed. Emulsifiers and fat-based substitutes provide up to 9 kcal/g, such as Salatrim(short- and long-chain acyltriglyceride molecules) (Benefat, Cultor Food Science, Inc, Ardsley, NY). Other fat-based fat substitutes, such as Olestra (Olean, Proctor and Gamble, Cincinnati, OH), have properties similar to naturally occurring fat but provide zero calories and pass through the body unabsorbed.

Olestra is a sucrose polyester consisting of a mixture of hexa, hepta, and octa esters of sucrose, esterified with long-chain fatty acids, derived from common edible oils. Olestra can be liquid or solid at room temperature based on the fat source in the sucrose polyester. It has organoleptic and thermal properties of fat but cannot be hydrolyzed by gastric or pancreatic lipase and is too large a molecule to be absorbed in the gastrointestinal tract and therefore cannot be metabolized for energy. In 1996, manufacturers using Olestra were required to add fat-soluble vitamins A, D, E, and K and to place a label statement informing consumers that olestra may cause abdominal cramping, loose stools, and inhibit absorption of fat-soluble vitamins. Subsequent scientific reviews have led the US Food and Drug Administration (FDA) to conclude that the warning is no longer warranted (Anonymous 2005b).

Other fat-based fat substitutes with triglycerides containing short-, medium-, and long-chain fatty acids randomly distributed on the glycerol backbone are only partially digested and absorbed and provide 5 kcal/g. Mono- and diglyceride fat-based substances have also been created. Emulsifiers are fat-based substances that are used with water to replace all or part of the shortening content in cake mixes, cookies, icings, vegetables, and dairy products. They provide the same calories as fat but less is required in the product, resulting in a reduction in total fat and energy. Some of these ingredients are heat stable and very versatile. Several studies have shown that their application in fried snack foods and yogurt may lead to decreased energy and macronutrient intakes in lean, overweight, and obese adult subjects up to 36 hours post consumption (Burns *et al* 2002, Burns *et al* 2001, Burns *et al* 2000).

3.3 Low-fat ice cream

Consumption of low-fat or non-fat dairy products has increased in recent years due to potential health benefits and nutritional advantages (Yackel and Cox 1992). The low-fat market extension has forced dairy food manufacturers to devise products in order to satisfy demands of consumers. However, the retention of organoleptic characteristics in low-fat products is difficult, and they faced a lot of challenges in maintaining quality of low-food products (Duxbury 1991; Farooq 1997).

3.3.1 Challenges

Texture is one of the most important factors in the choices of consumers. The primary difficulties to be overcome in low-fat or fat-free products are to maintain the quality of texture and flavor intensity. To meet this challenge, the dairy industry has endeavored to conduct a lot of research and development (Marshall 1991; Hatchwell 1994). Texture quality has been addressed with some achievements using fat mimetics but flavor is not so easily solved (Hatchwell 1994). Marshall (1991) demonstrated major challenges for manufacturing reduced-fat, low-fat and non-fat ice creams, which are related to providing creaminess and body, minimizing ice crystal formation, and finding good flavoring formulas.

3.3.2 Formulating reduced-fat ice cream

When formulating ice cream, the issues of fat, sugar and cholesterol reduction should be treated successfully to produce a high quality product. Fat can be replaced with the proper combinations of fat mimetics. Sugar alternatives can be used, while cholesterol can be removed from butter and egg yolk by several techniques, such as supercritical fluid extraction or chelation with β-cyclodextrin (Sandrou and Arvanitoyannis 2000).

There are too many functions that fat has in foods so it is not totally realistic to expect to find any one thing to replace it (Kuntz 1996). Texture and flavor are primary issues in developing low- or non-fat products.

Hatchwell (1996) discussed several important areas of consideration to match the objective of reformulating low-fat foods. First, the quality of raw material is really important because any defects in raw materials become more apparent in a reduced-fat product than in a full-fat product. In addition, the balance of sweetness and saltiness is critical because there is more water in reduced-fat systems.

3.3.3 Relationship between full-fat ice cream and low-fat ice cream

Lowering fat content in ice cream is achieved by using less of the original fat level or substituting fat with fat mimetics. In low-fat and fat-free ice creams, milk fat is replaced by fat mimetics, which cause changes in texture and affect perceptibility parameters (Marshall 1991; Brauss *et al* 1999).

Many studies indicated that ice cream containing higher amounts of milk fat was perceived to be low in iciness and hardness, high in thickness, smoothness, gumminess and mouth coating (Prindiville *et al* 2000; Ohmes *et al* 1998). Regular ice creams had higher intensity than low-fat and fat-free ice creams in milk flavor and aftertaste and sweet aftertaste, but were lower in stale flavor. In fact, studies indicated that milk fat itself has a sweet, buttery, creamy flavor due to fatty acids, fatty acid esters, lactones and carbonyl compounds (Hatchwell 1994). Milk fat also functions as a precursor that interacts with other food components during hydrolysis, oxidation, and processing to create new flavors, such as caramellic and cultured flavors (Prinvidille *et al* 2000). Milk fat also masks a lot of off-flavors due to their fat-solubility and being present at below threshold levels in ice cream (Hatchwell 1994). Kruel (2004) showed significant differences in sensory properties for strawberry ice creams with different fat levels, and significant effects of fat level on fat mimetics. The study found faster increases or decreases in flavor release, creaminess and thickness with lower fat levels of ice cream.

Low-fat ice creams containing a higher level of NMS generally had a significant influence on flavor perception, and it also offered a slightly salty taste in some cases (Guichard 2002). Low-fat ice cream usually tends to have a lower flavor impact because fat is not available to promote the flavor and both stabilizers and fat mimetics used could bind elements of the flavorings making them unavailable to the palate. In other words, ice cream technologists may need to increase sweeteners and flavor levels to overcome the problem in many low-fat systems (Kuntz 1996; Guichard 2002).

Only very few ice creams have successfully managed to combine low-fat and low-carbohydrate contents to achieve a low-calorie frozen dessert that is similar in taste, flavor and mouth feel characters to a high-fat equivalent (Hatchwell 1994).

3.3.4 Relationship between fat mimetics and low-fat ice cream

The amount of fat mimetics in ice creams cause changes in sensory properties. Therefore, in order to replace fat with fat mimetics in the food matrix, a good understanding of the functions of fat in that specific system prior to selecting the type of fat mimetics is necessary (Kruel 2004). The amount of fat being replaced and the degree of substitution also need to be considered in the choice of fat mimetics. Ice cream manufacturers have attempted to simulate texture and flavor of low-fat or reduced-fat ice creams by adding bulking agents, such as carbohydrate-based fat mimetics or concentrated milk components as protein-based fat mimetics to fat-free formulations (Roland *et al* 1999). The primary purpose of fat mimetics is to offer sufficient total solids and to achieve the desired texture, body and flavor in a low-fat or fat-free product. If a fat mimetic successfully replaces fat in a food product, the overall properties of the products should be similar (Schirle-Keller *et al* 1992).

An appropriate combination of two or more fat mimetics in frozen desserts may be better than a single fat mimetic (Glickman 1991). For example, the mixtures of soluble bulking agents, microparticulated protein and starch derivatives can produce desired reduced-fat or low-fat products due to their specific characteristics (Glickman 1991). Some studies also suggested that a combination of protein, starches and hydrocolloids creates synergistic effects for lowering fat and retaining textural characteristics of the products (Ordonez *et al* 2001; Ruthing *et al* 2001).

Ohmes *et al* (1998) showed that ice creams made with Simplesse® were not significantly different in flavor and texture from a nonfat control. Schmidt and others (1993) concluded that ice cream made with Simplesse® D-100 was more similar to full-fat ice cream in terms of rheological properties than was ice cream made with maltodextrin-based fat mimetics. Chung *et al* (2004) also came to similar conclusions for cherry–flavored ice cream with Simplesse®, but found there were distinctive condensed milk flavor and stickiness that distinguished them from the full-fat reference.

Kailasapathy and Songvanish (1998) used several fat mimetics, such as Slendid® and Simplesse®, in ice creams and evaluated their effects. Their studies found that Simplesse® ice cream showed the least iciness compared with the full-fat ice cream. The Slendid®, a carbohydrate-based fat mimetic, when added to ice cream, had the highest mix viscosity and foaming properties and melting characteristics, which were similar to the 13% fat ice cream.

Zhang and Wang (1999) indicated that the physical properties of ice creams were not significantly different if they were manufactured by using a proportion of 12%:2% of fructooligosaccharide to sorbitol to replace 14% sugar, 6% Litesse® to replace 6% cream and an addition of 0.2% sodium citrate and 0.6% sodium caseinate. In sum, fat mimetics, such as Tara gum, Litesse®, Slendid® and Simplesse® have been used in the development of low-fat ice cream. The type of fat mimetic is more important than the milk fat content in influencing the sensory properties of ice cream (Chung *et al* 2004).

3.4 Inulin

3.4.1 Introduction

Inulin belongs to a class of carbohydrates known as fructans. The main sources of inulin that is used in the food industry are chicory and Jerusalem artichoke. The inulin consists of a mixture of fructose polymers, with a chain length from 2 to 60/ 70 units usually with a terminal unit of glucose (Tungland 2000). The degree of polymerization (DP) depends of the vegetable source, the harvest date and storage length (Januário *et al* 1999).

Inulin is a powder, varying in color from white to grey depending on the purification degree. This powder does not have smell and practically no flavor. However, if the sample is impure it can present a slightly bitter taste (Tungland 2000).The solubility of inulin depends on solvent temperature, especially when inulin presents a high DP, being practically insoluble in cold water.

The use of inulin and of its hydrolysis products is dependent on the important nutritional and functional properties, allowing different technological applications.

In the food industry, inulin is considered a food ingredient, which could be potentially useful in developing functional foods. Those, besides supplying the basic nutritional needs, can improve some physiological functions, eventually reduce the risk of diseases occurrence. When incorporated in the diet, the inulin acts as “prebiotic”, promoting selective development of beneficial microorganisms - “probiotic” (Tungland 2000). Besides this action, it also exerts other functions on health, namely acting as dietary fiber. This fact derives from the incapacity of the stomach and small intestine endogenous enzymes to hydrolyse inulin and its derivatives. Degradation only occurs by bacterial fermentation at the colon level, indirectly contributing to its low caloric value (Tungland 2000; Silva 1996). Inulin consumption also contribute to the improvement of the mineral balance of the Ca, Mg and Fe, and possibly presents an anti-cancerigenous effect by stimulating Bifidus flora and so the immunity system (Silva 1996; Januário *et al* 1999; Niness 1999).

Inulin presents technological/functional interest. It can be considered an alternative ingredient allowing to substitute or to restore fats with success, producing a similar and pleasant sensation in the mouth. It can also be used as source of natural and alternative sweeteners (fructose and FOS) with low caloric value. As inulin possesses high fructose content, it constitutes an important raw material for the production of fructose rich syrups (Silva 1996; Januário *et al* 1999). Besides the already referred properties, the inulin exhibits other interesting functional properties like: gelation, foams and emulsions stabilizing action. Its use as a natural texture modifier is very interesting, as texture is an important attribute of food products consumer's acceptance. These characteristics are related with inulin behaviour in aqueous solution at different concentrations (Silva 1996).

Purified, analytical-grade inulin occurs as spherical crystals with radial striation. Its average molecular weight is between 5,600 and 6,300 fluctuations depending on the degree of polymerization of the molecules used in the measurement. However, refined native inulin powder from chicory is white, amorphous, and slightly hygroscopic; has a specific gravity of about 1.35 and an average molecular weight of about 1,600. It is neutral in odor and taste. Commercial inulin contributes a marginally sweet taste due to a small amount of naturally occurring mono-and disaccharides.

Inulin is soluble in water with the solubility dependent on the temperature of the water, degree of polymerization, distribution of the molecular chains, degree of molecular branching and how the molecule is processed. Typically, native chicory inulin is soluble to about 60 g/L. at 10ºC, while at 90ºC it is soluble to about 330 g/L. Under normal conditions native chicory inulin is dispersible in water but may have a tendency to clump during hydration due to its hygroscopic character. Dispersability may be improved either through mixing with sugar and/or starch or by instituting the final product. Native chicory inulin has a water binding capacity of about 1:1.5.

3.4.2 Food application of inulin

Inulin possesses unique physical characteristics making it widely useful for adding texture in food applications. For example, when inulin replaced corn syrups in reduced fat ice cream formulations a chewier texture was created. Moreover, ice crystal formation was reduced when 50% of the corn syrup was replaced with inulin during thermally abusive storage conditions (Schaller-Povolny and Smith 1999). In consumer tests, plain unsweetened yogurt containing inulin was preferred over samples without inulin. Yogurt with inulin was identified as being creamier in appearance, having a less chalky and creamier texture, and was sweeter with a less sour/fermented taste and aftertaste (Spiegel *et al* 1994). Yogurt made with 10% inulin with a DP of 12-16 was found to increase firmness compared to yogurt made with shorter chained inulin (DP 5-8) and controls with no inulin (Terry *et al* 1999). The unique functional properties inulin has to manage water effectively, affect rheology and improve texture in foods and act synergistically with high water binding hydrocolloids have allowed inulin to be used across all food product application areas, particularly in low and no fat and low and no sugar systems.

Native chicory inulin has a unique ability to add rheological and textural properties to food due to its ability to form discrete highly stable particle gels. Inulin gel characteristics are dependent on a number of factors including inulin solids concentration, which becomes more viscous and fat-like as inulin solids are increased. In addition to concentration, inulin chain length distribution also affects gel characteristics. Higher degrees of polymerization (long chain frictions) lower the inulin level required to form a gel. Increasing amounts of monomer and dozer content decrease viscosity, inulin gels are very creamy and fat-like, and as such can be used in fat reduction and fat-replacer systems.

3.4.3 Safety and tolerance

Estimates of current daily inulin consumption from various natural foods range from 1 to 4 g for Americans and up to 12 g for Europeans (Marchetti 1993). Historically, the dietary intake of inulin has been significantly higher than current day consumption estimates. Estimates of inulin intake from consumption of these foods include approximately 25 to 32 g of inulin per day by European populations substituting Jerusalem artichokes for potatoes and approximately 160 to 260 g of inulin per day from consumption by the Australian aborigines. Human tolerance to inulin, as a class of compounds, is primarily dictated by chain length and dosage (Tungland 2000). Abdominal symptoms, primarily gas and some abdominal discomfort, increased with increasing dose and decreasing chain length.

Osmotic diarrhea associated with ingestion of unavailable or unabsorbable oligosacchahides notably increases as the molecular weight of the molecule decreases and as such is the most significant factor in determining tolerance in humans (Nilsson and Bjorck 1988; Tokunaga *et al* 1986). Therefore, human tolerance to long chain inulin (DP > 5; average DP 23) is greater than native chicory inulin (DP of 2 to greater than 60, modal DP 9 units) is greater than the tolerance of FOS (DP 3 to 7, average 4.8), which, in turn, is greater than the tolerance of shorter-chain FOS (DP 3 to 5, average 3.7). In both historic times and contemporary times, dietary exposure to the entire range of chain lengths comprising inulin has been orders of magnitude greater than exposure to any specific subset of hydrolyzed or shorter length inulin-type compounds (fructooligosaccharides). Consequently, human and animal gut microflora utilizing these non-digestible carbohydrates have evolved active inulinase enzymes.

Similar to other dietary fibers, human tolerance to inulin has been demonstrated to be greater when inulin is part of the regular diet, spread out over the course of the day, as opposed to a bolus dose. Absolonne *et al* (1995) observed an increase in tolerance to FOS (DP 3 to 7) when the initial, single dose was split into two doses administered in the morning and afternoon, respectively. Under those conditions, the maximum daily dose that did not cause reactions was 27 to 31 g for men and 33 to 37 g for women. They determined the lowest laxative dose (not causing liquid stools) to be 41 g for men and 40 g for women (Tungland B C. 2000).

Shorter chain FOS (DP 3 to 5), which can caused adverse effects such as diarrhea when initially consumed in large amounts, were more readily tolerated with continued consumption (Oku 1986). The maximum dose to not cause diarrhea was approximately 21 to 24 g per day (Takahashi *et al* 1986). However, lower doses of 10 to 15 g FOS (DP< 10; median DP 3) has resulted in intestinal rumbling and flatulence (Rumessen and Gudmand-Hoyer 1998; Stone-Dorshow and Levitt, 1987). Lower doses of shorter chain FOS (DP 3 to 5) in the 3 day, are typically well-tolerated in healthy populations. A study by Tominaga *et al* (1999) involving 34 healthy female subjects 18-21 years of age ingesting 3 g/d FOS showed higher stool frequency for individuals having normal stool frequencies of $\leq$ 5 times/week than control groups. No significant difference was reported for individuals having stool frequency greater than 5 times/week when compared to the FOS treatment group. Moreover, stool condition (hardness and color) and mean transit time were unaffected by the FOS consumption.

Wilpart (1993) reported a rat study involving various indigestible dietary fibers, including inulin. They found that diarrhea incidence was higher with many polyols such as maltitol, mannitol, sorbitol or xylitol compared to most fructooligosaccharides. Adaptation to inulin took place within one week, resulting in no untoward effects. In a human clinical study, Kleessen *et al* (1997) showed that intakes up to 40 g /d of inulin produced no untoward effects, especially when divided over the course of a single day. For those who reported milk to be their cause of gastrointestinal symptoms (pseudohypolactasia), a 25 g dose of FOS was found to cause significantly more symptoms than in a control group. This 25 g level of intake may not initially be well tolerated by individuals who already experience gastrointestinal problems (Tungland 2000). Review of the clinical study data, indicates regular consumption of 40 to 70 g of native chicory inulin (DP 2 to 60; average. DP 9) per day by healthy adults appears to result in no significant adverse effects, especially when the consumption is in divided doses over the course of the day. This estimated consumption range is further reinforced by observations in recent review articles, reporting that consumption amounts up to 40 g of inulin daily in various food preparations do not lead to any undesired side effects (Feldheim 1993, as cited in Kleessen, 1997).

CHAPTER IV
MATERIALS AND METHODS

4.1 Materials

4.1.1 Inulin

Commercial inulin, Frutafit® HD (Figure 4-1), was used in this study. It was purchased from Helm Mahaboon Co., Ltd., Thailand (supplied from sensus, Roosendaal, the Netherlands). The product specification sheet and nutritional information of inulin, Frutafit® HD are shown in Appendix A.

Figure 4-1 Commercial inulin, Frutafit® HD

4.1.2 Ice cream ingredients

The raw materials used for ice cream making were all food-grade and purchased from local supermarkets and bakery stores in Bangkok, Thailand. The list of ice cream ingredients and the suppliers are shown in the Appendix B.

4.2 Preliminary ice cream making trial

This trial aimed at selecting the conventional full-fat formula for ice cream product. The full-fat formula in this study was selected from various conventional recipes of cookbook. The recipes required appropriate adjustments prior to the selection. The recipe which gave the product with best characteristics i.e. texture, flavor and taste was chosen as the final full-fat formula. Such formula was used as a reference in the formulation of modified fat ice cream products with inulin as fat replacer.

4.3 Formulation of modified fat ice cream with inulin as a fat replacer

In this study, five different ice creams bases as list below were prepared.

- Full-fat ice cream, containing 12% fat (used as a reference product).
- Modified fat ice creams:

  Non-fat, containing 0.5% fat

  Low-fat, containing 3% fat

  Light, containing 6% fat

  Reduced-fat, containing 9% fat

Each modified fat ice creams was added with a commercial inulin (Frutafit® HD) at 5, 7 and 9% (w/w) to replace milk fat. The level of inulin addition was chosen based on a previous study by El-Nagar *et al* (2002). Water was added to make the total weight of the recipes. The composition of modified fat ice cream based on weight percentage is shown in Table 4-1 and the recipe of each type of ice cream is shown in Appendix C.

Table 4-1 Composition (percent by weight) of ingredients in an ice cream mix

Mix	Fat	Nonfat milk solid	Sugar	GMS	CMC	Inulin
Full-fat	12	12	11	0.15	0.2	0
Non+5	0.5	12	11	0.15	0.2	5
Non+7	0.5	12	11	0.15	0.2	7
Non+9	0.5	12	11	0.15	0.2	9
Low+5	3	12	11	0.15	0.2	5
Low+7	3	12	11	0.15	0.2	7
Low+9	3	12	11	0.15	0.2	9
Light+5	6	12	11	0.15	0.2	5
Light+7	6	12	11	0.15	0.2	7
Light+9	6	12	11	0.15	0.2	9
Reduced+5	9	12	11	0.15	0.2	5
Reduced+7	9	12	11	0.15	0.2	7
Reduced+9	9	12	11	0.15	0.2	9

GMS- emulsifier (glycerol monostearate)
CMC- stabilizer (carboxy-methylcellulose)

4.4 Ice cream preparation

All ice creams were prepared in the pilot plant of the Food Science and Technology Division, Institute of Nutrition, at the Mahidol University. A 5 kg batch was prepared for each of the ice cream formulations.

All dry ingredients, which were weighed in advance, were mixed thoroughly with the weighed liquid ingredients in a mixing vat. Then agitation and heating were started. The mixes were pasteurized at 80 ºC for 25 s. followed by homogenization with a homogenizer (Ultra-Turrax T25, IKA-Labortechnik, Germany) at a speed of 13,500 rpm/min for 5 min. The ice cream mixes were then cooled at the ambient temperature for approximately 15 min and then aged overnight at 4 ºC.

A Taylor® ice cream freezer (model 103-34, Taylor Company, Rockton, IL, USA) was used to freeze the mixes to soft ice creams. Aliquots of the frozen ice creams were packed in containers. Samples designated for melting rate testing were filled directly into plastic cups and carefully leveled to avoid compaction. After that the soft ice creams were stored at -18ºC for hardening. All ice cream samples were made in triplicates.

4.5 Sensory evaluation

Sensory evaluation was conducted on the ice cream samples after storage in a freezer (-18 ºC) for one week. Sensory characteristics were evaluated by 50 untrained panelists who were graduate students and staff at the Institute of Nutrition, Mahidol University.

The sensory evaluation was carried out using a 9-point hedonic test for appearance, flavor, texture, and overall acceptability, with 1 represented the lowest intensity and 9 represented the highest intensity (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely). The samples with an overall acceptability score of 5 or above was accepted. Attributes of taste, color and appearance, body and texture, and flavor were evaluated using 5-point“just-about-right”scales, with 5 corresponded to “much too strong”, 1 to “much too weak”, and 3 to “just-about-right”. In addition, a comment column was provided on each ballot. The questionnaire appears as Appendix D.

During sensory test, each sample was placed in a white plastic cup (containing 20 g of sample per cup). It was coded with 3-digit random numbers selected from a random number table and presented to the panelists on a tray in air conditioned individual testing booths (at the Sensory Science Laboratory, Food Science and Technology Division, Institute of Nutrition) under daylight fluorescent bulb, free from cooking odor and noise. Moreover, the full-fat and inulin added modified fat formulas were served to each panelist each time in a completely random order. Panelists were instructed to clean their palate with soda water before tasting each sample. The experiment was designed as a completely randomized block (CRB). Samples with the highest overall acceptability score for each type of ice cream would be selected for further storage testing and nutritional determination.

4.6 Determination of physical quality

4.6.1 Viscosity

The viscosity of ice cream mix tempered to 4°C was measured at 100 rpm for 30 s using a digital viscometer (model DV-II; Brookfield Engineering Laboratories, Stoughton, MA) attached with spindle no. 1. The value was detected as % torque.

4.6.2 Color

The color value was measured in triplicates using a colorimeter model JS555 (JUKI spectro colorimeter, Color Techno System Corparation, Tokyo, Japan). The unit was standardized with a white tile (CHI-506001, L* = 98.34, a *= 0.02, b* = -0.66). The value was detected by reflective detection and expressed as L* (lightness), a* (redness), and b* (yellowness) values. Tungstan halogen lamp was used as a light source.

4.6.3 Texture (hardness)

Hardness measurement was obtained at room temperature (25 ± 2°C) using a texture analyzer (TA.XT-plus Texture Analyzer; Stable Micro Systems, UK) equipped with a P/36R cylindrical probe (Stable Micro Systems, UK). Twenty cups of each sample with 3 cm height were individually compressed using the penetration speed of the probe at 2 mm/s to a distance of 20 mm to determine hardness (g/cm^2): the maximum force required to compress the sample. Each cup of sample was left at room temperature (25 ± 2°C) for 3 min before testing.

4.6.4 Melting rate

Melting rate determination was carried out as follows. Samples were tempered at –18 °C overnight before melting rate testing. The plastic cup was carefully cut away to expose the sample that was then placed on a sieve (No. 25) over an empty cup. The amount of ice cream drained into the cup was weighed at 25 ± 1 °C every 5 minutes. A plot was created of mass of drip loss vs time. Melting rate was calculated by determining the equation for the linear melting data. The slope of the line represents the rate of melting as mass loss per min (Prindiville *et al* 2000).

4.6.5 Development of air cell size

Analysis of air cell was done following the methods developed by Thaiudom (2007), which was modified from Chang and Hartel (2001). The ice cream sample was cut into a 2×2 mm square and placed on a pre-chilled microscopie slide, then dispersed with a few drops of cooled glycerol, covered with a cover slip. Images were taken by a digital camera attached to the microscope to accumulate at least 300 cells of air cell. The size of each air cell was defined as the diameter of a circle (μm).

4.6.6 Overrun

The overrun of the final ice cream product was determined using the formula:

$$\%\text{Overrun} = \frac{(\text{Weight of unit mix-weight of equal volume of ice cream})}{\text{Weight of equal volume of ice-cream}} \times 100$$

(Roland *et al* 1999)

4.6.7 Extent of fat destabilization (turbidity)

The degree of fat destabilization was evaluated by spectroturbidimetry (Thaiudom 2007). A hardened ice cream was thawed at room temperature until melted and an aliquot of 40 mL was taken for analysis. The sample was diluted at 1: 500 with filtered water and the absorbance was measured by a spectrophotometer at 540 nm against deionized water as a blank. Lower absorbance, as the solution becomes less turbid, relates to higher levels of fat destabilization due to fluculation or coalescence of the fat.

$$\%\text{ Fat destabilization} = \frac{\text{turbidity of the ice cream}}{\text{turbidity of the mix}} \times 100$$

4.7 Determination of nutritional value

The selected ice cream for each type of modified fat formulas with the highest acceptability from sensory evaluation was analyzed for moisture, protein, fat, ash, carbohydrate, and energy. The determination was done by the Food Chemistry Laboratory, the Institute of nutrition, Mahidol University.

The analytical procedures were performed in duplicates according to methods of the Association of Official Chemists (AOAC 2000). The procedures are shown in Appendix E.

4.8 Storage test

A complete randomized design was used (with split-plot experiment) for storage test of modified fat ice creams. The selected ice cream for each type of modified fat formula with the highest acceptability from sensory evaluation was stored in a plastic container in a freezer (-18ºC) for 7 weeks during which instrumental texture profile analysis, determination of air cell size and sensory analysis was performed every 2 weeks.

4.9 Data analysis

Analysis of variance (ANOVA) was used to establish the significance of the individual differences in the physical properties and sensory evaluation data among ice cream samples at $p = 0.05$.

Significantly different means were compared using Duncan's Multiple Range test at $p=0.05$. All the statistical analyses were conducted using the SPSS (Version 13.0) commercial statistical package.

The overall experimental schematic is shown in Figure 4-2

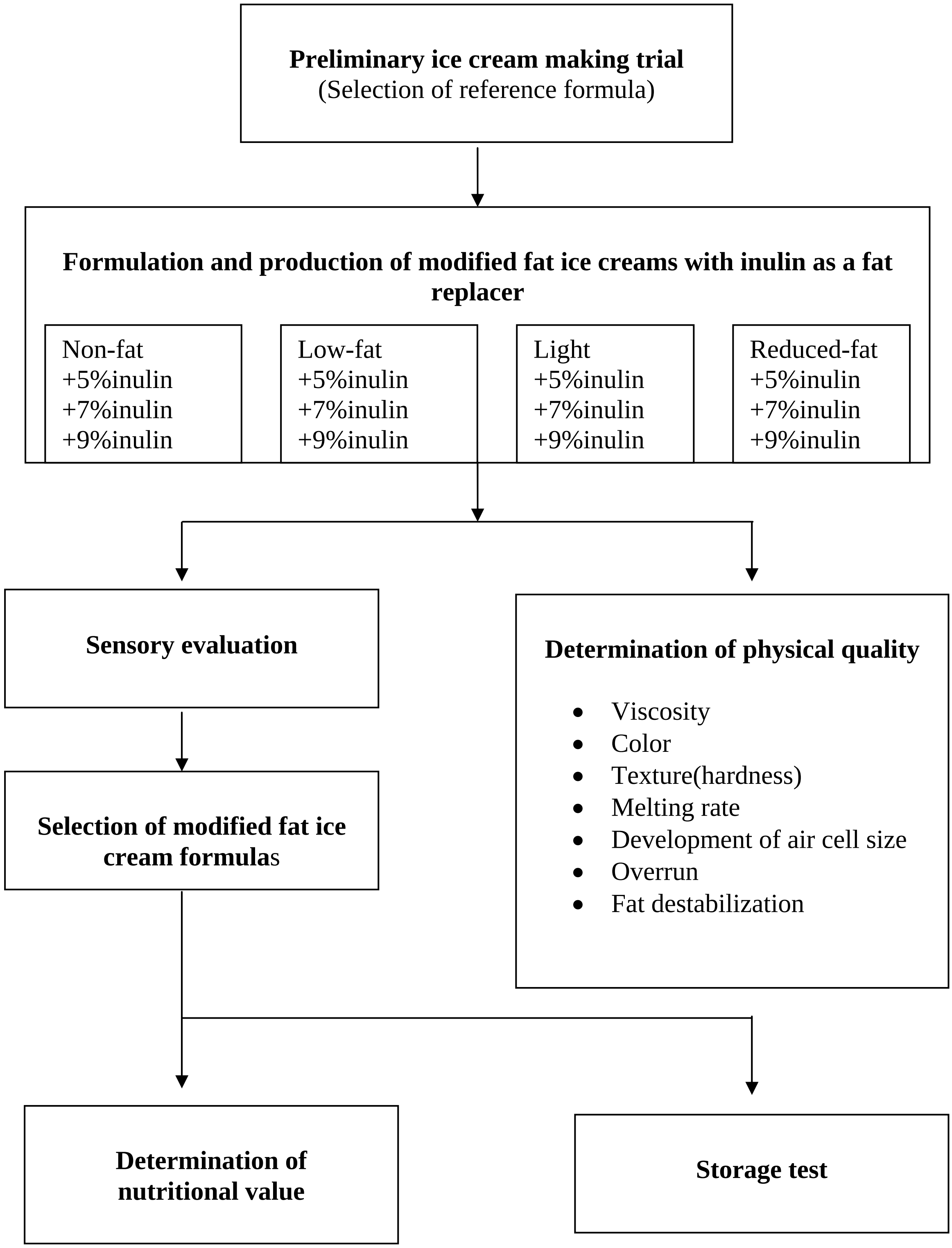


Figure 4-2 Experimental schematic

CHAPTER V
RESULTS

5.1 Preliminary ice cream making trial

Various conventional recipes for full-fat ice cream products were tested for selecting a reference formula. The recipes required appropriate adjustments to obtain the ice cream product with the desired characteristics. After several trials, the final recipe that was used as the reference (full-fat) formula in this study is shown in Table 4-1.

5.2 Formulation of modified ice cream with inulin as a fat replacer

Four types of modified fat ice cream were formulated, namely non-fat, light, low-fat, and reduced-fat ice cream. Inulin was added into each type of the modified fat ice cream mix, totaling 12 formulas, at levels of 5, 7 and 9% (w/w). Ice cream pro ducts were prepared from all formulas and screened for physical appearance and sensory characteristics by the researcher. All modified fat ice cream appeared to be satisfactory. Therefore, all formulas were tested for sensory evaluation and determination of physical quality in the next step of this study.

5.3 Sensory evaluation

All type of ice cream were tested for sensory acceptability by 50 untrained panelists aged between 21-50 years old, according to the procedures described in section 4.5.

Table 5-1 shows the sensory acceptability results of modified fat ice cream products using inulin as a fat replacer with different percentages of inulin and the full-fat formula in the terms of appearance, flavor, texture, and overall acceptability. There were no significant differences ($p \geq 0.05$) in appearance, flavor, texture, and overall acceptability among full-fat formula and the majority of inulin added modified fat formulas. Significantly differences (p<0.05) were found only in non-fat ice cream in all sensory characteristics. The sensory scores of non-fat ice cream were lower than those of other types of modified fat ice cream and full-fat ice cream, especially in nonfat ice cream with 5% inulin addition which showed the lowest scores in appearance, texture and overall acceptability.

Table 5-1 Sensory scores of modified fat ice creams using inulin as a fat replacer at 5, 7 and 9 % (w/w) compared with a full-fat formula [1,2]

Formula	Appearance[3]	Flavor[3]	Texture[3]	Overall acceptability[3]
Full-fat	7.68±0.99 d	7.40±1.03 e	7.43±1.16 d	7.63±0.90 b
Non+5	5.27±1.61 a	6.13±1.54 c	4.73±1.76 a	5.40±1.51 a
Non+7	5.78±1.67 b	5.58±1.30 b	5.40±1.62 b	5.69±1.53 a
Non+9	6.44±1.57 c	5.07±1.30 a	6.02±1.32 c	5.44±1.32 a
Low+5	7.40±0.72 d	7.20±0.78 de	7.04±0.90 d	7.31±0.73 b
Low+7	7.44±0.72 d	7.27±0.86 de	7.40±0.91 d	7.36±0.88 b
Low+9	7.58±0.62 d	7.22±0.97 de	7.44±0.65 d	7.35±0.81 b
Light+5	7.58±0.69 d	7.47±0.69 e	7.29±0.92 d	7.47±0.75 b
Light+7	7.64±0.83 d	7.49±0.79 e	7.38±1.17 d	7.56±0.78 b
Light+9	7.53±0.84 d	7.44±0.86 e	7.51±0.92 d	7.38±0.98 b
Reduced+5	7.51±1.06 d	7.27±0.98 de	7.42±1.01 d	7.47±0.94 b
Reduced+7	7.82±0.86 d	7.29±0.89 de	7.49±0.92 d	7.47±0.94 b
Reduced+9	7.56±0.78 d	6.84±1.02 d	7.44±1.05 d	7.22±0.90 b

1 Results are mean ± standard deviation (SD)
2 Means in the same column followed by a different letter (a-e) were significantly different (p<0.05)
3 Nine-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely)

The results of sensory evaluation of modified fat ice cream with inulin as a fat replacer at various levels compared with full-fat formula in the terms of color, odor, sweetness, creaminess, smoothness, and hardness are shown in Table 5-2.

Table 5-2 Sensory characteristics of modified fat ice creams using inulin as a fat replacer at 5, 7 and 9 % (w/w) compared with a full-fat formula [1,2]

Formula	Color[3]	Odor[3]	Sweetness[3]	Creaminess[3]	Smoothness[3]	Hardness[3]
Full-fat	2.99±0.18 ab	2.99±0.59 abc	3.28±0.59 de	3.11±0.54 cd	2.89±0.44 cdef	2.94±0.54 abc
Non+5	2.93±0.58 ab	2.80±0.72 ab	3.33±0.74 de	2.18±0.80 a	1.80±0.55 a	2.89±0.83 ab
Non+7	3.33±0.64 c	3.13±0.87 c	3.38±0.65 de	2.62±1.03 b	2.40±0.62 b	3.13±0.72 bcde
Non+9	2.87±0.34 a	3.53±0.89 d	3.20±0.73 bcde	3.11±0.80 cd	2.87±0.55 cde	3.31±0.73 e
Low+5	3.00±0.30 ab	2.78±0.47 a	3.11±0.53 abcd	2.87±0.54 bc	2.69±0.63 c	2.89±0.38 ab
Low+7	3.09±0.56 b	3.09±0.56 bc	3.36±0.48 de	3.04±0.60 cd	2.87±0.46 cde	2.87±0.34 ab
Low+9	2.96±0.21 ab	3.18±0.53 c	3.36±0.57 de	2.93±0.62 c	2.98±0.39 defg	3.02±0.45 abcd
Light+5	3.00±0.37 ab	2.96±0.60 abc	3.33±0.56 de	3.02±0.49 cd	3.02±0.49 efg	2.84±0.47 a
Light+7	3.02±0.26 ab	3.02±0.54 abc	3.24±0.53 cde	2.98±0.58 cd	2.76±0.48 cd	3.02±0.49 abcd
Light+9	2.96±0.21 ab	3.04±0.52 abc	3.40±0.62 e	3.24±0.64 d	3.16±0.56 g	3.02±0.58 abcd
Reduced+5	3.02±0.45 ab	3.04±0.63 abc	2.89±0.44 a	3.04±0.63 cd	2.98±0.54 defg	3.02±0.50 cde
Reduced+7	3.02±0.26 ab	3.00±0.60 abc	3.00±0.52 abc	3.02±0.54 cd	3.02±0.58 efg	3.22±0.67 de
Reduced+9	2.96±0.37 ab	3.11±0.64 c	2.98±0.58 ab	3.00±0.60 cd	3.11±0.57 fg	3.29±0.61 de

1 Results are mean ± standard deviation (SD)
2 Means in the same column followed by a different letter (a-e) were significantly different ($p<0.05$)
3 Five-point just-about-right scale (5 corresponded to “much too strong”, 1 to “much too weak”, and 3 to “just-about-right”)

From Table 5-2, the sensory acceptability results of modified fat ice cream products using inulin as a fat replacer with different percentages of inulin and full-fat formula were not significantly difference ($p \geq 0.05$) in terms of color, odor, sweetness, creaminess, smoothness and hardness. Significantly differences ($p < 0.05$) were found only in non-fat ice cream when compare to other formulas.

Overall, results of sensory evaluation indicated that most of the modified fat ice cream namely low-fat, light and reduced-fat formulas were well accepted by the consumer with the overall acceptability score being between like moderately and like very much. On the other hand, non-fat ice cream was barely accepted with the overall acceptability score being between neither like nor dislike and like slightly.

5.4 Determination of physical quality

The physical properties of all types of ice cream were determined according to the procedures described in section 4.6

Table 5-3 shows the physical properties of modified fat ice cream products using inulin as a fat replacer with different percentages of inulin compare to the full-fat in the terms of viscosity, overrun, and color.

From Table 5-3 the viscosity of all modified fat ice cream mixes with added inulin showed a significant increase corresponding to the proportion of inulin concentration. For overrun value, the highest overrun values were found in modified fat ice creams containing 5% inulin, except in the non-fat formula. The values were not significantly different ($p \geq 0.05$) from that of full-fat sample. For light, low, and reduced fat ice cream, increasing inulin concentration beyond 5% seemed to reduce the overrun value.

For color (Figure 5-1), L* value (lightness) was significantly different ($p < 0.05$) among all types of ice cream. Nevertheless, within each type of ice cream sample there were no significant differences ($p \geq 0.05$) between different levels of inulin addition except in non-fat formula. Addition of inulin significantly affected the a* value of redness ($p < 0.05$) in all types of ice cream corresponding to the level of inulin addition resulting in improving of the value to close to the value for full-fat formula. For b* value (yellowness), there were no insignificant differences ($p \geq 0.05$) among all types of ice cream and also within the ice cream type containing different levels of inulin. Furthermore, the increasing inulin level seemed to reduce b* value.

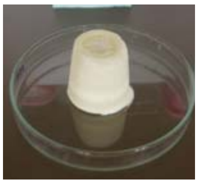
Table 5-3 Effect of inulin on viscosity, overrun, and color of modified fat ice cream compared to full-fat formula [1,2]

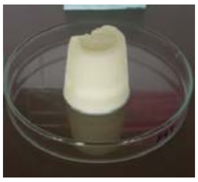
Formula	Viscosity (%t)	Overrun (%)	Color		
			L* (lightness)	a* (redness)	b* (yellowness)
Full-fat	74.53±2.97 d	20.62±1.23def	88.90±0.22ef	-1.69±0.03gh	12.92±0.56def
Non+5	43.26±0.23 a	8.56±0.18a	84.01±0.52a	-3.40±0.18a	12.39±0.53cde
Non+7	59.20±0.36 c	16.23±0.90 c	87.37±0.47cd	-2.70±0.07 b	12.48±0.36cde
Non+9	61.23±0.25 c	21.27±0.88 ef	90.35±0.21h	-1.86±0.07 f	10.70±0.38a
Low+5	54.26±0.28 b	23.74±0.49 g	86.94±0.35 c	-2.16±0.11de	12.71±0.47def
Low+7	73.03±2.19 d	14.02±2.19 b	87.73±0.21 d	-1.83±0.04fg	11.82±0.34bc
Low+9	80.16±0.46 e	12.67±0.43 b	87.39±0.51cd	-2.11±0.05de	12.22±0.18cd
Light+5	59.53±2.00 c	21.70±1.65 fg	85.10±0.29b	-2.25±0.05 c	12.29±0.29cde
Light+7	77.50±0.60de	19.18±1.51 de	84.69±0.51 b	-2.16±0.13de	12.34±0.51cde
Light+9	89.26±6.09f	19.36±3.36 de	85.33±0.15 b	-1.81±0.06fg	11.45±0.38b
Reduced+5	76.83±0.35de	25.89±0.41 h	88.35±0.30 e	-2.09±0.08 e	12.79±0.46def
Reduced+7	85.73±4.91 f	18.68±0.40 d	89.60±0.45 g	-1.63±0.02 h	13.43±0.23f
Reduced+9	96.43±3.15 g	18.90±0.54 de	89.29±0.02fg	-1.46±0.04 i	13.03±0.20ef

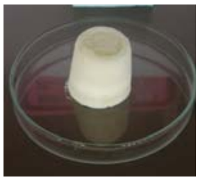
1 Results are mean ± standard deviation (SD)

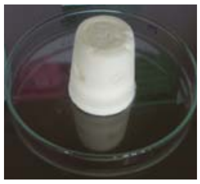
2 Means in the same column followed by a different letter (a-i) were significantly different (p<0.05)

Figure 5-1 Modified fat ice cream products using inulin as a fat replacer at 5, 7 and 9 % (w/w) compared with a full-fat formula


Full-fat


Non-fat+5%inulin

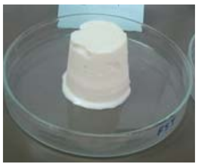

Non-fat+7%inulin


Non-fat+9%inulin

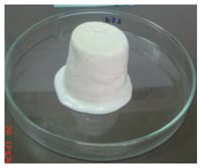

Low-fat+5%inulin

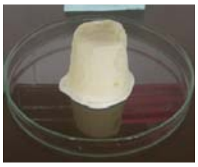

Low-fat+7%inulin

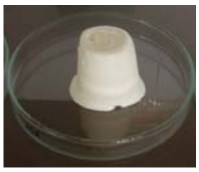

Low-fat+9%inulin


Light+5%inulin


Light+7%inulin


Light+9%inulin


Reduced-fat+5%inulin


Reduced-fat+7%inulin

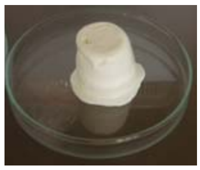

Reduced-fat+9%inulin

Table 5-4 shows the physical properties results of modified fat ice cream products using inulin as a fat replacer with different percentage of inulin and control formula in the properties of meltdown rate, destabilization of fat, air cell size, and texture (hardness).

Table 5-4 Effect of inulin on melting rate, destabilization of fat, air cell size and hardness of modified fat ice creams compared to full-fat formula [1,2]

Formula	Melting rate (g/min)	Destabilization of fat (%)	Air cell size (µm)	Hardness (g)
Full-fat	1.5372±0.01 cd	51.52±0.83 f	182.16±146.44 b	9865.45±2126.12 cb
Non+5	1.0797±0.09 a	27.15±0.74 ab	258.51±197.32 def	20213.39±5973.83 d
Non+7	1.2723±0.10 b	32.03±1.47 c	172.33±132.51 b	14766.10±4314.61 c
Non+9	1.4744±0.04 cd	45.00±0.00 e	129.33±77.95 a	21137.28±16502.2 d
Low+5	1.2732±0.16 b	25.13±3.76 a	279.33±221.36 f	4179.18±1412.80 a
Low+7	1.4253±0.01 bcd	26.65±1.31 a	273.66±220.15 ef	4551.04±1084.77 ab
Low+9	1.5621±0.03 d	29.09±0.09 b	243.66±186.93 cde	7396.09±1694.31 ab
Light+5	1.5149±0.14 cd	33.20±0.62 c	463.33±243.45 i	34713.66±9711.3 ef
Light+7	1.5322±0.05 cd	33.87±0.21 c	391.66±240.04 h	38485.80±7362.72 f
Light+9	1.4997±0.17 cd	36.42±0.54 d	312.50±134.27 g	32538.79±10442.42 e
Reduced+5	1.5285±0.07 cd	50.47±1.30 f	231.00±166.82 cd	6700.50±3035.01 ab
Reduced+7	1.2674±0.03 b	82.83±0.71 h	214.83±143.14 c	7405.79±2231.33 ab
Reduced+9	1.3655±0.03 bc	79.47±0.522 g	160.50±114.12 b	13703.12±2355.46 c

1 Results are mean ± standard deviation (SD)

2 Means in the same column followed by a different letter (a-i) were significantly different (p<0.05)

The rate of meltdown of non-fat and low-fat ice creams containing inulin significantly increased (p<0.05) as the inulin concentration increased. However, the rate was slightly lowered in light and reduced fat ice creams with increasing amount of inulin. The melting behavior of all ice cream is shown in Figure 5-2. The meltdown rates between each type of ice cream were different due to the difference in fat content. Increasing inulin concentration within each type of ice cream also significantly increased (p<0.05) the destabilization of fat. The extent of fat destabilization were significantly different ($p<0.05$) among different types of ice cream.

The results in Table 5-4 indicate that air cell size of modified fat ice creams with added inulin was significantly different from the control ($p<0.05$). An increase in inulin concentration significantly decreased ($p<0.05$) air cell size in each ice cream type, resulting in improving the air cell size quality to close to the full-fat ice cream as shown in the Figure 5-3. For hardness, modified fat ice creams with inulin was significantly different ($p<0.05$) in hardness from the full-fat sample. Within each type of modified fat ice cream containing different inulin concentration, most hardness values were not significantly different ($p\geq0.05$). Low-fat ice cream, exhibited the lowest hardness followed by reduced-fat, full-fat, non-fat and light ice cream respectively.

From the result of sensory evaluation and physical quality determination, modified fat ice cream could be formulated with satisfactory characteristics by using inulin as a fat replacer with an exception of non-fat ice cream. Increasing the level of inulin addition from 5 to 7 and 9% (w/w) did not significantly improve sensory acceptability as well as overrun of the ice cream. It did not morbidly affect other physical qualities either. Hence, modified fat ice cream formulas with 5% addition were selected for determination of nutritional values and storage test in the next step.

Figure 5-2 Melting characteristic of modified fat ice cream using inulin as a fat at 5, 7 and 9 % (w/w) compared with a full-fat formula

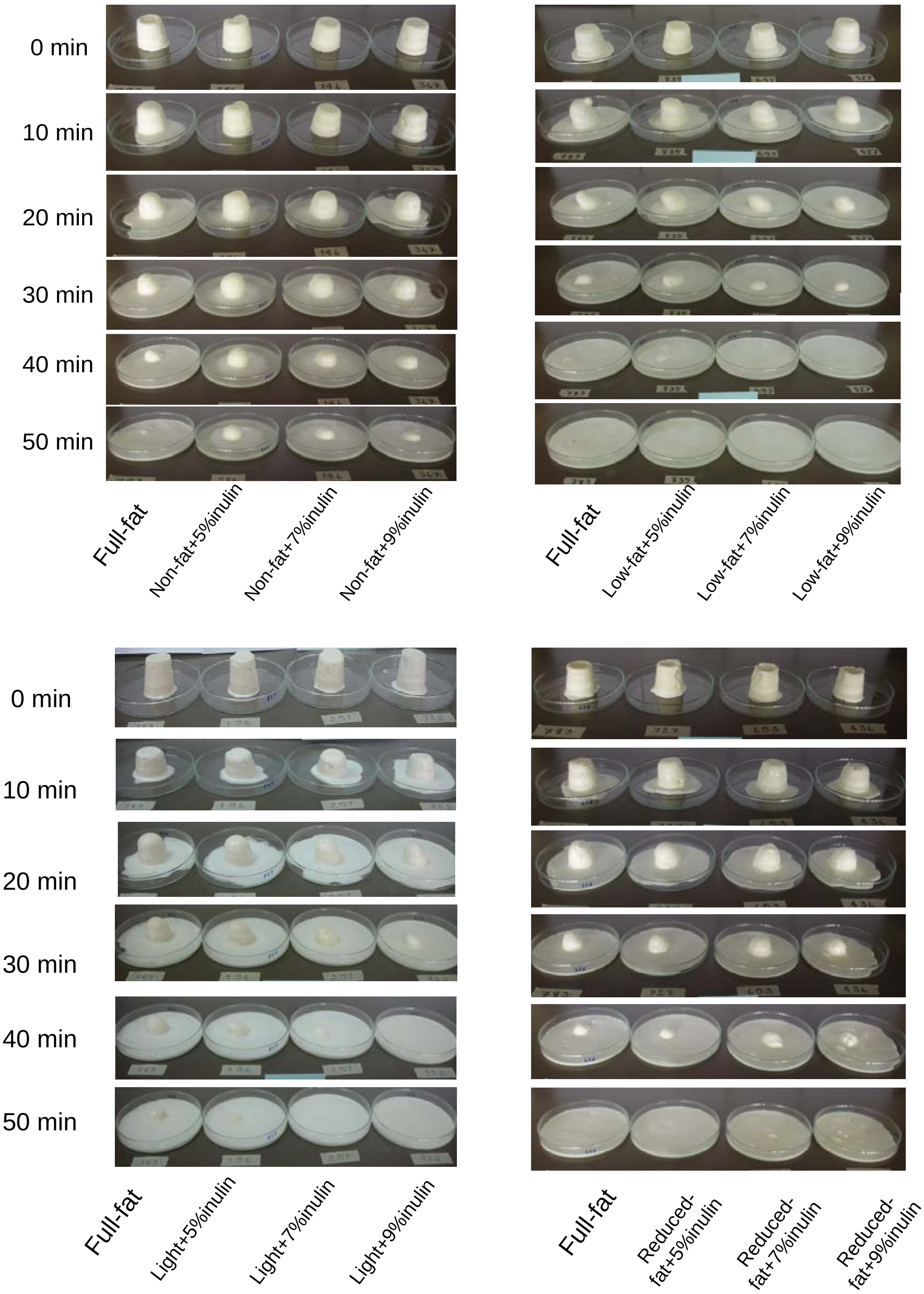
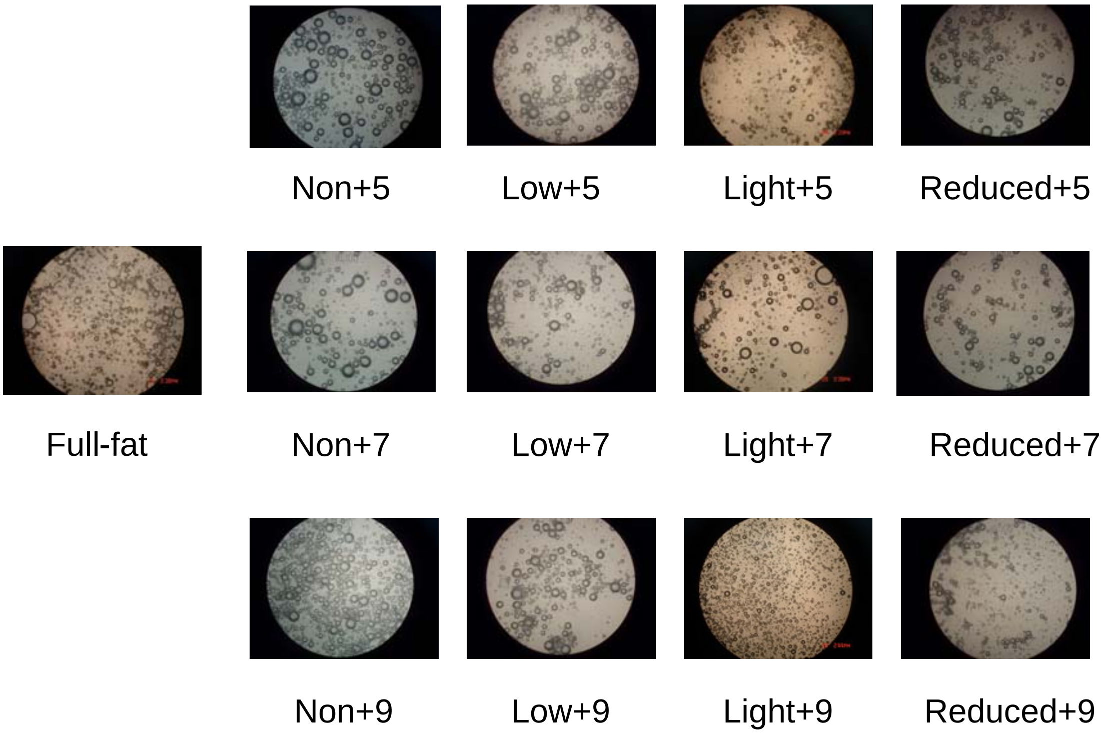


Figure 5-3 Air cell characteristic of modified fat ice cream using inulin as a fat replacer at 5, 7 and 9 % (w/w) compared with a full-fat formula



5.5 Determination of nutritional value

Modified fat ice cream products with 5% inulin were analyzed for moisture, protein, fat, ash, carbohydrate and energy. The analysis was performed by the Food Chemistry Laboratory, Institute of Nutrition, Mahidol University. The results are shown in Table 5-5

Table 5-5 Nutritional value of modified fat ice cream products containing 5% inulin and regular (full-fat) formula (per 100 g sample)

Formula	Energy (kcal)	Moisture (g)	Protein (N×6.25) (g)	Fat (g)	Carbohydrate (g)	Ash (g)
Full-fat	192.39	65.04	0.90	11.27	21.84	0.95
Non+5	106.00	72.67	0.40	0.11	25.87	0.95
Low+5	137.29	69.19	0.55	3.57	25.74	0.95
Light+5	165.53	65.45	0.65	6.21	26.76	0.93
Reduce+5	174.94	64.97	0.74	7.74	25.58	0.97

Results are mean of duplicate analysis

5.6 Storage testing

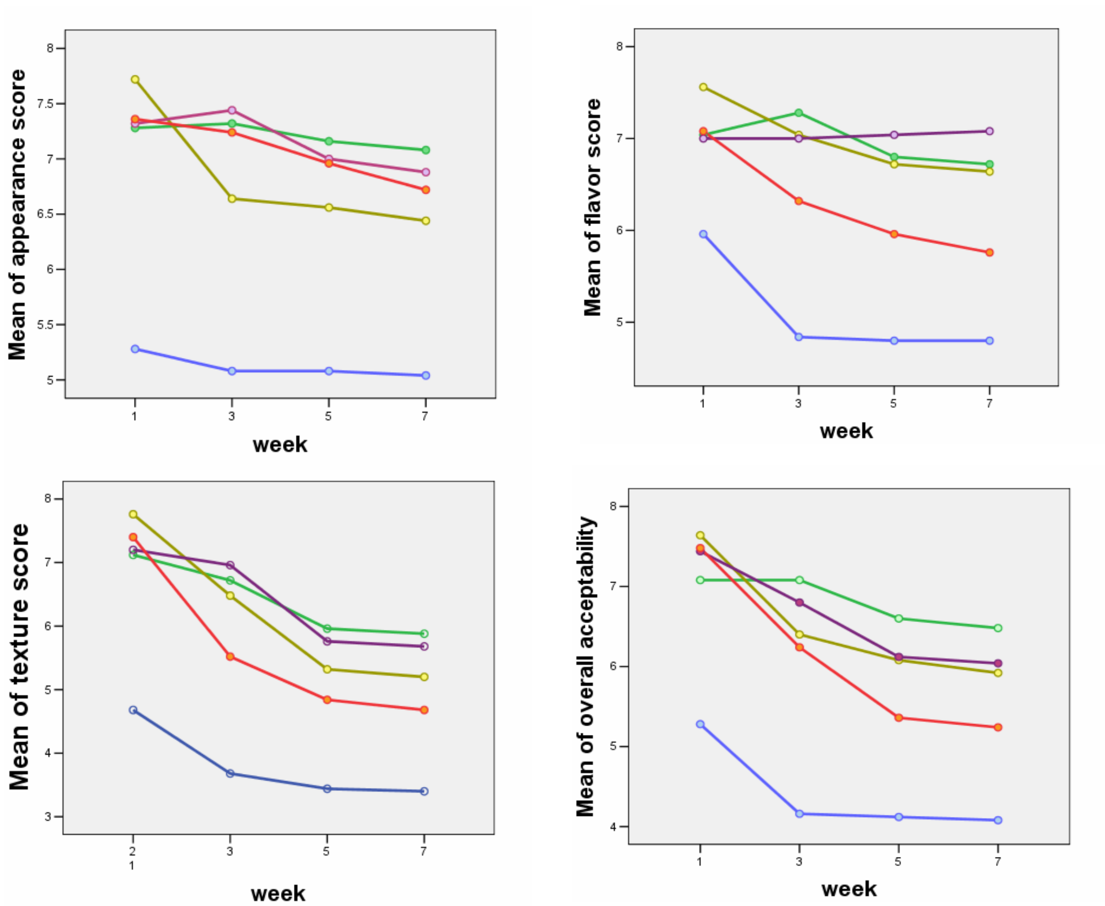
Modified fat ice cream products with 5% inulin were stored at -18ºC for 7 weeks. Sensory evaluation, texture profile analysis and determination of air cell size were performed on 1^{st}, 3^{rd}, 5^{th} and 7^{th} week. The same procedure was also carried out in full fat ice cream for comparison.

The results of sensory evaluation are shown in figure 5-4 to figure 5-5 and raw data are shown in appendix F. All sensory characteristic were affected by the storage time. Appearance, flavor, texture, and overall acceptability scores decreased as the storage time increased. In particular the texture and overall acceptability scores were significantly reduced (p<0.05) when compared to the scores at one week of storage.

For the suitability of color, odor, sweetness, creaminess, smoothness, and hardness, storage time did not affect the sensory characteristics of color, odor, and sweetness in all types of ice cream. Whereas the smoothness score decreased from 3 (just-about-right) to 2 (too coarse) when the storage time increased. Hardness significantly increased (p<0.05) when compared to the score at one week of storage.

Table 5-6 reveals the results of storage time on hardness as measured by texture profile analysis and air cell size of the modified fat ice cream products and full-fat formula. Hardness value of all ice cream significantly increased (p<0.05) during storage. Air cell size was not affected by storage except for reduced-fat ice cream with 5 % inulin addition where the air cell size is significantly increased (p<0.05) with storage time.

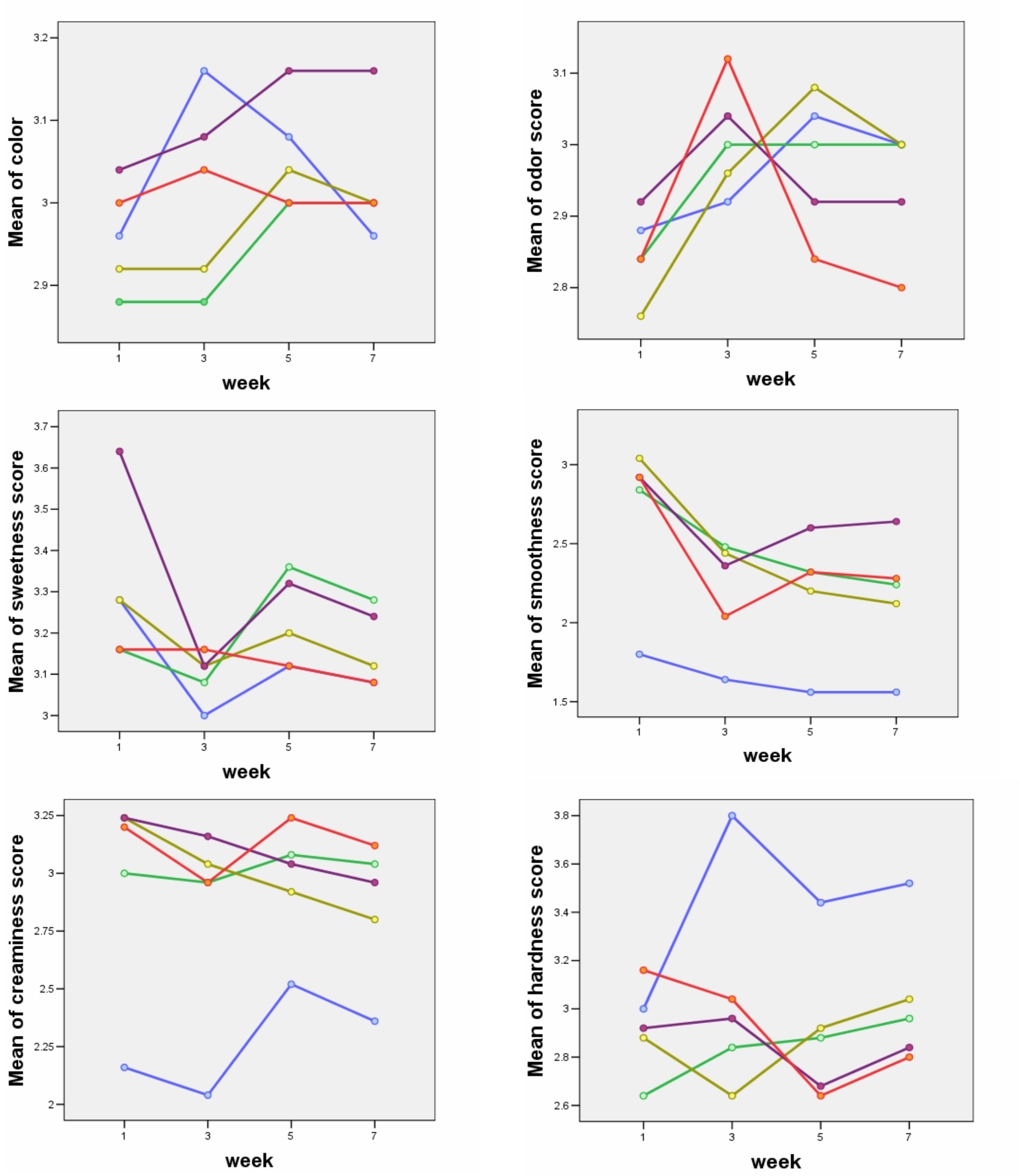
Figure 5-4 Sensory properties (appearance, flavor, texture and overall acceptability) of modified fat ice cream with 5 % inulin addition and full-fat ice cream during 7 weeks of storage[1]



non-fat + 5%inulin low-fat + 5% inulin light + 5%inulin
reduced-fat + 5 %inulin full-fat

1 Nine-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely)

Figure 5-5 Sensory properties (color, odor, sweetness, creaminess, smoothness and hardness) of modified fat ice cream with 5 % inulin addition and full-fat ice cream during 7 weeks of storage[1]



non-fat + 5%inulin   low-fat + 5% inulin   light + 5%inulin
reduced-fat + 5 %inulin   full-fat

1 Five-point just-about-right scale (5 corresponded to "much too strong", 1 to "much too weak", and 3 to "just-about-right")

Table 5-6 Physical properties of modified fat ice cream with 5% inulin addition and control formula ice cream during 7 weeks of storage on texture (hardness) and air cell size. [1,2]

Storage time	Full-fat		Non-fat + 5		Low-fat + 5		Light + 5		Reduced-fat + 5	
	Hardness (g)	Air cell size (µm)	Hardness (g)	Air cell size (µm)	Hardness (g)	Air cell size (µm)	Hardness (g)	Air cell size (µm)	Hardness (g)	Air cell size (µm)
1st week	4217.75 a	182.16 a	33291.32 a	258.51 d	5281.54 a	279.33 b	7311.74 a	436.33 b	3838.38 a	231.00 a
	(1224.86)	(146.44)	(13483.58)	(197.32)	(2024.97)	(221.36)	(2625.78)	(243.45)	(1586.31)	(166.82)
3rd week	17659.57 b	187 a	53027.08 b	149.83 a	31552.34 c	226.83 a	34144.74 b	224.16 a	25425.78 b	220.33 a
	(14507.70)	(134.69)	(7672.98)	(69.69)	(17558.14)	(188.69)	(5234.40)	(235.78)	(10605.92)	(165.61)
5th week	32190.07 c	254.16 b	51403.61 b	244.83 cd	19959.71 b	220.66 a	35334.33 b	236.83 a	45482.42 c	407.5 b
	(7734.54)	(212.42)	(11093.99)	(214.83)	(2702.99)	(161.01)	(17721.92)	(177.45)	(14418.63)	(292.83)
7th week	51258.15 d	199.16 a	>50000*	229.33 b	41502.37 c	210.83 a	>50000*	227.33 a	>50000*	326.83 c
	(7339.02)	(158.40)		(160.18)	(14749.22)	(239.37)		(172.87)		(229.55)

1 Results are mean (standard deviation, SD)

2 Means in the same column followed by a different letter (a-d) were significantly different ($p<0.05$)

* Maximum capacity of load cell = 50000 g

CHAPTER VI
DISCUSSION

During the last few decades a number of research works have been conducted ranging from improving the quality of full-fat ice creams to developing new low-fat products. These studies have indicated that some ingredients in ice cream, mainly fat, have significant effects on the characteristics of flavor and texture (King 1994; Specter and Setser 1994; Stampanoni-Koeferli *et al* 1996; Guinard *et al* 1997; Li and others 1997). The primary difficulties to be overcome in low-fat or fat-free products include adjusting the mouth feel and flavor perception to resemble that of full-fat products. To meet this challenge, ice cream manufacturers have been focusing on eliminating the problems resulting from the replacement or removal of milk fat (Marshall 1991; Hatchwell 1994). In recent years, carbohydrate-based fat mimetics, such as maltodextrin, Litesse®, Splendid™, N-Lite® and protein-based fat mimetics, such as Simplesse®, N-Lite™ have been widely used in manufacture of ice creams due to prevalence of low-calories foods (Kailasapathy and Songvanish1998; Yilsay *et al* 2006). However, the use of fat mimetics in ice cream affected flavor and texture characteristics of ice cream, which resulted in decreased overall acceptability by consumers.

This study concentrates on effect of inulin as a fat replacer on sensory characteristics and physical properties in ice cream.

6.1 Preliminary ice cream making trial

Common recipes for full-fat ice cream product used in this study were those generally found in cookbooks. They were prepared and tested for acceptability. After some adjustments, one recipe was selected for use as a reference formula. This formula formed a basis for the formulation of modified fat ice cream products with inulin as a fat replacer. In addition, the formula served to ensure that the changing in acceptability score from sensory evaluation of modified fat (inulin added) products did not result from inferior cooking skill and technique used by the researcher

The reference recipe of full-fat ice cream involved the use of emulsifier, CMC and stabilizer, GMS. The reasons for selecting them as emulsifier and stabilizer were because of the promising results reported by previous researchers. El-Nagar *et al* (2002) found that the use of GMS in ice cream product at 0.75% level, gave no negative effects on the product quality.

6.2 Formulation of modified fat Ice cream products

In this study, a commercial inulin (Frutafit®HD) was used to replace fat in ice cream product. It was added at 5, 7 and 9 % (w/w). The replacement level was determined in accordance to the previous research which involves the incorporation of inulin as a fat replacer in low fat yogurt-ice cream products (El-Nagar *et al* 2002). They reported that product application using 5% to 9 % inulin addition resulted in products with satisfactory characteristics when compared to full-fat yogurt-ice cream and low-fat yogurt-ice cream product without any fat replacers. After increasing the incorporation level of inulin in each type of ice creams, inulin could be incorporated up to 10 % for all types of ice cream. Problems with product processing and unpleasant product characteristics especially in taste (sweetness) and texture tended to appear when addition of inulin was above the mentioned level. Similar results were mentioned in a study by Akalin amd Erisir (2008), which used 4% of inulin as a prebiotic and a fat replacer in low-fat and non-fat probiotic ice creams.

Non-fat, light, low-, and reduced fat ice creams without added inulin or any fat replacers were not prepared for comparison with the modified fat formulas with added inulin. Only a regular full-fat formula was used. The reason followed the study of Roland *et al* (1998) that as fat content of the ice cream decreased, the sample was less white, harder and melt more quickly. In addition to the low-fat sample tasting less like cream, an increase in perception of the undesirable flavor occurred. Therefore, it was clear that low-fat ice creams without fat replacers are significantly different in sensory and physical properties from full-fat ice cream. Such differences and the markedly inferior quality make the modified fat formulas without fat replacers unacceptable. Hence, they should not be used as a basis for developing the modified fat counterpart.

6.3 Sensory evaluation

From the study of Roland *et al* (1998), the sensory characteristics of ice cream with different fat contents (0.1%, 3%, 7%, 10%) without the addition of a fat replacer were significantly different (p<0.05) in terms of textural appearance (air hole, stickiness, and glossiness). This increased as the percentage of fat in the ice cream increased. The flavor score was also influenced by fat. As fat content decreased, the sensory score for both milk powder flavor and corn syrup flavor ice cream increased significantly (p<0.05). The textural attributes showed significant changes at each percentage of fat (p<0.05). Iciness, melt ability and coldness decreased as fat content increased whereas stickiness and air hole content increased.

In this study the addition of inulin to light (3% fat), low- (6% fat) and reduced fat (9% fat) ice cream improved the sensory characteristics of the samples with the rating of these ice creams resembling that of the full-fat sample. Changing of inulin concentration appeared not to affect the sensory characteristics in these products (Table 5-1, 5-2). These results agree well with the studies of El-Nagar *et al* (2002) and Kowittaya *et al* (2005). They found that addition of inulin to low-fat base ice cream improved the sensory characteristics of the sample with the rating of ice cream resembling that of the high fat product. Moreover, a change in inulin concentration appeared not to affect the texture characteristics.

Replacing all milk fat with inulin in the non-fat (0.5%fat) ice cream, however, significantly lowered (p<0.05) the sensory scores when compared to the full-fat formula. In the case of non-fat formula, an increase in inulin addition tended to improve appearance, texture and creaminess sensory scores. Additional information from the comment ballots also indicated that undesirable milk powder flavor was more profound in ice cream with less fat content than that with higher fat content. These results were similar to the report of Roland *et al* (1998) as mentioned earlier.

In contrast, Devereux *et al* (2003) reported that there were no significant differences between control (full-fat) and low –fat ice cream with inulin in the sensory scores of appearance and color. Whereas, the scores of overall acceptability, flavor and texture for low-fat ice cream with inulin were lower than those of the control. In addition, Akin *et al* (2007) reported that addition of 1-2% inulin in full-fat probiotic ice cream had no effects on the sensory properties of the ice cream (p>0.05).

6.4 Determination of physical quality

6.4.1 Viscosity

From the results (Table 5-3), the viscosity of the modified fat ice cream mixes with added inulin showed a significant increase (p<0.05) corresponding to the proportion of inulin concentration. An increase in the viscosity value of the modified fat ice cream samples added with inulin could be explained by the interaction of the dietary fiber (inulin) and the liquid component of ice cream mix. Inulin, being hygroscopic, would bind water and form a gel-like network that would modify the rheology of the mix. Schmidt *et al* (1993) reported that an ice cream mix containing a carbohydrate-based fat replacer exhibited a viscous behavior because of the water imbibing capacity, which in turn would increase the viscosity of the system.

Similar results were found by El-Nagar *et al* (2002), Akalin and Erisir (2008) and Akìn *et al* (2007), which reported that there were significant differences (p<0.05) in viscosity among regular ice cream mixes and inulin-added ice cream mixes, and that viscosity increased with an addition of inulin to the mix.

The results from another study were also similar to our findings. Significantly higher apparent viscosity was obtained by replacing 100% of the 42 DE corn syrup with inulin in a reduced fat ice cream mix (Schaller-Povolny and Smith 1999). The authors reported that higher apparent viscosity resulted from the higher molecular weight of inulin and that a potential interaction between inulin and milk proteins could also be present in the system. Higher molecular weight of inulin may be related to a higher apparent viscosity of the ice cream mixes containing inulin in our study.

However, when compared to the full-fat ice cream, non-fat and low-fat with 5% inulin formulas exhibited a significantly lower viscosity. This may be because an insufficient amount of inulin was used. The remaining modified fat formulas had similar or higher viscosity than that of the control.

6.4.2 Overrun

The overrun value of ice cream in this study ranged from10% to 25% in all types of ice cream. The low overrun value may be due to the type of freezing and composition of ice cream. The freezer used in this study was a batch-type household ice cream maker. Akalin *et al* (2007) showed that the overrun value of ice cream in their study was low because of the freezing process that was carried out in a batch type freezer and overrun value varied depending on the composition. Chang and Hartel (2001) suggested that fat content did not influence the overrun value during batch freezing.

The highest overrun values were found in modified fat ice creams containing 5% inulin, except in the non-fat formulas (Table 5-3). The values were not significantly different (p>0.05) from that of the full-fat sample. For light, low-fat and reduced-fat ice cream, increasing inulin concentration beyond 5% seemed to reduce the overrun value. The main reason may due to the higher viscosity of sample when a larger amount of inulin was added. Schmidt *et al* (1993) found that the use of carbohydrate-based fat replacer in reduced fat ice cream resulted in mixes with higher viscosity. These mixes incorporated less air than the control. Similar results were found by Kowittaya *et al* (2005). In contrast, Akalin and Erisir (2008) found that addition of inluin at 4% level in low-fat and non-fat probiotic ice cream increased the overrun value. Akin (2005) reported that adding inulin in ice cream produced insignificant effects (p>0.05) to the overrun value. An opposite result obtained in non-fat ice cream could be explained by an insufficient amount of inulin addition resulting in low viscosity mixes which could not trap enough air into them. An increase in the level of inulin in such case may help to increase the overrun.

6.4.3 Color

Addition of inulin showed a significant effect (p<0.05) on the L* (lightness) corresponding to the inulin concentration, whereas, the changes in a* value (redness) and b* value (yellowness) were much less affected. Moreover, the L* value (lightness) increased with an increasing fat content among different types of the modified fat ice creams. Similar results were found by Roland *et al* (1998) that the color of the ice cream increased in whiteness (p<0.05) as the fat content increased from 0.1 to 10% fat. Correspondingly, ice cream samples were more red and less green as the fat content increased, as reflected by increasing a* value. The b* value increased as the fat content of the samples increased, which corresponded to the sample being more yellow and less blue. Roland *et al* (1999) also found that all products with fat replacers (maltodextrin, milk protein concentrate, and polydextrose) were whiter than 0.1% fat ice cream (p<0.05), but not as white as 10% fat ice cream. Whereas Akalin *et al* (2007) found no effect of inulin was obtained on the analytical measures of color. Mean value of yellowness (b*) was significantly higher in regular ice cream that contained 10% milk fat. The b* value corresponded well with the fat content of the products though no significant differences were obtained between the b* values of the products containing 6 or 3% milk fat. Lightness (L*) and redness (a*) values showed similar behavior. Those values were very close to each other (p>0.05).

6.4.4 Melting rate

According to the results in Table 5-4, the rate of meltdown of non-fat and low-fat ice cream containing inulin significantly increased (p<0.05) as the inulin concentration increased. However, the rate was slightly lower in light and reduced-fat ice cream with increasing amount of inulin. The results agree well with those of Akin *et al* (2007). They reported that samples with inulin lost their shape more quickly than other products. Reduced-fat and low-fat ice creams made with inulin melted faster than regular ice cream (p < 0.05). According to our results the meltdown rate was also different between each type of ice cream. This suggested that the level of fat content also affected the meltdown rate with sample higher in fat having a higher meltdown rate. In contrast, Akin *et al* (2007) reported that milk fat slowed the rates of heat transfer through ice creams. Therefore, ice creams that contain fat would be expected to melt more slowly than would non-fat ice creams containing similar amounts of total solids and stabilizer– emulsifier. Nevertheless, our results were similar to the study of Roland *et al* (1998) that found increasing fat content of ice cream caused an increase (p<0.05) in the half-life of ice cream.

On the other hand, the consistency coefficient of the mix was found to influence the melting rate by Muse and Hartel (2004). They found that the samples that were high in solids and fat melted faster (p < 0.05) than did the samples that were low in solids and fat. This was possibly due to the effect of dissolved solids on freezing point depression. Similar findings were obtained by Li *et al* (1997).

El-Nagar *et al* (2002) and Akalin *et al* (2008) reported that addition of inulin improved melting rate of ice cream, the 1st dripping time was also longer when compared to the control (low-fat type ice cream). Moreover, the melting rate of ice cream can be affected by many factors, including the amount of air incorporated, the nature of ice crystals and the network of fat globule formed during freezing. Sakurai *et al* (1996) and Sofjan and Hartel (2003) found that ice cream with low overrun melted quickly, whereas ice cream with high overrun began to melt slowly and had good melting resistance. These results were similar to our finding that ice cream containing higher inulin level had higher viscosity and was lower in overrun, resulting in an increase in meltdown rate. The fat network also plays a significant role in the melting rate of ice cream. An increase in fat destabilization level increases the fat network which is shown to decrease the melting rate of ice cream to promote shape retention. In our study, higher fat destabilization was also found in ice cream containing higher inulin. In addition, Roland *et al* (1999) found that all products with fat replacers (maltodextrin, milk protein concentrate, and polydextrose) melted faster ($p<0.05$) than 10% fat ice cream.

6.4.5 Fat destabilization

Increasing inulin concentration significantly increased ($p<0.05$) the destabilization of fat (Table 5-4). This may be explained by the ability of inulin to improve the stability of foams and emulsions in food system which gives emulsion destabilizing power (Franck 2002). Chang and Hartel (2001) reported that fat destabilization in ice cream is seen as partial coalescence of fat globules due to the destabilizing effect (from emulsifier addition) during freezing condition. The extent of fat destabilization in ice cream is controlled by the shear forces applied in the particular process. Formulation factors have also been shown to influence extent of fat destabilization.

6.4.6 Air cell size

Air (air cell size and overrun) in ice cream provides a light texture and influences the physical properties of meltdown and hardness. Air cell size is related to mouth feel, which enhances the sensory perception of smoothness (Granger *et al* 2005). There are numerous factors that influence development of air cell in ice cream upon freezing. Furthermore, shearing force during mixing breaks larger bubbles into smaller ones (Sofjan and Hartel 2003). In batch freezing of ice cream, development of air cell is influenced by formulation factors (fat, emulsifier, and stabilizer) and processing condition (whipping temperature and freezing power) (Chang and Hartel 2001).

The results in Table 5-4 indicate that air cell size of modified fat ice cream with added inulin was significantly different ($p<0.05$) from the control. An increase in inulin concentration significantly decreased air cell size in each ice cream type, resulting in improving the air cell size quality to close to the value for full-fat ice cream. Inulin improves the stability of foams and emulsions in food system (Franck 2002), thus it prevents air cell growth. Moreover, the sample with more inulin had the higher viscosity and thus, higher shear stress was required in breaking down the air cell (Muse and Hartel 2004).

Chang and Hartel (2001) reported that the air cell size distribution of ice cream was not influenced by fat content or formulation. Their results indicated that mean air cell sizes of both regular and non-fat ice cream were not statistically different to 90% confidence level or higher. They also suggested a strong correlation between mean air cell size and viscosity of the slurry within the freezer, the maximum size should decrease corresponding to the increase in shear stress (apparent viscosity) applied to break down the bubble.

As a consequence, the apparent viscosity increased, which caused a reduction in maximum air cell size due to the increased shear stress applied to disrupt the air cells.

6.4.7 Texture (hardness)

In this study, modified fat ice cream with inulin was significantly different ($p<0.05$) in hardness from the full-fat sample. Nevertheless, within each type of modified fat ice cream containing different inulin concentration, hardness values were not significantly different ($p>0.05$). An increase in hardness of samples with inulin may due to the lower amount of fat content in the ice cream. Guinard *et al* (1997) demonstrated that ice cream hardness was inversely related to fat and sugar content. In addition, the ability of inulin to bind water and form a particle gel network can enhance the hardness of the product (Franck 2002).

Akalin and Erisir (2008) and Niness (1999), reported that inulin increased the firmness in probiotic ice cream ($p<0.05$) due to its long chain length and the ability to form inulin microcrystals when sheared in water or milk. These crystals interact to form a creamy texture. Akalin *et al* (2007) and Roland *et al* (1998), found the hardness of reduced-fat and low-fat ice creams were observed to be considerably higher than the regular fat control ($p < 0.05$). Therefore, a reverse relation between fat content and hardness was obtained in the products. These results followed the change in composition towards a higher concentration of water.

Similar to our findings, Akalin *et al* (2007) reported that inulin increased (p<0.05) the hardness in reduced-fat or low-fat ice cream, possibly related to a decrease in freezing points as a result of higher solute concentrations. The addition of 5% inulin to low-fat ice cream (Aim *et al* 2001) or 5% modified starch to low-fat yogurt-ice cream base (El-Nagar *et al* 2002) increased the hardness in comparison to high fat control sample.

Muse and Hartel (2004) reported that the hardness in ice cream was also influenced by the rheological properties of the mix. According to the authors, ice cream mixes with high consistency coefficients were very viscous, and this viscosity increased the hardness. This reason was supported by the study of Akalin *et al* (2007). As apparent viscosity or consistency coefficients increased in the mix, the hardness increased in reduced-fat or low-fat ice cream. However, low-fat mixes that showed lower apparent viscosity or consistency coefficients were found to be harder than their reduced-fat counterparts possibly because of the presence of ice crystals.

Roland *et al* (1999) found all products with fat replacers (maltodextrin, milk protein concentrate, and polydextrose) significantly reduced the hardness of the product when compared to the 0.1% fat ice cream (p<0.05). In addition Sofjan and Hartel (2003) found that low overrun products were harder in texture.

6.5 Nutritional value

From the results that are shown in Table 5-5, all types of modified fat ice cream contained lower amount of fat than the full-fat formula corresponding to their formulation. The analytical values of fat content were slightly higher than expected. This may due to the remaining fat in non fat dry milk. Whereas, the analytical values of carbohydrate in modified fat ice cream were higher than full-fat formula. This may due to the method of carbohydrate determination (calculation from 100 subtract by the percent of moisture content, protein, ash and crude fat) which include inulin content in carbohydrate content. The formulated ice creams could provide lower fat alternatives to the consumers with a variety of choices ranging from low-fat (3 g per serving), light (50% less fat than a regular product) and reduced-fat (25% less fat than a regular product). Although non-fat product provided the lowest fat content (0.5 g per serving), it was not well accepted by the panelists in the sensory evaluation. Hence, further improvement was still needed.

6.6 Storage test

6.6.1 Sensory evaluation

Figure 5-4 and 5-5 show the results of sensory evaluation during storage test from the 1st week to the 7th week. Texture i.e. smoothness and hardness were significantly affected ($p<0.05$) by the storage time. For hardness and smoothness, an increase in the storage time significantly decreased ($p<0.05$) the sensory score. From the comment ballots, the panelists reported that ice crystals were first detected in the full-fat formula and non-fat formula with 5% inulin addition at the 5th week and in other samples at the 7th week. Schaller-Povolny and Smith (1999) studied the sensory attributes and storage life of reduced-fat ice cream replacing 50% and 100% of 42 DE corn syrup with inulin. They found that storage time affected the ice cream samples in terms of iciness. However, the sample with added inulin was found less icy than the control (normal reduced-fat ice cream). The explanation was inulin may help inhibit ice crystal growth during the first weeks of storage, but later become ineffective. This may be because during storage under thermally abusive conditions, some of the solids in the ice cream matrix were altered. This alteration may have caused a decrease in the ability of inulin to hold water, leading to more free water available for ice crystal growth.

6.6.2 Air cell size determination

Overall, there were no significant changes ($p>0.05$) in air cell size during storage. However, in reduced-fat ice cream with 5 % inulin addition, the air cell size significantly increased ($p<0.05$) related to the duration of storage time. Sofjan and Hartel (2003) determined the air cell size during manufacture and early storage of ice cream. They reported that the mean air cell size, in general, decreased ($p<0.05$) with increased overrun. An increase in overrun promoted break-up of larger air cells into smaller ones during freezing. This effect may have been related to increasing viscosity of ice cream as more air was incorporated. Upon hardening, air cells in each type of ice cream increased, with ice cream having a higher overrun showing the larger increase in mean air cell size. Upon storage, mean air cell size decreased in all types of ice cream at the 4th week, but after the 9th week, the air cell size increased once again.

6.6.3 Texture (hardness)

In this study, increasing storage time significantly increased the hardness value of ice cream ($p<0.05$) (Figure 5-4). A similar result was found in the study of Akalin and Erisir (2008). They reported that firmness was improved in all products by extension of storage, but significant increases were not found ($p > 0.05$). Prindiville *et al* (2000) carried out a study of milk fat in chocolate ice cream during storage. After storage treatments, non-fat ice cream appeared significantly less smooth and had more visible air bubbles than the other ice creams. After the heat-shock treatment, low-fat ice cream also appeared significantly less smooth than did reduced-fat or full-fat.

CHAPTER VII
CONCLUSION

The research was designed to develop non-fat, low-fat, light, and reduced-fat ice cream products containing inulin as a fat replacer and to determine the physical quality and consumer sensory acceptability of the products. The levels of inulin addition used were 5, 7 and 9% (w/w). All types of ice cream formulation were evaluated on sensory characteristics (n=50) for acceptability of appearance, flavor, texture and overall acceptability using nine-point hedonic scales. Whereas the suitability of taste, color and appearance, body and texture, and flavor were evaluated using 5-point "just-about-right" scales. The ice creams also were evaluated for physical quality including viscosity of ice cream mix using a digital viscometer, color of finished ice cream using a colorimeter, texture or hardness using a texture analyzer, melting rate, development of air cell size, overrun and extent of fat destabilization. The ice cream with the best sensory scores in each type of ice cream was chosen to determine the nutritional value and used in the storage test.

From the results, the application of inulin as a fat replacer in different types of modified fat ice cream showed that inulin clearly affected the physical quality of each type of ice cream. Increasing the inulin level in ice cream product significantly increased ($p<0.05$) the viscosity of ice cream mix. The reason was mainly due to the ability of inulin in binding water to form gel-like network. The changes in rheological property of ice cream mix by inulin addition resulting in the changes in other physical properties. The product with higher inulin content showed a higher viscosity, and also higher meltdown rate and fat destabilization whereas the overrun value and air cell size decreased. Some physical properties i.e. hardness and color, were mainly influenced by the level of fat content. From the sensory evaluation, addition of inulin to light (6% fat), low-fat (3% fat) and reduced-fat (9% fat) ice cream improved the sensory characteristics of the samples with the rating of these ice creams resembling that of the full-fat sample. Changing of inulin concentration appeared not to affect the sensory characteristics in this product. However, replacing all milk fat with inulin in the non-fat (0.5%fat) ice cream significantly lowered the sensory scores when compared to the full-fat sample, rendering it not quite acceptable to the consumers.

Different amount of inulin used in the formulation (5, 7 and 9%) did not markedly affect the quality and acceptability of the finished products. Hence, for the practical application, 5% inulin addition to replace fat at various levels to produce low-fat, light and reduced-fat ice cream was acceptable. Non-fat formula, however, requires further study to improve its quality and acceptability. Furthermore, the quality and acceptability of all modified fat products as well as the full-fat ice cream deteriorated with increasing storage time up to 2 months. Although the products, with the exception of non-fat ice cream, were still rated between like slightly to like moderately at the end of the storage period, some adjustment in the formulation and process may still be needed to achieve a better result.

In conclusion, this study shows that development of modified fat ice cream products was possible using inulin as a fat replacer. The level of inulin added could be as low as 5% by weight in the low, light and reduced-fat ice cream. The products were acceptable to the panelists in the sensory evaluation and could be stored far 7 weeks. These results could be used as a guideline in developing modified fat ice cream products using inulin or other fat replacers.

REFERENCES

Absolonne J, Jossart M, Coussement P and Roberfroid M. 1995. Digestive acceptability of oligofructose. In: Proc. First Orafti Research Conference, pp. 151–161. Orafti, Tienen, Belgium.

Adapa S, Dingeldein H, Schmidt KA and Herald TJ. 2000. Rheological properties of ice cream mixes and frozen ice creams containing fat and fat replacers. J Dairy Sci. 83(10): 2224–9.

Aime DB, Arntfield SD, Malcolmson LJ and Ryland D. 2001. Textural analysis of fat reduced vanilla ice cream products. Food Res Int. 34 (2/3): 237-46.

Akalin AS, Karagözlü C and Ünal G. 2007. Rheological properties of reduced-fat and low-fat ice cream containing whey protein isolate and inulin. Eur Food Res Technol. 227:889–895.

Akalin AS and Erisir D. 2008. Effect of inulin and Oligofructose on the Rheological Characteristics and Probiotic Culture Survival in Low-fat Probiotic ice cream. J food sci. 73(4), 184-188.

Akın S. 2005. Effects of inulin and different sugar levels on viability of probiotic bacteria and the physical and sensory characteristics of probiotic fermented ice-cream. Milchwisssenschaft. 60: 297–301.

Akìn MB, Akìn MS and Kırmacı Z. 2007. Effects of inulin and sugar levels on the viability of yogurt and probiotic bacteria and the physical and sensory characteristics in probiotic ice-cream. Food Chemistry, doi:10.1016/j.foodchem.2006.11.030

Akoh CC. 1998. Fat replacers. Food Technol. 52(3): 47–53.

Alexander RJ. 1997. Moo-ving toward fat-free dairy products. Food Prod Des. 7(4): 75-96.

Anonymous. 1992. Six fat mimetics developed for specific food applications. Food Technol. 46(4): 110-1.

Anonymous. 1997. Ice cream makers feel healthy products will be segment of greatest growth. The Cheese Reporter. 21(2): 7.

Anonymous. 2003. Market research report: Ice cream-US. Mintel International Group. London, UK. 126 p.

Anonymous. 2005a. The U.S. market for ice cream and related frozen desserts: Ice cream, frozen yogurt, sherbet, sorbet and frozen novelties, 4th ed., Packaged facts. New York, NY. 386 p.

Anonymous. 2005b. Position of the American Dietetic Association: Fat Replacers. J Am Diet Assoc.105 (2): 266-275.

Anonymous. 2007. Market research report: Ice cream-Thailand. Available from: http://www.marketresearch.com/product/display.asp?productid=1495686&xs=r Accessed Oct. 18. 2008.

Arbuckle WS. 1986. Ice cream. 4thed. The AVI Publishing Co. Inc. Westport. Conn. 483 p

Artz WE and Hansen SL. 1994. Other fat substitutes. In: Akoh CC, Swanson BG, editors. Carbohydrate polyesters as fat substitutes, New York: Marcel Dekker, Inc.197-236.

Baer RJ and Baldwin KA. 1984. Freezing points of bulking agents used in manufacture of low-calorie frozen dessert. J. Dairy Sci. 67: 2860-2.

Biedrzycka E and Bielecka M. 2004. Prebiotic effectiveness of fructans of different degrees of polymerization. Trends Food Sci Tech. 19: 170-175

Bodyfelt FW, Tobias J and Trout GM. 1988. The sensory evaluation of dairy products. Van Nostrand Renhold. NY. 598 p

Bo-Kang Lion. 2006. Sensory analysis of low fat strawberry ice creams prepared with different flavor chemicals and fat mimetics. Doctors Thesis, University of Missouri-Columbia, Columbia.

Brauss MS, Linforth RST, Cayeux I, Harvey B and Taylor AJ. 1999. Altering the fat content affects flavor release in a model yogurt system. J Agric Food Chem. 47(5): 2055–9.

Buisson DH. 2006. The changing consumer: Trends in preferences and tastes. Conferenz. Available from: http://www.conferenz.co.nz/content/view/128/31/ Accessed Oct. 28. 2007.

Burns AA, Livingstone MBE, Welch RW, Dunne A and Rowland IR. 2002. Dose-response effects of a novel fat emulsion (Olibra TM) on energy and macronutrient intakes up to 36 h post-consumption. Eur J Clin Nutr. 56:368-377.

Burns AA, Livingstone MBE, Welch RW, Dunne A, Reid A and Rowland IR. 2001. The effects of yoghurt containing a novel fat emulsion on energy and macronutrient intake in lean, overweight and obese subjects. Int J Obes Relat Metab Disord. 25:14871- 1496.

Burns AA, Livingstone MBE, Welch RW, Dunne A Robson PJ, Lindmark L, Reid CA, Mullaney U and Rowland I R. 2000. Short-term effects of yoghurt containing a novel fat emulsion on energy and macronutrient intakes in nonobese subjects. Int J Obes Relat Metab Disord. 24:1419-1425.

Caldwell KB, Goff HD and Stanley DW. 1992. A low temperature scanning electron microscopy study of ice cream. II. Influence of selected ingredients and processes. Food Struct. 11(1): l l-23.

Campbell JR and Marshall RT. 1975. The science of providing milk for man. McGraw-Hill Inc. New York, NY. 801 p.

Chang Y and Hartel RW. 2001. Development of air cells in a batch ice cream freezer. Int J Food Eng. 55: 71–78.

Chang Y and Hartel RW. 2001. Measurement of air cell distributions in dairy foams. Int Dairy J. 12(5): 463–472.

Chung SJ, Heymann H and Grün IU. 2004. Release of artificial cherry flavor from ice creams varying in fat and fat replacers. J Sens Stud. 19(3): 211-36.

Clark D. 1994. Fat replacers and fat substitutes. Food Technol. 48(12): 86.

Dahlberg AC. 1931. Ice cream with high solids content. Ice Cream Trade J. 29(1): 31.

Devereux HM, Jones GP, McCormack L and Hunter WC. 2003. Consumer acceptability of low fat foods containing inulin and oligofructose. J Food Sci. 68, 1850–1854.

Drake MA, Boylston TD, Swanson BG. 1996. Fat mimetics in low-fat cheddar cheese. J Food Sci. 61(6): 1267-70, 88.

Duxbury DD. 1991. Fat replacers-key ingredients in new product R&D efforts. Food Prod Develop. 61: 58.

El-Nagar G, Clowes G, Tudorica CM and Kuri V. 2002. Rheological quality and stability of yog-icecream with added inulin. Int J Dairy Tech. 55: 89–93.

Farooq K. 1997. Effect of fat replacers on the physico-chemical properties of lowfat and nonfat dairy products. Ph.D. Dissertation, Mississippi State University, Mississippi. 188 p.

Flamm G, Glinsmann W, Kritchevsky D, Prosky L and Roberfroid M. 2001. Inulin and oligofructose as dietary fiber: A review of the evidence. Critical Reviews in Food Science and Nutrition 41: 353–362.

Flores AA and Goff HD. 1999. Recrystallization in ice cream after constant and cycling temperature storage conditions as affected by stabilizers. J Dairy Sci. 82(7): 1408–15.

Frøst MB, Heymann H, Bredie WLP, Dijksterhuis GB and Martens M. 2005. Sensory measurement of dynamic flavour intensity in ice cream with different fat levels and flavourings. Food Qual Pref. 16(4): 305-14.

Franck A. 2002. Technological functionality of inulin and oligofructose. British Journal of Nutrition. 2: 287–291.

Gershoff SN. 1995. Nutrition evaluation of dietary fat substitutes. Nutr Rev. 53(11): 305-13.

Giese J. 1996. Fats, oils, and fat replacers. Food Technol. 50(4): 78-84.

Glicksman M. 1991. Hydrocolloids and the search for the “oily grail”. Food Technol. 45(10): 94-102.

Goff HD. 1995. Ice cream. Dairy Science and Technology at University of Guelph, Canada. Available from http://www.foodsci.uoguelph.ca/dairyedu/icecream.html Accessed: Oct. 18. 2008.

Goff HD. 1996. Freezing of dairy products. In Freezing Effects on Food Quality (L.E. Jeremiah, ed.), Marcel Dekker, Inc., New York, NY. p 299–35.

Goff HD, Kinsella JE and Jordan WK. 1989. Influence of various milk protein isolates on ice cream emulsion stability. J Dairy Sci. 72(2): 385-97.

Granger C, Legerb A, Barey P, Langendorff V and Cansell M. 2005. Influence of formulation on the structural networks in ice cream. Int Dairy J. 15: 255–262

Grotta B. 1994. Formulation of a nonfat reduced-lactose ice cream. Masters Thesis. California State University, Fresno, CA. 63 p.

Guichard E. 2002. Interactions between flavor compounds and food ingredients and their influence on flavor perception. Food Rev Int. 18(1): 49-70.

Guinard JX, Zoumas-Morse C, Mori L, Uatoni B, Panyam D and Kilara A.1997. Sugar and fat effects on sensory properties of ice cream. J Food Sci. 62(5): 1087–94.

Hagiwara T and Hartel R W. 1996. Effect of sweetener, stabilizer and storage temperature on ice recrystallization in ice cream. J Dairy Sci. 79(5): 735-44.

Haschke F, Pietsching B, Vanura H, Heil M, Steffan I, Hobiger G., Schuster E and Camaya Z. 1988. Iron intake and iron nutritional status of infants fed iron-fortified beikost with meat. Am J Clin Nutr. 47(1): 108-12.

Hatchwell LC. 1994. Overcoming flavor challenges in lowfat frozen desserts. Food Technol. 48(2): 98-102.

Hatchwell LC. 1996. Implications of fat on flavor. In: McGorrin RJ, Leland JV, editors. Flavor food interactions. ACS Symposium Series 633. Washington, D.C. p14-23.

Hyde GM. 2001. Ice cream. Department of Biological Systems Engineering, Washington State University, Pullman, WA Available from : http://www.wsu.edu/~gmhyde/433_web_pages/433webpages2001/ICE%20Cream2.htm Accessed Nov. 20. 2007.

Hyvönen L, Linna M, Tuorila H and Dijksterhyist G. 2003. Perception of melting and flavor release of ice cream containing different types and contents of fat. J Dairy Sci. 86(4): 1130-38.

Jackson KG, Taylor GRJ, Clohessy AM and Williams CM. 1999. The effect of a daily ingestion of inulin on fasting lipid, insulin and glucose cocentrations in middle aged men and women. Br J of nun. 82: 23-30.

Januário M, Leitão MAC and Leitão AEB. 1999. Changes in inulin and fructooligosaccarides content during storage of chicory roots. In: FUCHS, A., VAN LAERE, A. (ed.). Proceedings of the Seventh Seminar on Inulin, Leuven, Belgium, January 22-23. p 83-85.

Jiménez-Flores R, Klipfel N J and Tobias J. 1992. Ice cream and frozen desserts. In: Hui, YH. editor. Dairy Science and Technology Handbook. Vol. 2: Product manufacturing. VCH Publishers, Inc., New York, NY.

Jones SA. 1996. Roller S, Jones S A. editors. Handbook of fat replacers. Boca Raton: CRC Press.

Kagan J. 1985. Yogurt a rising star in the yogurt industry. Cult Dairy Prod J. 20: 24.

Kailasapathy K and Songvanish W. 1998. Effects of replacing fat in ice cream with fat mimetics. Food Austra. 50(4): 169-73.

Kaur N and Gupta A K. 2002. Applications of inulin and oligofructose in health and nutrition. J Biosci. 27: 703–714.

King BM. 1994. Sensory profiling of vanilla ice cream: flavour and base interaction. Lebensm Wiss Technol. 27(5): 450-6.

Klahorst SJ. 1997. Ice cream: combination chemistry. Food Prod. Des. August. Available from: http://www.foodproductdesign.com/archive/1997/0897AP.html Accessed Nov. 20. 2007.

Kleessen B, Sykura B, Zunft HJ and Blaut M. 1997. Effects of inulin and lactose on fecal microflora, microbial activity, and bowel habit in elderly constipated persons. Am. J Chin. Nutr. 65:1397-1402.

Kowittaya C, Thongngam M and Surapat S. 2005. Quality Improvement of Reduced Fat Vanilla Ice Cream by Inulin. Department of food science, Faculty of Agro-Industy, Kasetsart University.

Koxholt NMR, Eisenmann B and Hinrichs J. 2001. Effect of the fat globule sizes on the meltdown of ice cream. J Dairy Sci. 84(11): 31-7.

Kruel TM. 2004. Development of low-fat and fat-free strawberry ice creams using fat replacers. Maters Thesis, University of Missouri-Columbia, Columbia, MO. 144p.

Kuntz LA. 1996. Where is fat reduction going? Food Prod. Des. March, 24-47. Available from http://www.foodproductdesign.com/archive/1996/0396CS.html Accessed Nov. 20. 2007.

LaBarge RG. 1988. The search for a low-calorie oil. Food Technol. 42(1): 84-90.

Lee H, Stokols J, Palchak T, Bordi P. 2005. Effect of polyols versus sugar on the shelf life of vanilla ice cream. Foodserv Res Int. 16(1): 44-52.

Li Z, Marshall R, Heymann H, Fernando L. 1997. Effect of milk fat content on flavour perception of vanilla ice cream. J Dairy Sci. 80(12): 3133–41.

Marchetti G. 1993. Inulin and falcons. Industrys Alimentary. 32: 945-949.

Marshall RT. 1991. Fat in ice cream. Dairy Field. 74: 32.

Marshall RT and Arbuckle WS. 1996. Ice Cream, 5th ed. Chapman and Hall, New York, NY. 349 p.

Marshall RT and Goff HD. 2003. Formulating and manufacturing ice cream and other frozen desserts. Food Technol. 57(5): 32-45.

Marshall RT, Goff HD and Hartel RW. 2003. Ice cream, 6th ed. Kluwer Academic/Plenum Publishers, NY.

Minhas K, Sidhu J S and Mudahar GS. 1997. Effect of different stabilizers on the sensory quality of plain ice cream made from buffalo milk. Adv Food Sci. 19(5/6): 104-10.

Minhas K, Sidhu JS, Mudahar GS and Singh AK. 2002. Flow behavior characteristics of ice cream mix made with buffalo milk and various stabilizers. Plant Foods Hum Nutr. 57(1): 25-40.

Miraglio AM. 2006. Better tasting- better-for-you ice cream. Food Prod Des. Feb. 82-98. Available from: http://www.foodproductdesign.com/articles/465/465_621elements.html Accessed Sept. 20. 2008.

Muse MR and Hartel RW. 2004. Ice Cream Structural Elements that Affect Melting Rate and Hardness. J Dairy Sci, 87(1): 1-10.

Nilsson U and Bjorck I. 1988. Availability of cereal fructans and inulin in the rat intestinal tract. Carbohydrate and Fiber 1482-1486.

Niess KR. 1999. lnulin and oligofructose: What are they? J Nutr. 129:14025-14065.

Ohmes RL, Marshall RT and Heymann H. 1998. Sensory and physical properties of ice creams containing milk fat or fat replacers. J Dairy Sci. 81(5): 1222-8.

Oku T. 1986. Metabolism of new sweetener fiuctooligosaccharide. (Neosugar) and its application. Eiyogakac Zasschi 44(6):291-306

Ordonez M, Rovira J and Jaime I. 2001. The relationship between the composition and texture of conventional and low-fat frankfurters. Int J Food Sci Tech. 36(7): 749-58.

Prindiville EA, Marshall RT and Heymann H. 2000. Effect of milk fat, cocoa butter, and whey protein fat replacers on the sensory properties of lowfat and nonfat chocolate ice cream. J Dairy Sci. 83(10): 2216-23.

Pszczola DE. 2002. 31 ingredient developments for frozen desserts. Food Technol. 56(10): 46-65.

Roland AM, Phillips LG and Boor KJ. 1998. Effects of Fat Content on the Sensory Properties, Melting, Color, and Hardness of Ice Cream. J Dairy Sci. 82(1), 32-38

Roland AM, Phillips L G and Boor KJ. 1999. Effects of fat replacers on the sensory properties, color, melting, and hardness of ice cream. J Dairy Sci. 82(10): 2094-100.

Rumessen JJ and Gudmand-Hoyer E. 1998. Fructans of chicory: intestinal transport and fermentation of different chain lengths and relation to fructose and sorbitol malabsorption. Am J Clin Nutr. 68:357-364

Ruthig DJ, Sider D and Meckling-Gill KA. 2001. Health benefits of dietary fat reduction by a novel fat replacer: Mimix. Int J Food Sci Nutr. 52(1): 61-9.

Sakurai K, Kokubo S, Hakamata K, Tomita M and Yoshida S. 1996. Effect of production conditions on ice cream melting resistance and hardness. Milchwissenschaft, 51(8): 451–454.

Sandrou DK and Arvanitoyannis IS. 2000. Low-fat/calorie foods: current state and perspectives. Crit Rev Food Sci Nutr. 40(5): 427-47.

Schaller-Povolny LA and Smith DE. 1999. Sensory attributes and storage life of reduced fat ice cream as related to inulin content. J Food Sci. 64(5): 555-59.

Schirle-Keller JP, Chang HH and Reineccius GA. 1992. Interaction of flavor compounds with microparticulated proteins. J Food Sci. 57(6): 1448-51.

Schmidt K, Lundy A, Reynolds J and Yee LN. 1993. Carbohydrate or protein based fat mimicker effects on ice milk properties. J Food Sci. 58(4): 761-3.

Seekeow P. 2001. Formulation of dietary fiber- enriched cake using sugarcane bagasse, MS. Thesis in food and nutrition for development, Bangkok: Faculty of Graduate studies, Mahidol University.

Shamil S and Kilcast D. 1992. Improving the flavour acceptability of reduced fat. foods. Nutri. & Food Sci. 92(4): 7-10.

Silva RF. 1996. Use of inulin as a natural texture modifier. Cereal Food World**.** 41(10): 792 – 794.

Sofjan RP and Hartel RW. 2003. Effects of overrun on structural and physical characteristics of ice cream. Int Dairy J. 14: 255–262

Specter SE and Setser CS. 1994. Sensory and physical properties of a reduced-calorie frozen dessert system made with milk fat and sucrose substitutes. J Dairy Sci. 77(3): 708-17.

Spiegel J, Rose R, Karabell P, Frankos V and Schmitt D. 1994. Safety and Benefits of fiuctooligosaccharides as food ingredients. Food Technol. 48(1):85-89.

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

Stone-Dorshow T and Levitt MD. 1987. Gaseous response to ingestion of a poorly absorbed fructooligosaccharide sweetener. Am J Clin Nutr. 46:61-5.

Takahashi Y, Takagi Y, Toda M, Kashiwabara C, Ishiyama R and Kinoshita T. 1986. Effects of neosugar in chronic renal-failure patients. Proc. 3rd Neosugar Research Conf. Tokyo. Japan. 110.

Terry H, Rupnow J, Boeckner L and Schnepf M. 1999. Influence of long - and short - chained inulin on the firmness and sclerosis of nonfat yogurt. IFT Annual Meeting Technical Program Abstracts. 178.

Thaiudom S. 2007. Effects of ratio of milk fat to soy bean oil and whipping time on qualities of milk ice cream. Songklanakarin J. Sci. Technol. 29(1): 191-204.

Tokunaga T, Oku T, and Hosoya N. 1986. Influence of chronic intake of new sweetener fructooligosaccharide (Neosugar) on growth and gastrointestinal function of the rat J Nutr Sci Vitaminol. 32(1):111-121.

Tominaga S, Hirayama M, Adachi T, Tokunaga T and lino H. 1999. Effects of ingested fructooligosaccharides on stool frequency in healthy female volunteers: a placebocontrolled study. Bioscience microflora. 18(1):49-53.

Tungland BC. 2000. Inulin- A Comprehensive Scientific Review. Available from: http://members.shaw.ca/duncancrow/inulin_review.html Accessed Oct. 19. 2008

Tungland BC and Meyer D. 2002. Non digestible oligo-and polysaccharides (dietary fiber): Their physiology and role in human health and food. Comprehensive Reviews in Food Science and Food Safety. 1: 73–92.

Welty WM, Marshall RT and Grün IU. 2001. Effects of milk fat, cocoa butter, or selected fat replacers on flavor volatiles of chocolate ice cream. J Dairy Sci. 84(11): 21-30.

William G. Rothstein. 2006. Dietary fat, coronary heart disease and cancer: A historical review. Preventive Medicine. 43: 356–360.

Wilpart M. 1993. Dietary fiber-like action of inulin. Unpublished doctoral dissertation, L'Universite Blaise Pascal Clermont 11. France.

Wilson-Walker C. 1982. Sweetness control in yogurt flavor. Cult Dairy Prod. J. 17(1): 10-1.

Yackel WC and Cox C. 1992. Application of starch-based fat replacers. Food Technol. 46(6): 146-8.

Yackinous C and Guinard JS. 2000. Flavour manipulation can enhance the impression of fat in some foods. J Food Sci. 65(5): 909-14.

Yilsay TÖ, Yilmaz L and Bayizit AA. 2006. The effect of using a whey protein fat replacer on textural and sensory characteristics of low-fat vanilla ice cream. Eur Food Res Technol. 222(1/2): 171-5.

Zhang WM and Wang WL. 1999. Studies on non-sugar, low-fat, low-calorie and functional ice cream. China Dairy Ind. 27(5): 12-6.

APPENDIX

APPENDIX A

บริษัท เฮล์มมหาบุญ จำกัด
HELM MAHABOON LTD.
TST TOWER 12 TH FL.
21 VIPHAVADEE-RANGSIT RD.
CHOMPHON CHATTUCHAK
BANGKOK 10900
Tel 02-273-8140, 02-273-8061
Fax 0066-2-273-8137
Website www.[illegible].com

Product Data Sheet

Frutafit® HD

Description

Frutafit®HD is a native inulin / fructo-oligosaccharide (FOS). It is a *natural* powdered food ingredient based on chicory inulin with a high purity. Due to its physiological and technological characteristics, Frutafit®HD can be applied in a wide range of food products.

Inulin from chicory is a polydisperse mixture of linear fructose polymers with mostly a terminal glucose unit, coupled by means of β(2-1) bonds.

Specification

Physical aspects	
Dry matter content	95-99%
Composition on dry matter	
Inulin (DP2-DP60)	90-95%
Fibre (AOAC 997.08)	90-95%
Fructose, glucose, sucrose	5-10%
Average chain length	8-12 monomers
Ash	≤ 0.2%
Heavy metals	complies with legal requirements
Microbiology	
Aerobic plate count	≤ 2000 CFU/gram
Thermophilic plate count	≤ 2000 CFU/gram
Moulds	≤ 20 CFU/gram
Yeasts	≤ 20 CFU/gram
Bacillus cereus	≤100 CFU/gram
Enterobacteriaceae	absent in 1 gram
Staphylococcus aureus	absent in 1 gram
Salmonella	absent in 25 grams

Nutritional information

Average values per 100 grams Frutafit®HD:

- Carbohydrates:	
- digestible (fructose, glucose, sucrose)	7 grams
- non-digestible (dietary fibre, inulin)	90 grams
- Proteins	0 gram
- Fats	0 gram
- Cholesterol	absent
- Dietary fibres (AOAC 997.08)	90 grams
- Sodium	40 mg
- Calcium	11.5 mg
- Potassium	7.5 mg
- Iron	0.4 mg
- Other minerals	negligible
- Vitamins	negligible
- Gluten	absent
- Lactose	absent
- Folate	absent
- Insecticides, pesticides	absent
- Enzymatic activity	absent
- Colour, flavour, preservatives	absent
Calorific value	1,6 kcal/gram[1]
Glycaemic Index (GI) value	14[2]

[1] calculated value based on 1.5 kcal/gram pure inulin that has been established in scientific studies. Please check local legislation and adapt if necessary.
[2] The effect on the blood glucose level of 25 gram carbohydrate coming from Frutafit® HD is compared with the effect on blood glucose level of 25 gram glucose (control=100).

Additional product characteristics

- Appearance	fine white powder
- Dispersability	good
- Wettability	good
- pH	neutral
- Taste	neutral, slightly sweet
- Tapped density	550 ± 100 gram/litre

These data are indicative and only meant to provide additional information.

SENSUS

PO Box [illegible]
[illegible] Roosendaal
The Netherlands
[illegible]
[illegible]
www.sensus.nl
www.[illegible].nl

Other information

Packaging
20 kg, white multi layer paper bag with coloured PE inner liner

Labelling
In the ingredient list inulin/fructo-oligosaccharide can be declared as an ingredient, not an additive. The product can be labelled as inulin, fructo-oligosaccharide or polyfructose. In the US, Frutafit® inulin is officially recognised as GRAS.

Safety
GRAS status. FDA approved, notice no. GRN 000118

Storage
The product should be stored under dry conditions in the original unopened bag.

Shelf life
When stored in unopened bags under dry conditions, the product can be stored for at least 5 years after production date. Best before date is printed on each individual bag.

GMO
For the production of this product, Sensus only uses raw materials from conventionally cultivated chicory varieties. Therefore no labelling as a GMO derived ingredient is needed for application of this product according to the regulations EC (2001/18), EC (1829/2003), EC(1830/2003).

Allergens
Neither the raw material nor the process additives used in the production of this product contain the following allergens: gluten, components from milk, soy, nuts, fruit, eggs, meat or fish.

Kosher
Certified by circle K.

Halal
Certified by Halal Correct

Analyses
Fructans (inulin/fructo-oligosaccharides) in food products can be analysed by the following methods: AOAC 997.08 (AACC 32-31) and AOAC 999.03 (AACC 32-32).

OUR TECHNICAL SERVICE WILL SUPPORT YOU WITH THE NECESSARY INFORMATION REGARDING THE OPTIMAL PROCESS CONDITIONS AND MATERIAL FOR YOUR SPECIFIC APPLICATION! FEEL FREE TO CALL US: +31 165 582 578

December 2004

SENSUS

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APPENDIX B

Ice cream ingredients

Ingredients	Source
Heavy whipping cream (36% fat)	Friesland Foods Foremost, Thailand
Non-fat dry milk	Product of New Zealand
Sugar	Mitr Phol, Mitr Phol Sugat Co., Ltd., Thailand
Stabilizer as carboxy-methylcellulose (CMC)	Food grade
emulsifier as glycerol monostearate (GMS)	Food grade

APPENDIX C

Ice cream recipes (g/100g)

Formula	Whipping cream	Non-fat dry milk	Sugar	CMC	GMS	inulin	Water
Full-fat	34	10	11	0.15	0.2	-	44.65
Non+5	1.4	11.9	11	0.15	0.2	5	75.35
Non+7	1.4	11.9	11	0.15	0.2	7	73.35
Non+9	1.4	11.9	11	0.15	0.2	9	71.35
Low+5	8.4	11.5	11	0.15	0.2	5	63.75
Low+7	8.4	11.5	11	0.15	0.2	7	61.75
Low+9	8.4	11.5	11	0.15	0.2	9	59.75
Light+5	16.7	11	11	0.15	0.2	5	55.95
Light+7	16.7	11	11	0.15	0.2	7	53.95
Light+9	16.7	11	11	0.15	0.2	9	51.95
Reduced+5	25	10.6	11	0.15	0.2	5	48.05
Reduced+7	25	10.6	11	0.15	0.2	7	46.05
Reduced+9	25	10.6	11	0.15	0.2	9	44.05

APPENDIX D

แบบทดสอบทางประสาทสัมผัส

ชื่อ...อายุ.............................เพศ.......................

วันที่....................... ....เวลา...........................

ชื่อ ผลิตภัณฑ์ : ไอศกรีมนมดัดแปลงไขมัน ตัวอย่างที่.....................................

คำชี้แจง : กรุณาทดสอบตัวอย่างต่อไปนี้และให้ระดับความชอบต่อลักษณะต่างๆของผลิตภัณฑ์ โดยกากบาทในช่องที่ตรงกับความรู้สึกมากที่สุด และระหว่างการทดสอบแต่ละตัวอย่าง ให้ผู้ทำการทดสอบล้างปากด้วยน้ำโซดาก่อนทำการทดสอบตัวอย่างต่อไป

	ลักษณะโดยรวม (appearance)	กลิ่น-รส (Flavor) *	เนื้อสัมผัส (texture) **	ความชอบโดยรวม (overall acceptability)
ชอบมากที่สุด (like extremely)				
ชอบมาก (Like very much)				
ชอบปานกลาง (Like moderately)				
ชอบเล็กน้อย (Like slightly)				
เฉยๆ (Neither like nor dislike)				
ไม่ชอบเล็กน้อย(Dislike slightly)				
ไม่ชอบปานกลาง (Dislike moderately)				
ไม่ชอบมาก (Dislike very much)				
ไม่ชอบมากที่สุด (Dislike extremely)				

* กลิ่น-รส หมายถึง ความเปรี้ยว ความหวาน ความเค็ม ความขม ความมัน และ กลิ่น

** เนื้อสัมผัส หมายถึง ความมันลื่น ความเรียบเนียน การละลายในปาก ขนาดเกล็ดน้ำแข็ง

สี (Color)
.....................เข้มมากเกินไป
.....................เข้มเกินไป
.....................กำลังดี
.....................อ่อนเกินไป
.....................อ่อนมากเกินไป

กลิ่น (Odor)
.....................เข้มมากเกินไป
......................เข้มเกินไป
.... กำลังดี
.....................อ่อนเกินไป
.....................อ่อนมากเกินไป

ความหวาน (Sweetness)
....................หวานมากเกินไป
....................หวานเกินไป
.... กำลังดี
....................หวานน้อยไป
.....................หวานน้อยไปมาก

ความมัน (Creaminess)
.....................มันมากเกินไป
.....................มันเกินไป
.....................กำลังดี
.....................ไม่มัน
.....................ไม่มันมาก

ความเรียบเนียน (Smoothness)
......................เรียบเนียนมากเกินไป
.......................เรียบเนียนเกินไป
......................กำลังดี
.....................ไม่เรียบเนียน
......................ไม่เรียบเนียนมาก

ความแข็ง (Hardness)
.................แข็ง/แน่น มากเกินไป
.................แข็ง/แน่น เกินไป
..................กำลังดี
...................นิ่มเกินไป
...................นิ่มมากเกินไป

ข้อเสนอแนะ

....

....

APPENDIX E

Determination of nutritional value method (AOAC 2000)

1 Moisture by oven drying for 2 h at 135ºC (AOAC 930.15)

Procedure:

1. Dry aluminum dish with cover at 135º C ±2ºC for at least 2 h.
2. Cover dishes and move to desiccator.
3. Immediately cover desiccator and allow covered dishes to cool to room temperature. Do not allow dishes to remain in desiccator more than 2 to 3 h.
4. Weigh dishes with cover (W4) to nearest 0.1 mg, removing one at a time from desiccator and keeping desiccator closed between dish removals.
5. Add approximately 2 g sample to each dish. Record weight of dish with cover and sample (W5) to nearest 0.1 mg.
6. Shake dish gently to uniformly distribute the sample and expose the maximum area for drying.
7. Insert samples with lids removed to the side into preheated oven at 135ºC and dry for 2 h after oven has returned to temperature.
8. Move samples to desiccator, place cover on each dish, seal desiccator and allow to cool to room temperature. Do not allow samples to remain in desiccator for more than 2 to 3 h.
9. Weigh dish with cover and dried sample (W6), recording weight to nearest 0.1 mg.

Calculation: Percent total dry matter (total DM)

% Total DM = (W6-W4 / W5-W4) × 100

% Total moisture = 100 -% Total DM

2 **Protein by Kjeldhal method (AOAC 984.13)**

Procedure:

Digestion

1. Weigh approximately 1 g ground sample into digestion flask, recording weight (W) to nearest 0.1 mg. Include reagent blank and high purity lysine HCl as check of correctness of digestion parameters. Weigh a second subsample for laboratory dry matter determination.
2. Add 15 g potassium sulfate, 0.04 g anhydrous copper sulfate, 0.5 to 1.0 g alundum granules, or add 16.7 g K_2SO_4, 0.01 g anhydrous copper sulfate, 0.6 g TiO_2 and 0.3 g pumice. Then add 20 mL sulfuric acid. (Add additional 1.0 mL sulfuric acid for each 0.1 g fat or 0.2 g other organic matter if sample weight is greater than 1 g.)
3. Place flask on preheated burner (adjusted to bring 250 mL water at 25ºC to rolling boil in 5 min).
4. Heat until white fumes clear bulb of flask, swirl gently, and continue heating for 90 min for copper catalyst or 40 min for CuSO4/TiO2 mixed catalyst.
5. Cool, cautiously add 250 mL distilled water and cool to room temperature (less than 25ºC). Note: If bumping occurs during distillation, volume of water may be increased to ca. 275 mL.

Distillation

1. Prepare titration flask by adding appropriate volume (VHCl) accurately measured acid standard solution to amount of water so that condenser tip is immersed (try 15 mL acid and 70 mL water if undecided). For reagent blank, pipet 1 mL of acid and add approximately 85 mL water. Add 3 to 4 drops methyl red indicator solution.
2. Add 2 to 3 drops of tributyl citrate or other antifoam agent to digestion flask to reduce foaming.
3. Add another 0.5 to 1.0 g alundum granules.
4. Slowly down side of flask, add sufficient 45% sodium hydroxide solution (approximately 80 mL) to make mixture strongly alkali. (Do not mix until after flask is connected to distillation apparatus or ammonia will be lost.)

5. Immediately connect flask to distillation apparatus and distill at about 7.5 boil rate (temperature set to bring 250 mL water at 25ºC to boil in 7.5 min) until at least 150 mL distillate is collected in titrating flask.
6. Remove digestion flask and titrating flask from unit, rinsing the condenser tube with distilled water as the flask is being removed.

Titration

1. Titrate excess acid with standard sodium hydroxide solution to orange endpoint (color change from red to orange to yellow) and record volume to nearest 0.01 mL (VNaOH). Titrate the reagent blank (B) similarly.

Calculation: Percent Nitrogen (N)

$$\%N \text{ (DM basis)} = \frac{[(VHCl \times NHCl) - (VBK \times NNaOH) - (VNaOH \times NNaOH)]}{1.4007 \times W \times \text{Lab DM}/100}$$

- Where VNaOH = mL standard NaOH needed to titrate sample
- VHCl = mL standard HCl pipetted into titrating flask for sample
- NNaOH = Normality of NaOH
- NHCl = Normality of HCl
- VBK = mL standard NaOH needed to titrate 1 mL standard HCl minus B
- B = mL standard NaOH needed to titrate reagent blank carried through method and distilled into 1 mL standard HCl
- 1.4007 = milliequivalent weight of nitrogen x 100
- W = sample weight in grams

Calculation: Percent Crude Protein (CP)

CP (DM basis)= % N (DM basis) X F

- F = 6.25 for all forages and feeds except wheat grains
- F = 5.70 for wheat grains

3 Fat by acid digestion before continuous extracting using petroleum ether in Soxhlet system (Tecator, Sweden) (AOAC 920.85)

Procedure: Sample drying

1. Weigh 1.5 to 2 g of ground sample into a thimble recording the weight to nearest 0.1 mg (W1). Weigh a second subsample for dry matter determination.

   - Or -

1A) If the sample contains large amounts of carbohydrates, urea, glycerol, lactic acid or water-soluble components, weigh 2 g sample to nearest 0.1 mg (W1) into a small filter cone. Extract with five 20 mL portions of deionized water allowing each portion to drain, then insert the paper and sample into thimble.

2. Dry for 5 hr at 100ºC.
3. Dry beakers to be used for fat determination for at least 1 hr at 100ºC. Cool the appropriate number of fat beakers in a desiccator. Weigh and record the weight to the nearest 0.1 mg (W2).
4. When the drying period is over, remove the samples from the oven to a desiccator. (This is a convenient stopping point. The samples should be stored in a desiccator if not immediately extracted.)

Extraction

1. Line the fat beakers up in front of the extractor and match the thimbles with their corresponding fat beakers.
2. Slip the thimble into a thimble holder and clip the holder into position on the extractor.
3. Add about 40 mL of diethyl ether (one glass reclaiming tube full) to each fat beaker.
4. Wearing white gloves, slip the beaker into the ring clamp and tightly clamp the beaker onto the extractor. If the clamp is too loose, insert another gasket inside the ring.
5. Raise the heaters into position. Leave about a 1/4 inch gap between the beaker and the heating element.
6. Turn on the heater switch, the main power switch, and the condenser water.
7. After the ether has begun to boil, check for ether leakage. This can be detected by sniffing around the ring clamp. If there is leakage, check the tightness of the clamp and if necessary replace the gasket(s).
8. Extract for minimum of 4 h on a Hi setting (condensation rate of 5 to 6 drops per second), or for 16 h on a Low setting (condensation rate of 2 to 3 drops per sec).

9. After extraction, lower the heaters, shut off the power and water, and allow the ether to drain out of the thimbles (about 30 min). This is a good stopping point.

Ether Distillation and Weighing of Fat Residue

1. Remove the thimble from the holder, and rinse the holder with a small portion of diethyl ether from the washbottle. Clip an ether reclaiming tube in place and reattach the fat beaker.
2. Reposition the heaters and turn on the electricity and water. Proceed to distill the ether using a Hi setting. Watch Closely.
3. Distill until a thin layer of ether remains in the bottom of the beaker, and then lower the heater. Do not allow beakers to boil dry. Overheating will oxidize the fat. When the last beaker has finished, shut off the power and water.
4. Wipe the exterior of the beaker clean with a Kimwipe as it is being removed from the extractor.
5. Empty the reclaiming tubes into the "USED" diethyl ether container.
6. Place the tray of beakers in an operating hood to finish evaporating the ether. If there is no hurry, air moving through the hood will be sufficient without heat. A steambath may be used to speed up the evaporation. Beakers should remain in the hood until all traces of ether are gone. Carefully sniff each beaker to determine if any ether remains.
7. Place the beakers in a 102ºC gravity convection oven. Warning: If a beaker containing ether is placed in the oven an explosion may occur.
8. Dry for 1/2 h. No longer. Excessive drying may oxidize the fat and give high results.
9. Cool in a desiccator and weigh and record weight to the nearest 0.1 mg (W2).
10. The fat beakers are best cleaned by warming on a steambath or on a hot plate on a low setting. Add some used ether to dissolve the fat. The use of a rubber policeman is helpful. After soaking the beakers in Alconox detergent, wash them using hot water and vigorous brushing. The thimbles are best cleaned by blowing out with air.

Calculations: Percent Crude Fat (Ether Extract), DM basis

% Crude Fat (DM basis) = (W3 - W2) X 100 / W1 X Lab DM / 100

- W1 = initial sample weight in grams

- W2 = tare weight of beaker in grams
- W3 = weight of beaker and fat residue in grams

4. Ash by dry ashing method (AOAC 942.05)

Procedure:

1. Remove crucibles with cover which have been dried for at least 2 hr at 100ºC from oven, to desiccator. Cool, and record weight of crucibles with cover to the nearest 0.1 mg (W1).
2. Weigh 1.5 to 2.0 g of sample into the crucible, recording weight of crucible with cover and sample to the nearest 0.1 mg (W2).
3. Ash in furnace at 600ºC for 2 hr after the furnace reaches temperature.
4. Allow crucibles to cool in furnace to less than 200ºC and place crucibles with cover in desiccator with vented top. Cool and weigh crucible with cover and ash to the nearest 0.1 mg (W3).

Calculation: Percent Ash, DM basis

% ASH (DM basis) = (W3 - W1)X 100 / (W2 - W1) X Lab DM/100

- W1 = tare weight of crucible in grams
- W2 = weight of crucible and sample in grams
- W3 = weight of crucible and ash in grams

5. Carbohydrate by calculation

Using the follow equation

Carbohudrate = 100 **–** (percent of moisture content +protein +ash + crude fat)

6. Energy by calculation

Using the factor of 4, 4 and 9 for carbohydrate, pratein and fat, respectively.

APPENDIX F

Sensory properties of modified fat ice cream with 5% inulin addition and full-fat ice cream during 7 weeks of storage

F 1 Sensory properties (appearance, flavor, texture, and overall acceptability) of full-fat ice cream during 7 weeks of storage. [1, 2]

Storage	Appearance score[3]	Flavor score[3]	Texture score[3]	Overall acceptability score[3]
1st week	7.36±1.32 a	7.08±1.22 b	7.4±1.12 c	7.48±1.23 c
3rd week	7.24±1.42 a	6.32±1.72 ab	5.52±1.45 b	6.24±1.56 b
5th week	6.96±1.79 a	5.96±1.69 a	4.84±1.37 ab	5.36±1.44 a
7th week	6.72±1.67 a	5.76±1.51 a	4.68±1.22 a	5.24±1.33 a

1 Results are mean ± standard deviation (SD)
2 Means in the same column followed by a different letter (a-c) were significantly different (p<0.05)
3 Nine-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely)

F 2 Sensory properties (color, odor, sweetness, creaminess, smoothness, and hardness) of full-fat ice cream during 7 weeks of storage. [1, 2]

Storage	Color[3]	Odor[3]	Sweetness[3]	Creaminess[3]	Smoothness[3]	Hardness[3]
1st week	3.00±0.00 a	2.84±0.47 a	3.16±0.55 a	3.20±0.50 a	2.92±0.40 b	3.16±0.47 c
3rd week	3.04±0.20 a	3.12±0.52 a	3.16±0.55 a	2.96±0.73 a	2.04±0.73 a	3.04±0.61 bc
5th week	3.00±0.00 a	2.84±0.80 a	3.12±0.33 a	3.24±0.83 a	2.32±0.75 a	2.64±0.57 a
7th week	3.00±0.00 a	2.80±0.58 a	3.08±0.40 a	3.12±0.66 a	2.28±0.68 a	2.80±0.57 ab

1 Results are mean ± standard deviation (SD)
2 Means in the same column followed by a different letter (a-c) were significantly different (p<0.05)
3 Five-point just-about-right scale (5 corresponded to “much too strong”, 1 to “much too weak”, and 3 to “just-about-right”)

F 3 Sensory properties (appearance, flavor, texture, and overall acceptability) of non-fat formula ice cream with 5% inulin addition during 7 weeks of storage. [1, 2]

Storage	Appearance score[3]	Flavor score[3]	Texture score[3]	Overall acceptability score[3]
1st week	5.28±1.65 a	5.96±1.81 b	4.68±1.91 b	5.28±1.77 b
3rd week	5.08±1.98 a	4.84±1.43 a	3.68±1.77 ab	4.16±1.52 a
5th week	5.08±2.31 a	4.80±1.53 a	3.44±1.83 a	4.12±1.94 a
7th week	5.04±2.05 a	4.80±1.41 a	3.40±1.61 a	4.08±1.75 a

1 Results are mean ± standard deviation (SD)
2 Means in the same column followed by a different letter (a-b) were significantly different ($p<0.05$)
3 Nine-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely)

F 4 Sensory properties (color, odor, sweetness, creaminess, smoothness, and hardness) of non-fat formula ice cream with 5% inulin addition during 7 weeks of storage. [1, 2]

Storage	Color[3]	Odor[3]	Sweetness[3]	Creaminess[3]	Smoothness[3]	Hardness[3]
1st week	2.96±0.61 a	2.88±0.83 a	3.28±0.74 a	2.16±0.80 a	1.8±0.58 a	3.00±0.87 a
3rd week	3.16±0.62 a	2.92±0.76 a	3.00±0.57 a	2.04±0.79 a	1.64±0.64 a	3.80±0.87 b
5th week	3.08±0.64 a	3.04±0.67 a	3.12±0.66 a	2.52±1.23 a	1.56±1.12 a	3.44±0.96 ab
7th week	2.96±0.61 a	3.00±0.64 a	3.08±0.64 a	2.36±1.07 a	1.56±0.71 a	3.52±0.92 ab

1 Results are mean ± standard deviation (SD)
2 Means in the same column followed by a different letter (a-b) were significantly different ($p<0.05$)
3 Five-point just-about-right scale (5 corresponded to “much too strong”, 1 to “much too weak”, and 3 to “just-about-right”)

F 5 Sensory properties (appearance, flavor, texture, and overall acceptability) of low-fat formula ice cream with 5% inulin addition during 7 weeks of storage. [1, 2]

Storage	Appearance score[3]	Flavor score[3]	Texture score[3]	Overall acceptability score[3]
1st week	7.28±0.84 a	7.04±1.48 a	7.12±1.13 b	7.08±1.15 a
3rd week	7.32±1.34 a	7.28±1.74 a	6.72±1.93 ab	7.08±1.63 a
5th week	7.16±1.25 a	6.80±1.47 a	5.96±1.59 a	6.60±1.58 a
7th week	7.08±1.08 a	6.72±1.34 a	5.88±1.51 a	6.48±1.50 a

1 Results are mean ± standard deviation (SD)
2 Means in the same column followed by a different letter (a-b) were significantly different (p<0.05)
3 Nine-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely)

F 6 Sensory properties (color, odor, sweetness, creaminess, smoothness, and hardness) of low-fat formula ice cream with 5% inulin addition during 7 weeks of storage. [1, 2]

Storage	Color[3]	Odor[3]	Sweetness[3]	Creaminess[3]	Smoothness[3]	Hardness[3]
1st week	2.88±0.52 a	2.84±0.69 a	3.16±0.55 a	3.00±0.58 a	2.84±0.69 b	2.64±0.64 a
3rd week	2.88±0.33 a	3.00±0.41 a	3.08±0.28 a	2.96±0.45 a	2.48±0.51 ab	2.84±0.55 a
5th week	3.00±0.00 a	3.00±0.50 a	3.36±0.64 a	3.08±0.40 a	2.32±0.80 a	2.88±0.88 a
7th week	3.00±0.00 a	3.00±0.41 a	3.28±0.54 a	3.04±0.54 a	2.24±0.66 a	2.96±0.73 a

1 Results are mean ± standard deviation (SD)
2 Means in the same column followed by a different letter (a-b) were significantly different (p<0.05)
3 Five-point just-about-right scale (5 corresponded to “much too strong”, 1 to “much too weak”, and 3 to “just-about-right”)

F 7 Sensory properties (appearance, flavor, texture, and overall acceptability) of light formula ice cream with 5% inulin addition during 7 weeks of storage. [1, 2]

Storage	Appearance score[3]	Flavor score[3]	Texture score[3]	Overall acceptability score[3]
1st week	7.72±0.98 b	7.56±1.26 a	7.76±1.05 c	7.64±1.19 b
3rd week	6.64±2.18 a	7.04±1.27 a	6.48±1.66 b	6.40±1.80 a
5th week	6.56±2.24 a	6.72±1.99 a	5.32±1.41 a	6.08±1.63 a
7th week	6.44±1.98 a	6.64±1.78 a	5.20±1.22 a	5.92±1.47 a

1 Results are mean ± standard deviation (SD)
2 Means in the same column followed by a different letter (a-c) were significantly different ($p<0.05$)
3 Nine-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely)

F 8 Sensory properties (color, odor, sweetness, creaminess, smoothness, and hardness) of light formula ice cream with 5% inulin addition during 7 weeks of storage. [1, 2]

Storage	Color[3]	Odor[3]	Sweetness[3]	Creaminess[3]	Smoothness[3]	Hardness[3]
1st week	2.92±0.28 a	2.76±0.44 a	3.28±0.68 a	3.24±0.43 b	3.04±0.20 b	2.88±0.33 ab
3rd week	2.92±0.27 a	2.96±0.20 ab	3.12±0.33 a	3.04±0.45 ab	2.44±0.77 a	2.64±0.64 a
5th week	3.04±0.20 a	3.08±0.49 b	3.20±0.41 a	2.92±0.70 ab	2.20±0.82 a	2.92±0.76 ab
7th week	3.00±0.29 a	3.00±0.50 ab	3.12±0.33 a	2.80±0.64 a	2.12±0.66 a	3.04±0.54 b

1 Results are mean ± standard deviation (SD)
2 Means in the same column followed by a different letter (a-b) were significantly different ($p<0.05$)
3 Five-point just-about-right scale (5 corresponded to “much too strong”, 1 to “much too weak”, and 3 to “just-about-right”)

F 9 Sensory properties (appearance, flavor, texture, and overall acceptability) of reduced-fat formula ice cream with 5% inulin addition 7 weeks of storage. [1, 2]

Storage	Appearance score[3]	Flavor score[3]	Texture score[3]	Overall acceptability score[3]
1st week	7.32±1.03 a	7.00±1.35 a	7.20±1.44 b	7.44±1.39 b
3rd week	7.44±1.44 a	7.00±1.87 a	6.96±1.31 b	6.80±1.50 ab
5th week	7.00±1.58 a	7.04±1.31 a	5.76±1.61 a	6.12±1.66 a
7th week	6.88±1.54 a	7.08±1.15 a	5.68±1.46 a	6.04±1.48 a

1 Results are mean ± standard deviation (SD)
2 Means in the same column followed by a different letter (a-b) were significantly different (p<0.05)
3 Nine-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely)

F 10 Sensory properties (color, odor, sweetness, creaminess, smoothness, and hardness) of reduced-fat formula ice cream with 5% inulin addition during 7 weeks of storage. [1, 2]

Storage	Color[3]	Odor[3]	Sweetness[3]	Creaminess[3]	Smoothness[3]	Hardness[3]
1st week	3.04±0.20 a	2.92±0.57 a	3.64±0.57 b	3.24±0.60 a	2.92±0.49 b	2.92±0.49 ab
3rd week	3.08±0.28 a	3.04±0.45 a	3.12±0.66 a	3.16±0.47 a	2.36±0.49 a	2.96±0.20 b
5th week	3.16±0.37 a	2.92±0.49 a	3.32±0.48 a	3.04±0.54 a	2.60±0.64 ab	2.68±0.63 a
7th week	3.16±0.37 a	2.92±0.40 a	3.24±0.52 a	2.96±0.54 a	2.64±0.57 ab	2.84±0.37 ab

1 Results are mean ± standard deviation (SD)
2 Means in the same column followed by a different letter (a-b) were significantly different (p<0.05)
3 Five-point just-about-right scale (5 corresponded to “much too strong”, 1 to “much too weak”, and 3 to “just-about-right”

BIOGRAPHY

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