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UMI

Evaluation of the Texture and the Freezing and Melting Properties for Vanilla Ice Cream of Varied Fat Content

A Thesis
Submitted to the Faculty
of
Graduate Studies
The University of Manitoba
by
David B. Aime

In Partial Fulfillment of the Requirements for the Degree
of

Master of Science

Food Science Department
University of Manitoba
Winnipeg, Manitoba

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

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for Vanilla Ice Cream of Varied Fat Content

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A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University

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ABSTRACT

Modified starch was used as a fat replacer in light, low fat and fat free vanilla ice creams. The texture of ice creams were compared by trained panelists against regular fat ice cream. Samples having the same targeted composition prepared during separate process trials were observed during preparation to be different. From trial 1, all samples were determined to be similar for the attributes of coldness and firmness with differences found for viscosity, smoothness and mouth coating. From trial 2, all samples were similar for coldness and viscosity although differences were determined between samples for firmness, smoothness and mouth coating. Strong relationships (R^2>0.87) resulted between the attributes of smoothness and firmness and the level of fat in ice cream. Instrumental measurements showed the light ice cream of both trials to be the highest in viscosity and consistency whereas fat free ice creams showed the highest values for flow behavior. Only in trial 1 did the sensory results for viscosity, smoothness and mouth coating, relate strongly (R^2>0.90) to instrumental measurements for flow behavior and firmness. The regular fat ice cream mixes demonstrated the highest average steady-state continuous freezing temperature (-4.52°C) whereas all other samples showed similar temperatures. Differences in continuous freezing flow rates were noticed between all samples with fat free ice creams showing the slowest rates of 79.7 and 80.0 kg/hour for trials 1 and 2 respectively. Results from the analysis of ice cream hardening and melting were observed to be highly affected by the type of package and experimental conditions. Based on both sensory and instrumental results, it is clear that the presence of modified starch in light ice cream can mimic many of the properties of regular fat ice cream in terms of texture and freezing properties.

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1 INTRODUCTION

Commercial ice cream processors are currently developing new products which may carry the labels 'Reduced fat', 'Light', 'Low fat' and 'Fat free'. Movement towards such products has been a result of public concern over the increased risk of coronary heart disease attributed to total fat, saturated fat, and cholesterol levels in the diet. On Sept.16/94, FDA released the following definitions on new product lines (International Dairy Food Assoc., 1994): (1) Reduced Fat ice cream will be 25% or lower in fat, or contain a maximum of 7.5% milk fat, (2) Light ice cream will be 50% or lower in fat, or contain a maximum of 5% milk fat, (3) Low fat ice cream must contain not more than 3 grams of total fat per half cup serving and (4) Fat free ice cream must contain not more than 0.5 grams of total fat per half cup serving. Table 1.1 lists the relative proportions of these products and other frozen dairy products in the market. While regular fat ice cream is still the predominant product the reduced and fat free ice creams make up approximately 15% of this market.

Table 1.1 1997 gallon share of frozen dairy market by product type.

Product Type	Gallon Share (%)
Nonfat ice cream	4.2
Reduced, light & low fat ice cream	10.4
Regular fat ice cream	73.2
Frozen yogurt	7.5
Sherbet	3.5
Sorbet	0.6
other	0.6

Adapted from Markgraf, 1997

Overall, consumption of ice cream is on the rise as a global increase of 17% has occurred from 1993 to 1997 (Markgraf, 1997). Markgraf (1997), also stated that although the volume of United States ice cream exported to Canada increased 21% from 1995 to 1996, the overall dollar value remained low at 3.9 million.

Fat mimetic is a term used interchangeably with the terms protein-based fat replacer or carbohydrate-based fat replacer and has been defined by Akoh (1998) as "...substances that imitate organoleptic or physical properties of triglycerides but which can not replace fat on a one-to-one basis". Table 1.2 lists the three categories of fat replacers and their general functions. This current study is concerned with the functionality of a carbohydrate based fat replacer and the many types of carbohydrate-based fat mimetics available to food technologists are listed in Table 1.3.

Table 1.2: Functions of fat replacers in dairy products.

Type of Fat Replacer	General Functions
lipid based	- provide flavour, body, mouth feel, and texture - stabilize, increase overrun
carbohydrate based	- increase viscosity, thicken, aid gelling, stabilize
protein based	- stabilize, emulsify

Adapted from Akoh, 1998

Table 1.3: Types of carbohydrate-based fat mimetics.

Type	Examples/Descriptions
gums	- guar, xanthan, locust bean, carrageenan, gum arabic, and pectin
starches	- high amylose corn, waxy maize, wheat, potato, tapioca, rice, waxy rice and numerous modified versions
celluloses	- microcrystalline, powdered, and numerous chemically modified versions
maltodextrins	- corn, potato, oats, rice, wheat, and tapioca
polydextrose	- a randomly bonded polymer of glucose, sorbitol, and citric or phosphoric acid
Oatrim[1]	- partial enzymatic hydrolysis of the starchy hull or bran portions of whole oat and or corn flour with 5% β-glucan
Z-Trim[2]	- insoluble fibre from the high-cellulose portion of hulls from oats, soybeans, peas, rice, or bran from corn or wheat

Adapted from Akoh, 1998

1 Oatrim, developed and patented by the US. Dept. of Agriculture (USDA)
2 Z-Trim, developed by the USDA and is patent pending

In the North American diet, there is a trend towards increased consumption of reduced fat products and while this trend has resulted in a decline in fat intake, fat consumption remains above recommended levels (Frazao, 1996). As a result there has been and will continue to be a demand for reduced fat products. One area where this potential exists is the production of fat reduced ice cream.

Supermarket sales in the United States of reduced fat (≤ 7.5 % milk fat), light (≤ 5.0 milk fat) and low fat (≤3 gm for a 112 gm serving) ice cream increased by 8.2% from 1994 to 1995. Also, during the same time period sales of non-fat ice cream increased by 66.6% (International Dairy Food Assoc., 1996). In 1997 total ice cream sales in the United States increased by 7.5% with regular fat ice cream accounting for 67.8% of the increase (Markgraf, 1997). While there was a 9% increase in the sales of light ice cream in 1997, sales of both low fat and fat free have declined (Markgraf, 1997). It has been suggested that improvements in product formulations for lower fat ice creams are required to deliver the level of quality expected by consumers (Keehner, 1996). This is particularly true for ice cream products containing less than 3% milk fat.

The objectives of this project were to (1) develop light, low fat, and fat free vanilla ice cream products using a modified starch as the essential ingredient while applying commercial-like process conditions, (2) to develop a sensory testing protocol including a ballot to focus on the textural attributes of the developed ice cream products and (3) to evaluate the textural properties of these products using a trained sensory panel and thermo-physical measurements. The information from this research will contribute to our understanding of the structures and texture associated with vanilla ice cream when

a modified starch is used for fat replacement in products of reduced fat content.

2 LITERATURE REVIEW

2.1 Recent History of Ice Cream-Related Studies

One of the goals in modifying ice cream formulations is to produce a product with a desirable texture and the enhancement of texture will only occur through improvements in the product's physical structure (Stanley et al., 1996). The structure of ice cream has been identified as a three component foam made up of a network of fat globules and ice crystals dispersed in a high viscosity aqueous phase (Prentice, 1992; Dickinson, 1992). In specific, Prentice (1992), described the foam structure of ice cream as a highly concentrated syrup continuous phase consisting of a suspension of aggregates of damaged fat globules partially coated with plastic fat and ice crystals. Also in reference to ice cream structure, Goff et al (1995), stated that low fat products provide a special challenge to the creation of a stable foam.This challenge is related to the fact that the fat globule network would either be disrupted or absent and this could seriously impact the texture of the product. Overall, in order to meet this challenge, researchers must focus on the two structural components other than the fat globule network, ice crystals and the highly viscous aqueous phase.

Two ingredient factors which affect ice cream texture are stabilizers and emulsifiers. In work with full fat ice cream, it has been shown that stabilizers promote viscosity development in the aqueous phase (Jimenez-Flores et al., 1993) and affect ice

crystal growth (Stanley et al., 1996). Modified starches could have a similar effect on the viscous liquid phase and could thereby improve the texture of reduced fat ice creams.

Emulsifiers are added to ice cream to enhance whipping, improve resistance to meltdown, increase dryness and stiffness, and enhance product uniformity (Arbuckle, 1986; Goff and Jordan, 1989). These same functions as well as the ability to reduce ice crystal size have also been demonstrated for low fat products (Baer et al., 1997). While mono- and di- glycerides have often been used for this purpose the potential for the milk protein alone to serve this function has also been demonstrated (Segall and Goff, 1998).

Most of the literature on ice cream texture has focussed on ice cream with fat levels of 10% or higher (Wittinger and Smith, 1986; Goff et al., 1995a; Guinard et al., 1997). Investigations into ice creams with reduced fat content have been less frequent. In some instances, the fat level was reduced by simply working with milk or creams with a reduced level of fat (Stampanoni Keoferli et al., 1996; Baer et al., 1997). Some work has been done on the use of carbohydrate based fat replacers in the preparation of ice cream having reduced fat levels (Schmidt et al., 1993; Specter and Setser, 1994; Li et al., 1997). Ice milk products - ice cream having a minimum of 5% milk fat - have also been prepared using protein based fat replacers (Schmidt et al., 1993) and a recent study compared fat free ice creams prepared using various whey protein based fat replacers (Ohmes et al., 1998).

With respect to the carbohydrate based fat replacers, Li et al. (1997) demonstrated (Table 2.1) that the levels of fat in vanilla ice cream impacts important physical properties such as apparent viscosity and melting rate. Their findings indicated a

relationship between fat content and apparent viscosity. As fat content was decreased in formulations so did the apparent viscosity and a similar same relationship was noted between fat content and melting rate.

Table 2.1: Various physical and chemical properties for regular fat vanilla ice cream, and vanilla ice cream with lower fat levels containing Litesse®.

Fat Content (%)	Litesse®[1] Content (%)	Total Solids (%)	Apparent Viscosity (Pa s)	Melting Rate (%/min.)
9.65	0	39.50	0.074[a]	2.44[a]
5.63	4	39.42	0.046[b]	1.72[b]
2.35	2	33.92	0.023[c]	1.29[c]
0.53	4	33.88	0.020[d]	1.45[bc]

means within a column with no common superscript letter differ ($P < 0.05$)

Adapted from Li et al., 1997

1 Litesse®, a polydextrose fat substitute from Pfizer Inc., New York, NY.

Specter and Setser (1994), noticed a similar relationship between fat content and viscosity. Table 2.2 illustrates that as the levels of fat decreased so did the mix viscosities. However, the degree of decrease in viscosity appeared to be dependent on the type of carbohydrate-based fat replacer used.

Table 2.2: Mix viscosities and deformation forces for ice cream containing variable levels of milk fat and carbohydrate-based fat replacers.

Milk fat (%)	N-Oil® gel[1] (%)	Paselli SA2 gel[2] (%)	Mix viscosity[3] (centipoise)	Force of deformation[4] (kg)
12	0	0	66.7	30.7
8	4	0	51.2	34.6
4	8	0	45.8	49.3
0	12	0	38.8	88
8	0	4	58.2	33.3
4	0	8	52.7	51.6
3.6	0	12	45.5	34.1

Adapted from Specter and Setser (1994)

1 N-Oil®: a gel prepared from tapioca dextrin (National Starch, Bridgewater, NJ)
2 Paselli SA2: a gel prepared from potato maltodextrin (Avebe Inc., Hopelawn, NJ)
3 viscosity testing occurred at 4 +/- 1°C using a Brookfield viscometer
4 indentation testing occurred at between -15°C and -12°C using an Universal Instron Testing Machine with a plunger attachment

2.1.1 Continuous freezing

In addition to the crystallization of approximately 48% of the available water in the ice cream mix, continuous freezing also establishes the nuclei essential for continued crystal growth during the hardening and storage of ice cream (Brochu et al., 1985).The residence time of ice cream mix within continuous freezing barrels, and freezing rates, can vary from 0.4 to 2 minutes and from 5 to 27°C/minutes, respectively (Berger, 1990). The variation in the rate of crystallization that occurs during continuous freezing will be

affected by two main factors (1) the temperature difference between the freezing medium and the ice cream mix, and (2) the heat transfer characteristics of both the ice cream mix and the equipment used (Goff and Sahagian, 1996). After the continuous freezing process, only a portion of the total water in ice cream mix is frozen. Bradley (1984), generated equilibrium freezing curves to demonstrate that at a drawing temperature (4.2.2) of -5°C, approximately half of the water remains unfrozen but it has also been demonstrated that due to a large portion of undercooled water, ice cream is not at equilibrium (Caldwell et al., 1992).

2.1.2 Hardening

The hardening process is defined as the conditions necessary to lower the geometric centre product temperature of ice cream to a minimum of -18°C (Arbuckle, 1986). The hardening process must rapidly crystallize a portion of the unfrozen water and therefore reduce the slow growth of large ice crystals during frozen storage.

In Table 2.3, Arbuckle (1986) outlines the important factors that affect hardening time. It should be noted that the factors affecting hardening time will also affect ice crystal size and product storage stability. Two hardening systems used commercially include air blast freezing tunnels operating at temperatures of -35°C and air velocities of greater than 5 m/s, and automatic plate freezers (Everington, 1991).

Table 2.3: Factors affecting the hardening time for ice cream.

Factor
size and shape of container
air circulation
air temperature
section of hardening room
ice cream temperature at drawing
mix composition
percentage overrun

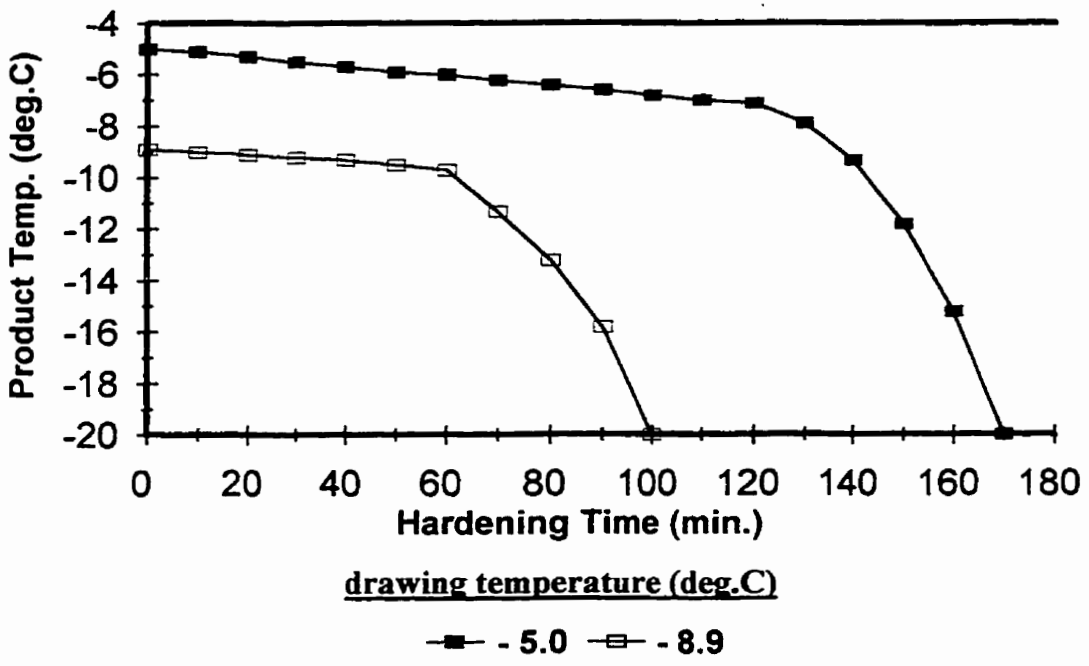
Adapted from Arbuckle (1986)

The ultimate ice crystal size is largely dependent on the size of ice crystals formed during continuous freezing as well as the time required for hardening (Everington, 1991). Ice crystal size in ice cream is kept to a minimum if only small crystals are formed during freezing and hardening time is short. Marshall and Arbuckle (1996), listed ice creams having an average ice crystal size of 56 μm, as being slightly coarse and ice creams with average ice crystals sizes of 39 μm and 32 μm, as being smooth and very smooth respectively. Thus, freezing processes which yield ice creams with average ice crystal sizes of 40 μm or smaller, should also yield ice creams smooth in texture.

By measuring the temperature of ice cream during hardening Everington (1991) demonstrated that the drawing temperature during ice cream production has a significant influence on the time and temperatures encountered during hardening (Figure 2.1). Ice

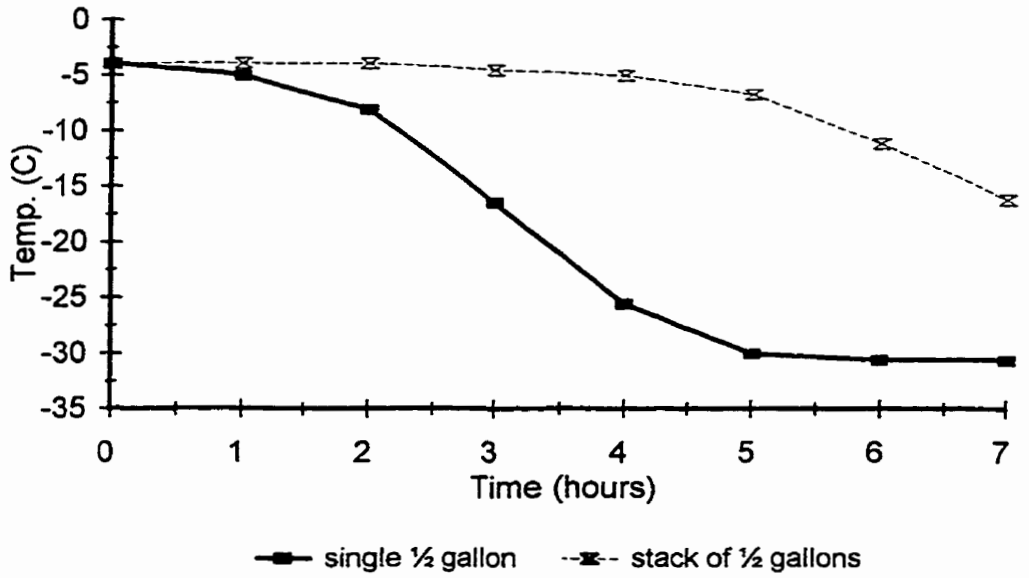
cream produced at a drawing temperature of -8.9°C reaches the final temperature much sooner than ice cream at a drawing temperature of -5°C and is at lower temperatures during the entire freezing process. As a result ice crystal size will be smaller in the ice cream with a -8.9°C drawing temperature.

Figure 2.1 Freezing time required for hardening regular fat ice cream packaged in 4 liter containers passed through a spiral air blast freezing tunnel. (Adapted from Everington, 1991)



This work clearly demonstrated the importance of drawing temperature in determining ice crystal size in regular fat ice cream. In fact, it has been reported that for every 1°C increase in drawing temperature the hardening time requirement will increase from 10 to 15% (Arbuckle, 1986). Arbuckle (1986) also stated that as fat content decreases hardening time will decrease slightly and as the level of overrun in ice cream increases, hardening time is expected to increase slightly.

Figure 2.2 Rate of convection hardening for ice cream packaged in half gallon containers in one commercial plant. (Adapted from Jimenez-Flores et al., 1993)



Hardening processes often vary in terms of the equipment and conditions used. Equipment choices can include continuous spiral air blast freezers or much larger bulk hardening chambers similar to the commercial scale hardening conditions cited by Jimenez-Flores et al. (1993). In commercial size bulk hardening rooms the stacking of ice cream is an important factor and Jimenez-Flores et al. (1993) illustrated the difference in hardening rates for single vs stacked ½ gallon containers of ice cream (Figure 2.2). Clearly, the conditions during both production and hardening of ice cream products must be examined if the impact of changes in formulations are to be evaluated.

3 SENSORY AND INSTRUMENTAL TEXTURE ANALYSIS

3.1 Introduction

The success of any new or modified product will depend on consumer acceptance. In terms of the acceptability of ice cream products the textural properties play a significant role (Arbuckle, 1986; Stanley et al., 1996). There is a wide range of methods for examining textural properties although the use of a sensory panel is perhaps the only way of determining the quality of ice cream texture and has been extensively used in the past (Stone et al., 1974; Moore and Shoemaker, 1981; Specter and Setser, 1994; Baer et al., 1997; Li et al., 1997). In the current investigation a sensory panel has been used to evaluate the textural properties of ice creams whose fat level has been reduced through the use of modified pea starch. In addition, instrumental measurements of the firmness of the hardened ice cream and viscosity of melted ice cream have been taken to support the sensory work.

3.2 Materials and Methods

3.2.1 Manufacture of Ice Cream

Ice cream mixes were blended using the ingredients and proportions listed in Table 3.1. For each vanilla ice cream sample, a 150 kg batch of ice cream mix was prepared. Two separate batches of each treatment sample ice cream mix were prepared as indicated by the codes listed in Table 3.2. Full fat cream (Rockwood Agri-Business, Stony Mountain, MB, Canada) was used for the regular fat ice cream. The average composition of the cream used was 41.75% fat and 48.14% total solids. A modified starch fat replacer (Nickel and Berger, 1997, US Patent 5,703,226) supplied by Woodstone Technologies (Winnipeg, MB, Canada), was used to replace part of the cream used for regular fat ice cream in the light, low fat, and fat free treatment samples.

Ingredients were added to a 500 L mixing tank for preparation of regular fat ice cream mix in the following order: water, cream, skim milk powder, corn syrup solids (CSS), granular sugar, and stabilizer-emulsifier (S/E). Ingredient addition for fat reduced ice cream mixes followed the same order, with one exception; the addition of modified starch occurred in the place of cream for fat free. For light and low fat ice cream mixes, only portions of the milk fat was removed through reductions in cream. Prior to commencement of this thesis research, approximately three months of pilot plant formulation trials were required to determine the levels of modified starch (Table 3.1) to use in the light, low fat and fat free ice creams.

Table 3.1 Formulations of vanilla[1] ice cream treatment samples for texture assessment.

Product	Fat (%)	Sugar (%)	CSS[2] (%)	S/E[3] (%)	Modified Starch[4] (%)	NFDM[5] (%)	T.S[6] (%)
Regular fat	10	14.75	7.72	0.3	0	11	38.98
Light	5	14.75	7.72	0.3	5.07	11	37.41
Low fat	2.53	14.75	7.72	0.3	5.19	11	34.94
Fat free	0.42	14.75	7.72	0.3	5.36	11	32.83

[1]Vanilla;Foremost Vanilla Blend #30 (David Michael & Co., Inc., Philadelphia, PA, U.S.)

[2]CSS;corn syrup solids, Dri-Sweet® 42 (HTG Inc., Keokuk, Iowa, U.S.).

[3]S/E;commercial stabilizer-emulsifier blend, Party Pride® (Safeway Stores Inc., Myrtle Point, Oregon, U.S.).
[4]Modified Starch; pea starch acetylated according to commercial standards (Woodstone Foods, Winnipeg, MB, Canada).
[5]NFDM;non-fat dried milk solids, low-heat skim milk powder (Beatrice Foods, St.Claude, MB, Canada).
[6]T.S;total solids content of product (the remaining content is water).

The modified starch used as the fat replacer was a chemically substituted and stabilized starch. With acetic anhydride used as the reagent, acetyl groups are randomly attached to the starch polymers, amylose and amylopectin. The starch was modified to a degree of substitution of 0.09 acetyl groups per glucose monomer. This chemical substitution restricts the reassociating of the starch polymers. In the absence of chemical substitution, the hydrated starch polymers would reassociate or re-crystallize resulting in the release of moisture. The release of hydration moisture would then be available to

contribute to texture defects during the storage of ice cream. Defects such as coarseness and chalkiness.

Table 3.2 Guideline for all product codes.

Product Code	Product Description
FFS1	Fat free, sensory process trial 1
FFS2	Fat free, sensory process trial 2
LFS1	Low Fat, sensory process trial 1
LFS2	Low Fat, sensory process trial 2
LS1	Light, sensory process trial 1
LS2	Light, sensory process trial 2
RFS1	Regular fat sensory process trial 1
RFS2	Regular fat sensory process trial 2

The skim milk powder and CSS were added to the water-cream liquid via a funnel positioned in-line between the mixing tank (500 L) and a centrifugal pump (Crepaco, Toronto, ON, Canada) operating at 1700 rpm. The centrifugal pump dispersed the powders into the liquid and cycled the liquid back into the mixing tank. During cycling of the mix, the mixing tank agitator operated continuously at medium speed. Prior to the in-line addition of skim milk powder, CSS, and sugar, approximately 12 kg of the water-cream liquid was collected from the mixing tank into a separate pail and used to hydrate the S/E.

For the addition of S/E to ice cream mix, modified conditions for S/E handling were used to improve the functionality of the type of S/E available. The S/E powder was dry blended with one quarter of the total sugar used in each mix. Dry blending granular sugar with stabilizers and emulsifiers is a common practice used by ice cream manufacturers. However, during this project the sugar-S/E dry blend was hydrated separately from the other ingredients by stirring into the 12 kg of water-cream liquid. This slurry was then heated to 82°C using a small steam kettle.

While the sugar-S/E slurry was heating, the other ingredients were blended. Once the sugar-S/E slurry had reached 82°C, it was immediately added to the mixing tank. The pump-cycling system was shut off and the mix temperature was increased to between 30°C and 32°C, while keeping the mix tank agitator at medium speed. These temperatures and agitation were maintained for 30 minutes. The mixing conditions of 30°C for 30 minutes were similar to the blending conditions suggested by Goff et al.(1994) and are commonly used in commercial processes.

After mixing, ice cream mix was transferred to a small holding tank and then pumped through a high temperature short time (HTST) processing system (APV, model HX, serial no. 696-885, Toronto, ON, Canada). Prior to homogenization, the mix passed through a regeneration section of the HTST system where mix temperature increased from between 30°C and 32°C, to an average temperature of 54.5°C. Homogenization pressures for all ice cream mixes were set at 17,237 kPa total pressure – 13,790 kPa lst stage and 3,447 kPa 2nd stage – using a 15 hp, three piston, Gaulin homogenizer (model

M3, serial no. 11694527, Gaulin Corp., Everett, Mass., U.S.). After homogenization, but prior to reaching the holding tubes, ice cream mix passed through the heating section where mix temperatures increased to 82°C. Immediately following the heating section, ice cream mix flowed through holding tubes having an estimated residence time of 28 seconds. Following the holding tubes, ice cream flowed through the cooling section of the heat exchanger and depending on the type of mix, mix temperatures decreased to between 18°C and 10°C.

Ice cream mix was collected in three 35 L stainless steel milk cans. The cans were placed into a walk-in cooler and held overnight at a temperature between 2°C and 4°C. Prior to continuous freezing, all ice cream mixes were flavoured with vanilla (David Michael & Co., Philadelphia, PA, U.S.) at 1.5 ml/kg mix. All ice cream mixes were frozen to a target overrun of 100% using a 1954 Star Vogt Instant continuous ice cream freezer (320 L/hr., serial no. 4460, APV Crepaco, Toronto, ON, Canada). Overrun is the term used to describe the volume increase for ice cream that occurs during continuous freezing. Air was incorporated into the mixes by the vacuum generated from the continuous freezer mix pump as opposed to the forced injection of compressed air which is common for more modern freezing equipment. The continuous freezer operating conditions of rotor speed and back pressure were held constant for all mixes. Rotor speed was set at 50% of maximum speed and back pressure was set at 10%. Air intake was targeted to produce 100% overrun. Ice cream was hardened and stored at temperatures of -28°C to -32°C. The bulk of semi-frozen ice cream leaving the continuous freezer was

packaged into 2 L cardboard boxes. Ice cream for sensory panels was filled into 175 g plastic containers. The 175 g containers were filled at approximately two-thirds of the way through the continuous freezing process for each batch. In other words, after approximately 125 Kg of ice cream was packaged into 2 L boxes and two 10 L plastic cylinders, the 175 g containers were filled. Prior to conducting sensory training sessions and formal panels, all samples were held in storage at an average temperature of -30°C for a minimum of four months.

3.2.2 Ballot Development, Panellist Training and Formal Panels

The ballot development involved numerous "expert" panels. The panels were conducted at the George Weston Ltd. Sensory and Food Research Centre, Department of Foods and Nutrition, University of Manitoba, Winnipeg, Manitoba. The experts were three individuals with extensive sensory experience as well as this researcher. It was necessary to establish agreement on both attribute interpretation and wording of definitions. The importance for consistency in sample presentation temperature, serving size, assessment technique, and attribute definition, was also evident.

A commercial regular fat vanilla ice cream of "economy" grade was selected as the reference sample for training sessions and formal panels. The approximate composition of commercial economy grade ice cream was cited by Marshall and Arbuckle (1996) to be 10% milk fat, 10-11% non-fat milk solids, 15% sweeteners, 0.30%

stabilizer-emulsifier and 35-37% total solids. With the attributes used for the ballot in consideration, the reference sample was selected on the basis of its textural properties and availability in the "dixie cup" (175 g) packaged form similar to that used for experimental samples. During the final meeting of the expert panel, positions for the reference sample on the line scale for each attribute were agreed upon. The ballot generated from the expert panels is presented in Figure 3.1 and contains instruction and definitions for five texture attributes positioned above 15 cm unstructured line scales.

For individuals with little or no experience in ice cream sensory testing to properly assess the texture of fat reduced ice cream products, extensive training is required. Panellists were selected from a University student population having no previous knowledge of the researchers project and willingness to participate. The panellists consisted of nine students, seven females and two males, all between the ages of 21 and 25.

Prior to conducting the four formal panels, a total of eight separate 30 minute training sessions were held over a time span of one month. Training sessions were conducted in a round table setting but during formal panels, judges evaluated samples within individual booths. The first meeting focussed on an overview of the ballot, spooning technique, and specifying the amount of ice cream to place in the spoon while testing samples. The next five sessions: (1) introduced a new attribute and definition; (2) discussed and practised the new attribute on the reference sample and also on two or three treatment samples; and (3) practised and reviewed the attributes learned during the

previous training sessions. The remaining two sessions involved practising use of a full ballot containing attributes for four treatment samples. Thus, prior to the formal panels each judge evaluated each treatment sample at least once.

To compare the performance of judges and the effectiveness of training in general, the mean values of judge responses for each attribute were plotted after the first six meetings. The plotting of responses indicated that judges experienced difficulty with the attributes of viscosity and mouth coating. However, a clear understanding and high level of agreement was noted for the following attributes in descending order: smoothness, firmness, and coldness. Prior to the two full ballot practice sessions, the attributes of viscosity and mouth coating were re-addressed through discussion with panellists. As a result, panellists achieved a clearer sense of understanding for viscosity and mouth coating and the definitions were re-worded.

As a result of discussion and debate among panellists, the following changes were made to the ballot and to the overall presentation in general: the final wording for the viscosity definition was agreed upon (Figure 3.1); in the attribute order, the viscosity attribute was moved ahead of smoothness; a warm-up sample at the beginning of the ballot was introduced; a five minute rest period after testing viscosity was deemed necessary, and a fresh reference sample after the 5 minute rest period was provided.

During formal panels, the five minute rest period commenced immediately after the judges had completed the first three attributes, coldness, firmness and viscosity. While leaving the judging room for the rest period panellists discarded the two reference

samples originally provided in the sample box. After the rest period, while re-entering the judging booths, each panellist selected one fresh reference sample from a separate sample box positioned adjacent to the judging room door. Red lamps within the individual booths were not used because it was noted that the heat generated from them, softened the samples during the evaluations.

To control temperatures, ten sample boxes were constructed using 4 cm (1.5") inter-locking Styrofoam SM (Dow Corning Corp., Midland, MI, U. S.), freeze-thaw stable glue and exterior duct tape for reinforcement. Each box measured 14.3 cm (5 5/8") in depth, 23.2 cm (9 1/8") in width and 27.6 cm (10 7/8") in length. Box lids were properly fitted and the boxes were lined with industrial strength plastic to eliminate the permeation of ambient air into the boxes.The purpose of the sample boxes was to stabilize sample temperatures during transportation to the sensory testing laboratory and to reduce the warming of samples during testing. Between 8:30 am and 9:30 am of each testing day, the sample boxes were loaded with crushed ice and the appropriate samples for judging. The temperature of samples at the time of loading the boxes was -28°C, and prior to the time of judging at 11:30 am, sample temperatures had risen to between -20°C and -18°C. At the completion of judging, sample temperatures had risen further to between -13°C and -11°C.

Figure 3.1 Ballot for ice cream texture.

Name _____

Date _____

For each attribute, take a level teaspoon of ice cream from the center of the sample cup. If necessary, level the ice cream off using the side of the container to ensure that a consistent amount of sample is taken. Place a vertical line across the horizontal line at the point that best describes the intensity of each attribute. Write the code number above your mark. Rinse your mouth with water before evaluating each attribute. A reference sample is provided for each attribute. Evaluate the reference sample prior to judging the coded samples. Judge all coded samples in relation to the reference sample. Prior to starting, perform a warm up sample using the reference.

1. INTENSITY OF COLDNESS:

Place sample in the mouth and manipulate in your mouth. Judge coldness as the cooling effect which precedes meltdown of the sample. Extreme coldness occurs when a very sharp cooling effect is detected during manipulation of the sample. Slight coldness reflects a low degree of cooling.

slight coldness — extreme coldness

2. FIRMNESS:

Place sample in the mouth and press against the upper palate. Judge firmness as the amount of force required by your tongue to flatten the ice cream. Ice cream that is soft provides very little resistance to flattening whereas firm ice cream requires considerable force to flatten.

soft — firm

3. VISCOSITY:

Place ½ teaspoon of sample in the mouth. Gently manipulate the sample by slowly rotating the sample between the tongue and palate. During the melting process and immediately after the sample has liquified, assess the ease of movement within the mouth. High viscosity means the sample does not move easily within the mouth and may feel sticky on the palate offering resistance to movement. Low viscosity means that the sample offers very little resistance to movement, and may be perceived as watery immediately after the sample has liquified.

low viscosity — high viscosity

4. DEGREE OF SMOOTHNESS:

Spread the sample onto the upper palate with the tongue and assess the degree of smoothness. Ice cream that is not smooth is perceived as a coarse or rough texture. A high degree of smoothness means the sample has a smooth and uniform spread onto the palate and no coarse or rough texture is detectable.

not smooth — high degree

5. MOUTH COATING:

Eat a piece of cracker and rinse with water to remove any residual coating within the mouth. Place sample in the mouth, gently manipulate the sample in a circular motion between the tongue and palate. Judge the intensity of mouthcoating as the amount of film remaining in your mouth after swallowing.

low mouth coating — high mouth coating

Arbuckle (1986), indicated that ice cream temperatures ideal for sensory evaluation are between -13°C and -16°C. Specter and Setser (1994), presented their samples to panellists at -12 +/- 1°C. Thus, satisfactory control over sample warming and sample presentation temperatures were achieved during this study. Eight samples, 2 each of regular fat, light, low fat, fat free and reference samples, were presented to the panellists for evaluation. The tested composition of samples are listed in Table 3.3. Samples were coded with 3 digit random numbers. The serving order of samples presented to panellists was completely randomized and balanced following the procedure provided by Watts et al., (1989).

Table 3.3 Tested composition of treatment samples used for sensory panels.

Treatment Sample	Milk fat[1] (%)	Protein[2] (%)	Overrun[3] (%)	TS[4] (%)
FFS1	0.5	3.81	100	32.8
FFS2	0.45	3.82	75	32.5
LFS1	2.4	3.34	100	33.5
LFS2	2.4	3.42	95	34.53
LS1	5.2	3.64	105	37.1
LS2	4.8	3.6	105	36.7
RFS1	9.4	3.42	110	38.5
RFS2	9.4	3.51	95	38.6

[1]Milk fat;standard Babcock test for ice cream for all samples except FFS1 and FFS2 where the Babcock test for skim milk was used.

[2]Protein;standard Kjeldahl procedure, 6.38 for conversion factor.

[3]Overrun;Overrun = [((volume of product - volume of mix)/(volume of mix)) * 100].

[4]TS;total solids.

3.2.3 Physical Measurements - viscosity

For the measurement of apparent viscosity, a Bohlin VOR Rheometer System (Lund, Sweden) was used and the Bohlin VOR software version 2.5 was used to determine consistency coefficients, and flow behaviour indices. The Bohlin VOR instrument consisted of a cup and bob (concentric cylinders) attached to a temperature controlling unit. The internal diameter of the cup was 27.5 mm. The bob height was 37.5 mm and the bob diameter was 25.0 mm, thus, when the bob was lowered into the cylinder containing ice cream, a 1.25 mm annular gap remained within which samples were stressed over a broad range of shear rates.

Rheological measurements for all samples consisted of ten readings taken over a shear rate sweep between 18.61 s^{-1} and 232.2 s^{-1}. In addition to using the data from this sweep to fit a power law relationship between shear rate and shear stress, values obtained at a shear rate of 29.3 s^{-1} were compared. In the power law model, $\sigma = K^{n-1} \cdot \gamma$, where σ = shear stress (millipascals), K = consistency coefficient index (millipascal·seconds $^{n-1}$), n = flow behaviour index and γ = shear rate (per second). The shear rate of 29.3 s^{-1} was chosen for comparison as it was as close to the shear rate within the oral cavity while eating fatty foods similar to ice cream. Dickie and Kokini (1983), have estimated oral cavity shear rates on fatty dairy foods similar to ice cream to be 11.5 s^{-1} or less. The two shear rate readings lower than 29.3 s^{-1} of 18.6 s^{-1} and 23.3 s^{-1} were not used for apparent viscosity comparisons because during a few sample tests the desired consistent relationship between shear rate and shear stress was not established until 29.3 s^{-1} due to

background noise. The rheometer torque was set at 18.8 g•cm for all measurements.

Four samples from each of the treatment sample codes listed in Table 3.3 were tested and each sample represented one 175 g container of ice cream. Samples for rheology testing were removed from frozen storage at -28°C and transferred to a warmer freezer set at -18°C on the afternoon prior to the day of testing. The following morning, the samples were transferred from the -18°C freezer to a 4°C cooler and held for four hours prior to conducting the rheology tests. The step-wise tempering routine was necessary to ensure gradual sample warming and to retain as much of the original frozen foam structure as possible. Samples were then loaded into the concentric cylinders of the rheometer. The amount of sample loaded varied within a range of 8.5 g to 15 g. The variation depended on the original overrun of the sample. The temperature of ice cream upon loading samples for testing ranged from between -3°C and -6°C. A constant temperature of 30°C was maintained by the rheometer for all apparent viscosity, flow behaviour index and consistency coefficient measurements. The testing temperature of 30°C was selected to approximate oral cavity temperatures and therefore validate the sensory-physical measurement comparison. The loaded sample was allowed to equilibrate to this temperature prior to the shear rate sweep.

3.2.4 Physical Measurements - firmness

For measuring firmness, the TA-TX2i Texture Analyser (Texture Technologies Corp., Scarsdale, New York, U.S.) was used. For each sample a total of eight measurements for firmness were performed; four measurements using a cylindrical probe/plunger attachment, and four measurements using a knife attachment specifically designed for testing ice cream. All measured data were analysed using the Texture Expert software program which accompanied the instrument. The cylindrical probe was made of acrylic material and measured 25 mm in diameter and 35 mm in height. The probe dimensions were similar to the probe dimensions cited in the materials and methods of Guinard et al. (1997). The knife dimensions were 3 mm blunt end width, 50 mm blunt end length and 83 mm in height. The knife edges were flat and square. The firmness tests were performed on ice cream packaged in two litre cardboard boxes. One, 2 L box was used for each measurement. Also, in accordance with the methods of Guinard et al. (1997), the speed of penetration for the machine attachment into the ice cream, was set at 2 mm/second.

Sample preparation for each firmness test followed a strict routine. The afternoon of the day prior to testing, eight boxes of the appropriate treatment sample code were transferred from the storage room temperature of -28°C to a smaller freezer and held overnight at -18°C. The following morning a hacksaw was used to cut, evenly, 2.5 cm (1.0") off the top of a 2 L box of ice cream. This was necessary because a flat surface was required for the test and uneven surfaces occurred during the filling of ice cream into the

boxes. After cutting, the samples were returned to the tempering freezer and held 10 minutes and then placed into a larger sample holding box (one of the sensory panellist sample boxes described earlier) which was packed with crushed ice to surround the sample. In addition to the prevention of sample warming, the packing of crushed ice maintained the sample in a rigid position within the holding box. The solid positioning of the treatment sample, within the holding box, is believed to be important because of the considerable force imparted to the sample during measurements. Rigid sample positioning was especially important for tests involving the probe attachment as opposed to the knife attachment. For probe tests, greater forces were exerted onto the samples due to the contact area and diameter of the probe. Thus, the potential dissipation of force to the sample carton exterior, was greater. Once assembled, the sample and holding box were transferred to the texture analyser. Immediately prior to starting a test, the centre and surface ice cream temperatures were recorded using two hand-held digital temperature probes. For each test, the indenter was positioned immediately above the geometric centre of the sample. The penetration distances into the ice cream for the cylindrical probe and knife attachments were 30 mm and 75 mm respectively.

3.3 Data Analysis

A complete randomized block design was used for the sensory panel experiments. Analysis of variance (ANOVA) tables were generated using a spreadsheet program and by following the methods outlined by Watts et al. (1989). The Spearman's rank order correlation analysis was also generated using a spreadsheet program and followed the criteria outlined by Ott (1988). The Spearman's test was used to determine if there were relationships between the different levels of fat and the perceived sensory attributes. The Duncan's New Multiple Range Test was used as the multiple comparison test for determining statistical significance among treatment means. The ANOVA tables and multiple comparison test values generated using a spreadsheet program, were verified using SAS software (SAS Institute, Inc., 1991). For the rheological data, the Bohlin VOR software was used to apply the power law model to determine consistency coefficients and flow behaviour indices of all treatment samples. Data generated from the instrumental rheology and firmness measurements were analysed for statistical significance using the Number Crunching Statistical Analysis software system (J. L. Hintze Co., Kaysville, Utah, 1987).

3.4 Results and Discussion

3.4.1 Ballot Development and Panellist Training

Although panellists can be trained to minimize variations in responses, they must still be considered as a source of error. When measuring attributes such as firmness, coldness, and iciness, ice cream temperature has been shown to contribute even more error than the panellist effect (King and Arents, 1994). In work using audio-intensity for profiling the sensory texture of ice cream, King and Arents (1994), concluded that the use of prepacked portions, controlled warming of the samples and careful choice of order for the attribute evaluation can minimize the error associated with temperature and carry over effects. In this study, these issues were addressed in the sample handling and the ballot development.

Previous studies have used a variety of sensory methods to descriptively analyse ice cream. Stampanoni-Koeferli et al. (1996) used a Quantitative Texture Profiling method which was a modified version of the Quantitative Descriptive Analysis technique originally used by Stone et al. (1974). Li et al. (1997) applied time-intensity and nine-point scale free choice profiling methods. Baer et al (1997) also used a nine-point scale, although unlike the methods of Li et al. (1997), judges were not given the freedom to select their own terms to be used on the scale. Specter and Setser (1994) used a 15.2 cm (6") line scale divided into 2.5 mm units whereas Moore and Shoemaker (1981) used a 10.5 cm unstructured line scale and Guinard et al. (1997) a 16.5 cm unstructured line scale with anchors positioned 2 cm from each end of the line. As the unstructured line

scales were shown to be effective, in this study, a 15 cm unstructured line scale was chosen.

The order and timing of attribute evaluation was determined by input from both the expert panel and during the training sessions for the formal panel. Panellists felt that by using the order established (coldness, firmness, viscosity – break – smoothness, and then mouth coating; Figure 3.1), their ability to evaluate these attributes was optimized and the carry over between samples kept to a minimum.

In this study, an ice cream sample was used as the reference sample for the formal panel rather than non-ice cream reference samples as was done by Stampanoni-Koeferli et al. (1996). While the non-ice cream references, which included Philadelphia Double Cream Cheese for mouth coating and ice cubes for coldness, can truly reflect the attribute in question, it was felt that it was unlikely that any of the prepared samples would approach the texture intensities of these references. The ballot developed as a result of the expert panel and training sessions is given in Figure 3.1. The ability of the panellist to effectively use this ballot is evident from the fact that there were no significant effects attributable to the panellist, replication, or interaction between panellist and replication.

3.4.2 Coldness

As there were significant trial effects and interactions between trials and other parameters the data from the two process trials were analysed separately (Appendix 5). In other words, the lettering for statistical significance, listed in Tables 3.4 and 3.5, is based only on the ANOVA and treatment means from within one process trial. The modified starch used for FFS2, although originating from the same source, was from a different batch and appeared to alter the physical properties of the ice cream.

Table 3.4 Sensory mean values[1] of textural attributes of vanilla ice cream prepared during process trial 1.

% Fat and treatment code	Textural Attributes				
	Coldness	Firmness	Viscosity	Smoothness	Mouth Coating
9.40 (RFS1)	7.3 a	8.1 a	9.3 a	9.9 a	8.3 ab
5.20 (LS1)	7.4 a	10.1 a	9.6 a	9.0 a	9.2 a
2.40 (LFS1)	9.3 a	9.8 a	7.1 b	5.5 b	6.7 b
0.50 (FFS1)	8.4 a	9.8 a	6.9 b	5.5 b	6.3 b

[1]mean of x panellists and two test sessions

ab values within a column with no different letter are significantly different ($p < 0.01$).

Table 3.5 Sensory mean values[1] of textural attributes of vanilla ice cream prepared during process trial 2.

% Fat and treatment code	Textural Attributes				
	Coldness	Firmness	Viscosity	Smoothness	Mouth Coating
9.40 (RFS2)	7.2 a	8.4 a	9.4 a	9.8 a	9.0 a
4.80 (LS2)	8.3 a	9.3 ab	9.3 a	7.8 b	8.3 ab
2.40 (LFS2)	8.2 a	11.5 b	6.7 a	7.4 b	6.2 c
0.45 (FFS2)	8.1 a	11.8 b	7.9 a	7.2 b	7.0 bc

[1]mean of x panellists and two test sessions

ab values within a column with no different letter are significantly different ($p < 0.01$).

Overall, FFS1 and FFS2 were observed as being different in both the unfrozen and frozen states with FFS1 having the properties desired by the experimenter. Since the modified starch was the critical ingredient for all treatment samples of less than regular fat content, considerable experimental error was introduced if the critical ingredient used in one of the treatment samples was significantly different from the other treatment samples.

As melting occurs within the mouth, larger ice particles are momentarily left behind creating the distinct sensation of coldness (Bodyfelt et al., 1988). Bodyfelt et al. (1988) also suggested that the higher the level of fat in the ice cream the lower the perceived intensity of coldness. This is based on the assumption that as the fat level in the ice cream decreases the water content increases such that more water is available to form larger ice particles (Bodyfelt et al., 1988). As a result, the sensation of coldness is

expected to intensify as the fat levels, and consequently the solid levels, in ice cream are decreased. However, results from both trials in this study (Tables 3.4 and 3.5) indicate no significant difference between samples for coldness and no relationship between coldness and fat level (Table 3.6). The results are similar to those of Specter and Setser (1994) who used two sources of modified starch (tapioca dextrin and potato maltodextrin) as ingredients for fat replacement in ice creams of 0-12% milk fat.

Table 3.6: Correlation (R^2) values[1] for the relationship between levels of fat and the intensity of textural attributes from samples prepared during process trials 1 and 2.

Attribute	R^2 values	
	Process Trial 1	Process Trial 2
coldness	0.554	0.643
firmness	0.616	0.899
viscosity	0.754	0.519
smoothness	0.87	0.928
mouth coating	0.546	0.729

[1]correlation values; determined using linear regression analysis on the treatment means from four formal sensory panels.

In contrast, the work of Stampanoni-Koeferli et al. (1996) using reduced fat milk products, demonstrated that decreasing coldness perception accompanied increasing levels of fat as theorized by Bodyfelt et al. (1988). The reported decrease in coldness perception was accompanied by an increase in mouth coating and decreases in ice crystal perception and melting rate. These results were supported by the earlier work of Donhowe et al. (1990), who stated that the presence of fat favoured the growth of small ice crystals over large ones and Kokuba (1993) who indicated that the melting rate would be lower if there is more free fat coalesced during the freezing process.

In addition to their findings for the effects of fat content on coldness, Stampanoni- Koeferli et al. (1996), demonstrated that increased levels of non-fat milk solids (NFMS) lowered the perception of coldness in ice cream of less than regular fat. Increasing NFMS levels beyond typical levels, however, is not recommended as this could affect ice cream flavour. A similar scenario was noted by Ohmes et al. (1998) as they reported that the use of 4.8% of a whey protein based fat replacer in fat free vanilla will intensify the flavour of whey, syrup and cooked milk.

The use of modified starch as a component in fat replacers clearly has the potential to overcome the increased perception of coldness that accompanies many low fat ice cream products. The inability of panellists to detect differences in coldness between the regular fat and fat reduced ice creams with the modified starch fat replacer used in this study supports the earlier work of Specter and Setser (1994). This effect of modified starch is, in part, due to the fact that the total solids in the ice cream mix would

be increased in the same way as Stampanoni-Koeferli et al. (1996) reported for the addition of NFMS. A bland modified starch could impair the formation of large ice crystals without adversely affecting the flavour of the product. In addition, the presence of starch could reduce the perception of coldness in the mouth.

3.4.3 Firmness - Sensory

For process trial 1, no significant differences were detected between samples (Table 3.4). However, for process trial 2 (Table 3.5) the RFS2 samples were judged to be significantly different from all samples except LS2. In fact for the second trial, there was a strong relationship ($R^2 = 0.899$) between fat level and firmness (Table 3.6), such that samples containing higher levels of fat tended to be less firm as has been reported previously (Bodyfelt et al., 1988). The lower correlation value ($R^2 = 0.616$) for trial 1 indicated that the relationship between fat content and firmness was weaker in comparison to trial 2 (Table 3.6).

Samples for which fat and total solids have been reduced, such as LFS1 and FFS1, have been reported to be firmer in comparison to samples of higher fat and total solids due to the higher levels of ice and hence the lower levels of crystallized milk fat, a softer component than ice. Evidently, the fat replacement used in LFS1 and FFS1 was effective in mimicking the sensorial firmness of samples of higher fat content, while the modified starch used for FFS2 did not provide the same effective fat replacement noted in LFS1 and FFS1.

When the inclusion of modified starch results in undesirable ice cream firmness, as was the case for the FFS2 sample, the behaviour of the individual starch polymers is most likely responsible. Unlike an effective fat replacer where modified amylose and amylopectin chains interact with water/ice and other polymer constituents in a dispersed and homogeneous way, it is probable that the starch polymers in the firmer products are interacting with each other, producing gelled particles which would be responsible for the higher firmness intensities during sensory testing. During the melting that occurs within the mouth during a sensory test for firmness, the gelled particles of modified starch would increase the resistance of the samples to deformation by the tongue. Ideally, if the modified amylose and amylopectin chains are able to align at the air cell, milk fat and ice crystal interfaces, the force required by the tongue to flatten the ice cream sample will be reduced. It would appear that the modified starch used in trial 1 was able to perform this function and thereby produce ice cream products whose sensory firmness was not significantly different from that of regular fat ice cream.

3.4.4 Firmness - Instrumental

The firmness of ice cream is related to its structure. The air cells of ice cream structure are essentially spherical although there is some distortion due to fat and ice crystal formation (Prentice, 1992). The material surrounding these air cells is a non-Newtonian fluid containing, primarily, clumps of fat (up to 80%) and small ice crystals. In fat reduced ice cream products, it is clear that the rheology of the composite fluid

surrounding the air cells will be altered due to the reduction in the fat clumps which predominate the composite fluid of conventional ice cream structure. The instrumental analysis of ice cream firmness and apparent viscosity should provide some insight into the foam structure of fat reduced ice cream products.

As was the case with sensory firmness, the results for the two trials for instrumentally determined firmness using a plunger were quite different (Tables 3.7 and 3.8). There were no differences in firmness values for the FFS1, LS1 and RFS1 for trial 1; the LFS1 value, however, was higher (Table 3.7). For trial 2, the value for FFS2 was approximately 3 times higher than the RFS2 and LS2 ice creams (Table 3.8).

Specter and Setser (1994) also conducted physical tests for softness using a plunger attachment on an Instron Universal Testing Machine (IUTM). While the magnitude of the forces measured was higher than in the current study, the sample which contained 0% milk fat and 12% modified starch gel (N-Oil®) for fat replacement differed significantly from the control sample of 12% milk fat, with indentation forces of 862.4 and 300.8 Newton (N) respectively. Like the FFS2 sample, this represents approximately a 3 fold increase in firmness. Samples of intermediate fat levels had firmness values comparable to the regular fat ice cream.

Table 3.7: Mean values[1] for instrumental measurement of firmness[2] and tackiness[3] on ice cream prepared during process trial 1.

Treatment Code	Probe/Plunger Attachment		Knife Attachment	
	Firmness[2] (N)	Tackiness[3] (N)	Firmness[4] (N)	Tackiness[5] (N)
FFS1	92.48 a	-16.59 b	57.72 a	-14.20 b
LFS1	157.63 b	-21.02 a	67.38 ab	-13.51 b
LS1	101.37 a	-16.47 b	83.18 b	-16.77 ab
RFS1	102.46 a	-14.59 b	96.21 c	-19.07 a

values within a column with no common letter, significantly differ ($p < 0.05$).

[1]mean values were determined from 4 assessments for each attachment.

[2]firmness;firmness values represent the peak force values for each deformation.

[3]tackiness;tackiness values represent the peak negative force values upon withdrawal of the attachment after deformation.

[4]standard error = 8.88

[5]standard error = 7.98

[6]standard error = 1.05

[7]standard error = 3.58

Previous work with ice creams made from modified starch were performed using small batch freezing equipment with overruns of only 45% (N-Oil®; Specter and Setser, 1994) and 75% (N-Lite™; Schmidt et al., 1993). The higher overruns obtained in this study (≥95% for all samples except FFS2; Table 3.3) are more representative of commercial ice cream production and therefore provide a more representative material for sensory analysis.

Table 3.8: Mean values[1] for instrumental measurement of firmness[2] and tackiness[3] on ice cream prepared during process trial 2.

Treatment Code	Probe/Plunger Attachment		Knife Attachment	
	Firmness[1] (N)	Tackiness[2] (N)	Firmness[3] (N)	Tackiness[4] (N)
FFS2	322.05 c	-50.98 a	284.22 b	-33.70 a
LFS2	122.75 b	-19.53 b	88.75 c	-15.81 b
LS2	57.06 a	-12.05 b	40.68 a	-11.86 c
RFS2	75.53 a	-12.74 b	73.27 a	-15.36 b

values within a column with no common letter, significantly differ ($p < 0.05$).

[1]mean values were determined from 4 assessments for each attachment.

[2]firmness;firmness values represent the peak force values for each deformation.

[3]tackiness;tackiness values represent the peak negative force values upon withdrawal of the attachment after deformation.

[4]standard error = 6.64

[5]standard error = 4.84

[6]standard error = 1.22

[7]standard error = 0.58

Guinard et al. (1997) also performed indentation tests on ice cream samples of varying solids and milk fat contents but the fat level ranged from 8.73% (32.49% total solids) to 19.3% (53.16% total solids). As was the case in the current study, the instrument used for their texture evaluations was the TA TX2 Texture Analyser. Their results showed the force of deformation for their low fat- low solids sample to be more than five times the force measured from their high fat - high solids sample. This demonstrated the contribution that the presence of ice crystals can make to the detection of firmness. The five fold increase in the force values observed between the low fat and

high fat samples of Guinard et al. (1997), was greater than the differences in force values observed between the fat reduced samples of this study. This supports the observation that the presence of modified starch can control the development of firmness in lower fat products. However, direct comparison of firmness values between this study and that of Guinard et al. (1997) is not practical. Guinard et al. (1997) tempered samples to -10°C whereas samples for this study were tempered to between -16.8°C and -17.6°C.

In addition to the indentation force values for softness, Guinard et al. (1997) reported the negative peak values generated as the probe/plunger was withdrawing from the sample as representing "tackiness". Similarly obtained values for tackiness for this study are shown in Tables 3.7 and 3.8. The results look very much like the firmness results with the LS1 value being slightly higher in trial 1 (Table 3.7) and the FFS2 value being much higher in trial 2. This would suggest that the molecular changes affecting firmness also impact the measurement of tackiness. It would appear that puncture force values are extremely sensitive to sample temperature handling conditions and instrument settings as the full fat ice creams tested by Goff et al. (1995a) all measured less than 5 N maximum force. Values in this study for full fat were greater than 50 N. Goff et al. (1995a), tempered samples to -10°C and used a different texture instrument and settings. Such methodology would contribute substantially to the difference in force values determined between the two studies.

As an alternative to determining ice cream firmness using a plunger attachment, as has been the case in most previous studies (Specter and Setser, 1994; Guinard et al.,

1997), a knife attachment was also used to evaluate both firmness and tackiness (Tables 3.7 and 3.8). There are several advantages to using a knife rather than a plunger for measuring ice cream texture. The knife blade is longer than the plunger and the depth of penetration greater so that it will be less influenced by small temperature gradients at the surface. In using a plunger, the amount of material compacted below the plunger will contribute to the measured force. As the end of the knife is only 0.3 cm in width, the contribution of compacted material to the measured force will be minimal.

As it was the case with the plunger, the results for the two trials when testing with the knife were quite different and the trends seen for firmness were also apparent for the tackiness although the actual forces measured were considerably lower for the knife (Tables 3.7 and 3.8). For trial 2, the firmness and tackiness for the FFS2 samples was much higher than the other samples as was the case when using the plunger. For trial 1, however, a decrease in the fat level resulted in a decrease in the firmness value in that the highest values were obtained with the regular fat product. This would suggest that firmness values for the reduced fat ice creams measured with the plunger may have a significant amount of compressed material contributing to the measurement.

Based on both the sensory and instrumental results it is clear that the presence of modified starch can overcome some of the problem caused by increased ice crystal volume that have been associated with increased firmness in a number of low fat ice cream products.

3.4.5 Viscosity - sensory

A physical property of ice cream that has a major influence on sensory quality in general, and texture assessment in particular, is apparent viscosity. Apparent viscosity in the partially melted state is an important factor because it influences how a sample of ice cream reacts within a person's mouth. The resistance of ice cream to the mechanical forces imparted by the tongue, upper palate, and teeth, will dictate the overall perception of ice cream texture. Viscosity building has been cited as a general function of carbohydrate-based fat replacers (Akoh , 1998).

While Specter and Setser (1994) did not evaluate viscosity as such, they did examine wateriness which they described as rapidly melting leading to a loss of viscosity, and the development of a thin and watery character. On the basis of this description, discussions involving viscosity and wateriness as related attributes are valid. In the current study, only the FFS1 sample (Table 4a) was viewed as having a significantly lower viscosity in trial 1 and all samples from trial 2 (Table 4b) were perceived as being similar in terms of viscosity. The high firmness value for the FFS2 sample did not result in a higher perception of viscosity. In contrast to these findings, five of the six treatments evaluated by Specter and Setser (1994) were perceived as having significantly higher degrees of wateriness compared to the regular fat (12% milk fat) control sample. Even their sample which contained 8% milk fat and 4% fat replacer (for both N-Oil ® and Paselli SA2) was judged as being significantly more watery that the control.

In research by Li et al. (1997), using the polydextrose fat substitute Litesse®,

significant differences in apparent viscosity between their regular fat (9.65% milk fat) sample and some of their lower fat (5.63%, 2.35%, and 0.53%) samples were reported. Their work demonstrated that the use of Litesse® as a fat replacer will affect the apparent viscosity of fat reduced ice cream samples but the degree to which viscosity is altered will depend on the level of fat and total solids. In comparison, with the FFS1 and LFS1 samples (Table 3.4), the modified starch used for the current study appeared to reproduce the viscosity of the regular fat ice cream as perceived by trained panellists.

3.4.6 Rheological Viscosity Measurements - instrumental

For instrumental apparent viscosity (Tables 3.9 and 3.10), the RFS1 and RFS2 samples measured 88.3 MPa and 86.0 MPa respectively at 30°C and a shear rate of 29.3 s^{-1}. These values were significantly lower than those for the LS1 and LS2 samples but higher than the ice cream samples with even lower fat contents. This is an indication that the level of modified starch used in the light samples could be lowered if its formula were to be further optimized. Interestingly, the values for the LS1 and LS2 samples were similar to those obtained by Goff et al (1994) of 130 MPa at 20 s^{-1} and 30°C for a regular fat formulation. Thus, the optimal level of modified starch to use for light ice cream may be variable depending on the apparent viscosity of the regular fat ice cream which is used as the viscosity target. The rank order analysis to examine correlations did not show a strong relationship between sensory and instrumental viscosity (Table 3.11) for individual trials.

Table 3.9: Mean values[1] for the rheological properties of ice cream samples prepared during process trial1.

Treatment Code	Apparent Viscosity[2] (mPa·s)	Flow Behavior Index[3]	Consistency Coefficient[4] (Pa s^{n-1})
FFS1	23.8 a	0.661 d	0.073 a
LFS1	20.0 a	0.482 c	0.456 b
LS1	169.8 c	0.358 a	1.488 c
RFS1	88.3 b	0.438 b	0.537 b

values within a column with no common letter, significantly differ ($p < 0.05$).

[1]mean values were determined from 4 assessments of each sample.

[2]apparent viscosity standard error = 8.8, all values were reported at 29.3 s^{-1}.

[3]flow behavior index standard error = 0.011.

[4]consistency coefficient standard error = 0.076.

Table 3.10: Mean values[1] for the rheological properties of ice cream samples prepared during process trial 2.

Treatment Code	Apparent Viscosity[2] (mPa·s)	Flow Behavior Index[3]	Consistency Coefficient[4] (Pa s^{n-1})
FFS2	53.8 b	0.591 b	0.065 a
LFS2	17.7 a	0.378 a	0.395 b
LS2	129.0 d	0.386 a	1.024 d
RFS2	86.0 c	0.428 a	0.569 c

values within a column with no common letter, significantly differ ($p < 0.05$).

[1]mean values were determined from 4 assessments of each sample.

[2]apparent viscosity standard error = 3.8, all values were reported at 29.3 s^{-1}.

[3]flow behavior index standard error = 0.021.

[4]consistency coefficient standard error = 0.027.

In the work of Specter and Setser (1994), the highest mix viscosity was associated with the regular fat control sample (66.7 MPa) with the lowest viscosity occurring for the fat free sample (33.8 MPa) made with 12% N-Oil® gel. Three of the four fat free ice creams evaluated by Ohmes et al. (1998) had measured mix viscosities in the range of 24.5 to 38 MPa s and these values are similar to values determined for FFS1 and LFS1. Despite these similarities the light control sample used by Ohmes et al. (1998) was significantly lower in viscosity compared to their fat free ice creams, whereas the opposite was noticed during this study (Tables 3.9 and 3.10). Comparison of the actual values obtained by Specter and Setser (1994) and Ohmes et al. (1998) to results from this study is not practical due to the different methodologies and instrumentation used. However, the higher apparent viscosity values for the light samples attained in this study suggests the inclusion of a modified starch can at least partially overcome the decrease in viscosity associated with fat reduced samples.

Table 3.11: Spearman's rank order correlation coefficient for analysis of the relationship between selected sensory and physical measurements.

Sensory Attribute	Physical Property	Process Trial 1 R^2	Process Trial 2 R^2
Viscosity	Flow Behaviour Index	0.902	0.164
Smoothness	Flow Behaviour Index	0.544	0.044
Mouth Coating	Flow Behaviour Index	1	0.163
Firmness	Firmness	0.143	0.642
Firmness	Apparent Viscosity	0.543	0.362
Viscosity	Apparent Viscosity	0.543	0.643
Smoothness	Apparent Viscosity	0.544	0.364
Mouth Coating	Apparent Viscosity	0.644	0.641
Viscosity	Firmness	0.904	0.363
Smoothness	Firmness	0.903	0.643
Mouth Coating	Firmness	0.642	0.361
Coldness	Firmness	0.643	0.162

In general, the rheological properties of most stabilized ice cream mixes have been described as non-Newtonian pseudoplastic in that they become thinner with increased shear rate (Cottrell et al., 1980; Goff and Davidson, 1992). As expected, the rheological data from this study gave similar results in that all flow behaviour indices (n values) were less than 1 (Tables 3.9 and 3.10), which is characteristic of pseudoplastic behaviour.

For ice cream mixes, values for n as low as 0.48 but as high as 0.94 have been reported by Cottrell et al (1980). For an ice cream mix containing 10% milk fat, 37.3% total solids and 0.3% stabilizers (an ice cream mix similar in composition to the regular fat samples in this study), Smith et al. (1984) reported n values between 0.48 and 0.55. These n values are slightly higher than those determined for RFS1 and RFS2 (0.438 and 0.428, respectively), but their testing temperature was 2°C compared to 30°C in this study. This temperature difference could account for the difference in n values obtained.

It has been suggested that the aggregation of fat globules in ice cream is partly responsible for its shear rate thinning behaviour (Arbuckle, 1986). On this basis, the fact that the FFS1 and FFS2 displayed the least shear thinning behaviour (highest n values) may be attributed to the lack of fat globules. The n value for the LS2 sample, on the other hand, may reflect the shear thinning of aggregated material other than fat globules. Significant correlations of 0.90 and 1.00 were noted between the flow behaviour index and the sensory viscosity and mouth coating in trial 1 respectively (Table 3.11). The lack of correlation noted for trial 2 appeared to be due to the different properties of FFS2.

The consistency coefficient (K), also referred to as the consistency index (Goff and Davidson, 1992; Schmidt et al., 1993), was also obtained from the power law model (Tables 3.9 and 3.10). These values were positively correlated with the viscosity values (R^2=0.778), which is not surprising as they both reflect the thickness or viscosity of the sample. The apparent viscosity is measured at a single shear rate while the K values are based on a range of shear rates. The main difference in these two measurements was seen

for the FFS and LS samples. The K values were significantly lower for the fat free samples whereas this was not the case with the apparent viscosity measurements. Otherwise the trend was the same with the light samples having the greatest apparent viscosity and K values followed by the regular fat samples. Overall, the values tended to agree with the apparent viscosity and sensory viscosity data indicating the low fat and fat free samples were not as viscous as the regular fat and light samples.

Comparison of K values between studies is difficult due to differences in sample handling and sample temperature during measurement. Previous viscosity measurements were made on ice cream mixes at room temperature, whereas in the current study, the ice cream had been frozen, stored, and thawed prior to viscosity measurement at 30°C. The values obtained, however, are lower than the 4.6-6.7 reported by Smith et al (1984) but similar to the 0.093-1.69 reported by Schmidt et al. (1993).

3.4.7 Smoothness

It has been proposed that the ability of carbohydrate-based fat replacers to effectively mimic the physical properties of milk fat will be determined by the colloidal properties of the carbohydrates involved and their impact on mouth feel (Specter and Setser, 1994). It is possible that the melting of ice cream within the oral cavity may be influenced by the hydrated particles of the fat replacer such that the perception of creaminess is intensified. High correlations existed between smoothness and fat content

(Table 3.6). Of interest was the correlation of 0.903 noted between smoothness and the instrumental measurement for firmness (Table 3.11).

The results for smoothness from process trial 1 (Table 3.4) indicated that a decrease in ice cream smoothness occurred when the fat level was decreased from 5.20 to 2.40%. For the second trial a similar trend was seen yet only the RFS2 sample was judged to be significantly smoother than other treatments. This inverse relationship between fat content and smoothness is in agreement with previously published results where decreases in creaminess were reported when the fat level was decreased from 10 to 3% (Morris, 1992) and from 12 to 8% or from 8 to 3% (Stampanoni-Koeferli et al., 1996). The creaminess measured in these investigations should be close to the smoothness evaluated in this study. It would appear, therefore, that the use of modified starches in low fat ice cream cannot result in a product with smoothness or creaminess similar to that of the regular fat ice cream, even though the smoothness of LS1 sample was comparable to the regular fat ice cream.

3.4.8 Mouth Coating

The results for mouth coating indicated that a lower rating for mouth coating was generally associated with a sample with lower fat contents (Tables 3.9 and 3.10). In trial 1, the LS1 sample had the highest value and the regular fat sample was not significantly different from the lower fat samples. In trial 2, the regular fat sample had the highest

degree of mouth coating and this was significantly higher than either of the LFS and FFS products. A similar increase in mouth coating with increased fat content has been reported previously by Stampanoni-Koeferli et al. (1996). It should be noted, however, that panellists expressed difficulty in assessing mouth coating in the reduced fat samples. It is possible that the nature of the mouth coating is different in reduced fat ice cream than it is in regular fat ice cream.

For the modified starches used by Specter and Setser (1994), no significant differences were reported between the mouth coating properties of the regular fat ice cream and their reduced fat ice creams which contained 8%, 4% and 0% milk fat. Overall, it is clear that the intensity of mouth coating for reduced fat ice creams is dependent on the source of modified starch used for fat replacement. Also the type of mouth coating between regular fat and reduced fat ice cream is likely to be different.

4 ANALYSIS OF FREEZING AND MELTING

4.1 Introduction

In addition to being able to produce a reduced fat ice cream that is acceptable to the consumer it is important that processing conditions be examined. This is necessary to provide information essential to achieve consistency in product manufacture through an understanding of structure formation during the preparation steps. In addition, drawing temperature is an important consideration as it can determine the extent of ice crystal formation and hardening behaviour (Everington, 1991) which are in turn related to the thermal properties of the material. Also important in characterizing the quality of reduced fat products is the melting behaviour (Ohmes et al., 1998). This can be examined through the rate of temperature change during warming or by monitoring the change of state during melting through the decrease in weight of an inverted package of ice cream. In this study the properties of the regular and fat reduced fat samples were evaluated by monitoring ice cream temperatures during continuous freezing, hardening and melting. To further understand these properties, thermal diffusivities were calculated and the rate of liquid released during the meltdown of frozen ice cream was measured.

4.2 Materials and Methods

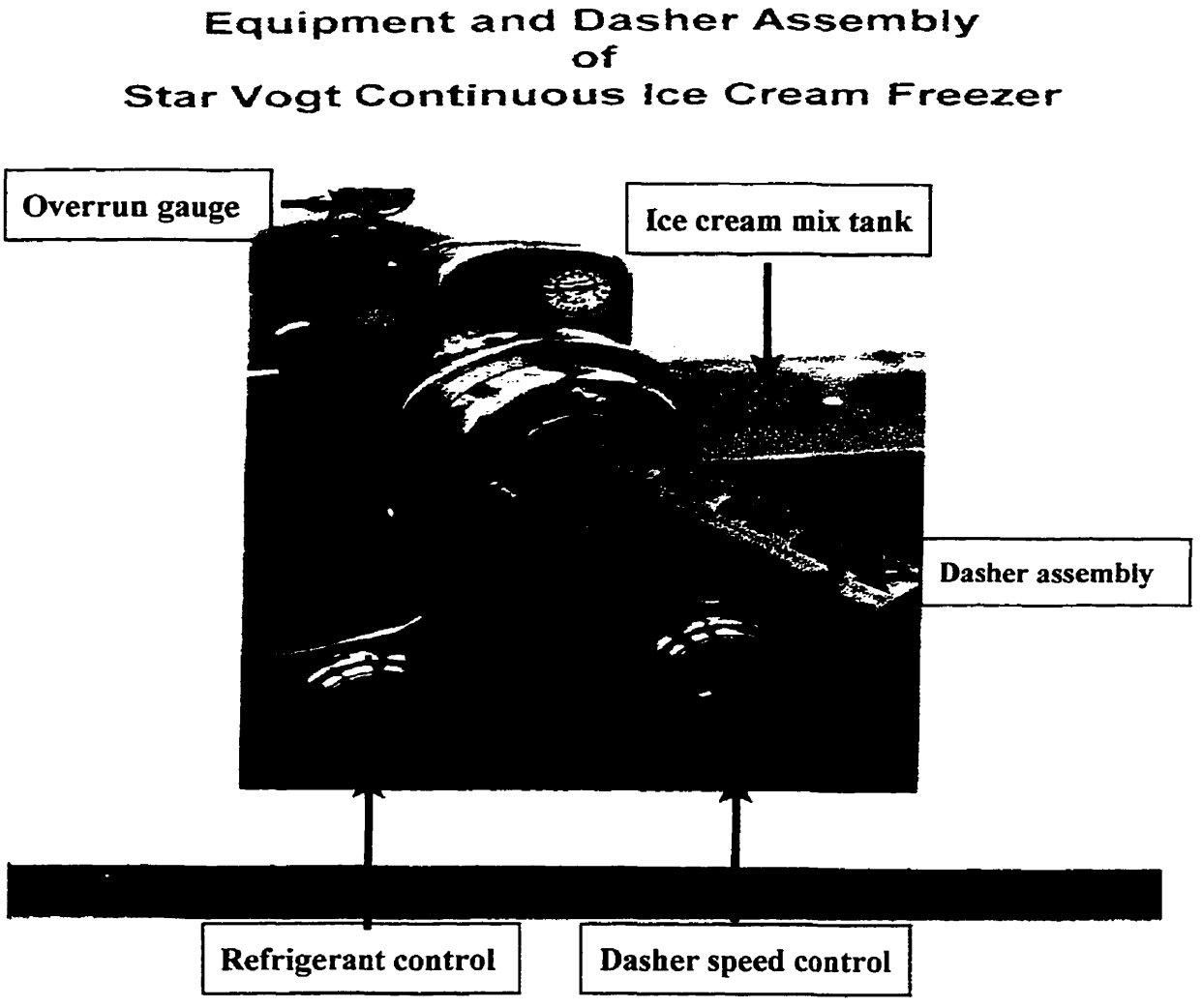
4.2.1 Manufacture of ice cream

The manufacture of ice cream followed the guidelines cited in section 3.2.1. However, the samples for sensory and texture evaluations were prepared separately from the ice cream used for continuous freezing, hardening and melting analysis. The insertions of thermocouples in the samples to monitor temperatures during continuous freezing precluded their use in sensory testing for food safety reasons. Figure 4.1 illustrates the continuous freezing equipment used to freeze all samples. The tested composition of ice creams used for freezing and melting analysis are given in Table 4.1. Minor differences between duplicate runs resulted in slight differences in sample composition. Fat levels were all within target range. Sample codes in these experiments contained the letter "D" (Table 4.1) to distinguish them from the earlier trials where samples of similar composition were used in sensory ("S") trials (Table 3.3).

4.2.2 Continuous freezing

An important aspect of continuous freezing is the drawing temperature of ice cream. The drawing temperature is the temperature of semi-solid ice cream as it is extruded from the freezing barrel outlet. At the beginning of most continuous freezing operations the semi-frozen ice cream appears wet or shiny and may lack stiffness. It is a desirable quality of ice cream to have a dry appearance during drawing and to have a certain degree of stiffness so that it extrudes smoothly from the freezing barrel.

Figure 4.1



During the continuous freezing step where ice cream mix and semi-frozen ice cream were present within the freezing barrel, drawing temperature data was collected every 30 seconds using thermocouple wire (P24T, insulation range of -40°C to 105°C, ThermoElectric, Brampton, ON, Canada) and a Hewlett Packard data acquisition system (HP 75000, Loveland, CO, US.).

To determine ice cream mix temperatures, the thermocouple was firmly positioned at the center of the mix supply tank outlet. For measurement of drawing temperatures, the thermocouple was positioned at the geometric center of a 2.54 cm (1") pipe immediately adjacent to the freezing chamber outlet (Figure 4.2).

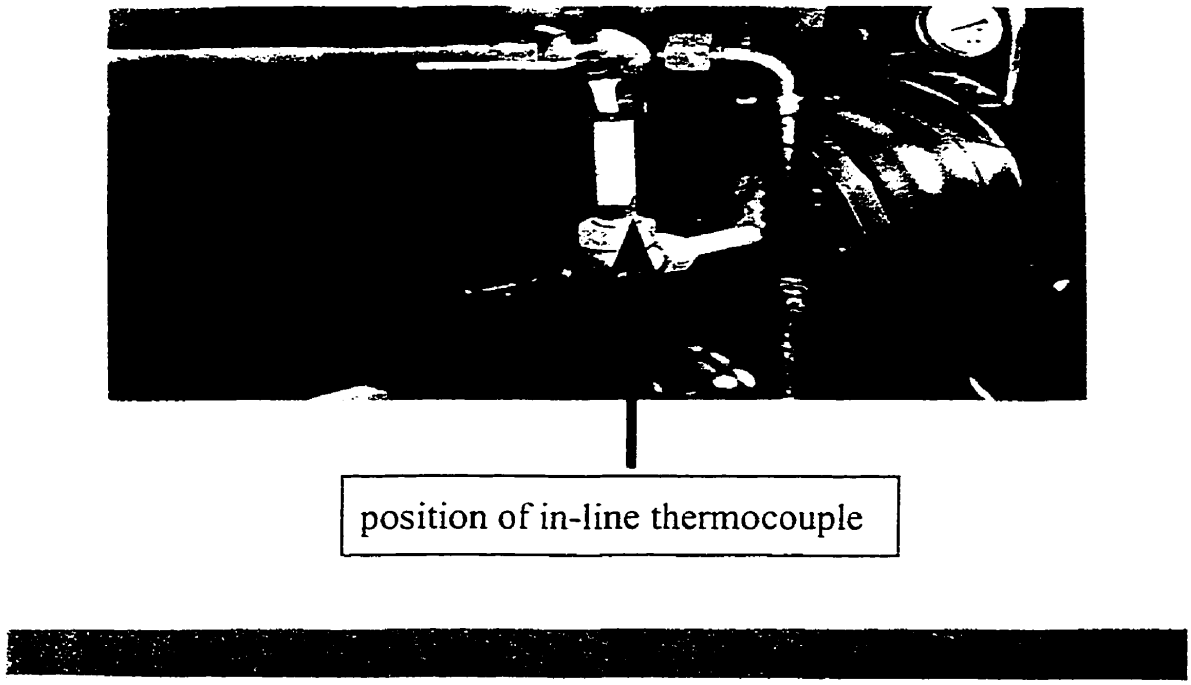
Table 4.1 Tested composition of ice cream prepared for freezing and melting analysis.

Sample code	% milk fat[1]	% total solids[2]	% overrun
RFD1	9.0	37.90	105
RFD2	10.0	38.83	100
LD1	5.0	37.70	97
LD2	4.9	37.46	100
LFD1	2.4	34.50	95
LFD2	2.4	34.53	97
FFD1	0.5	32.60	100
FFD2	0.4	32.70	80

[1] %milk fat; Pennsylvania modified Babcock method used for all samples except for FFD1 and FFD2 where the Babcock method for skim milk (Marshall, 1992) was used.
[2] %total solids; forced-draft oven method (Marshall, 1992).

Figure 4.2

Location of Drawing Temperature Data Collection during Continuous Freezing of Vanilla Ice Cream

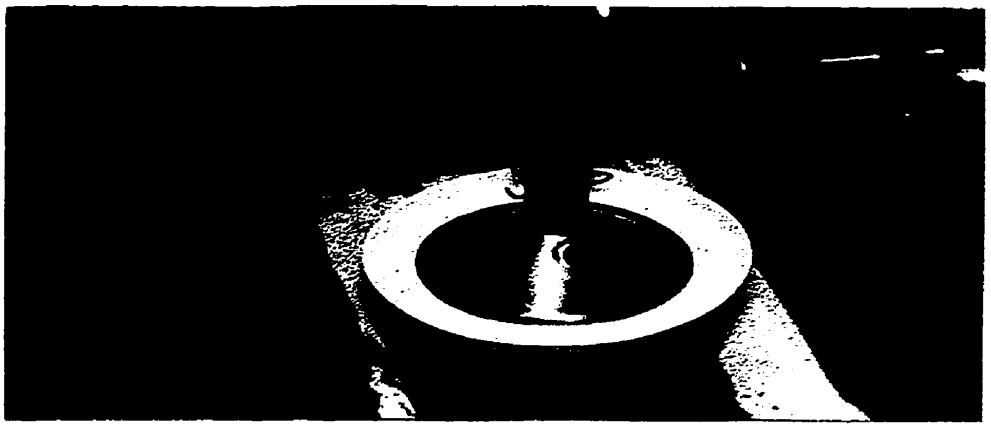


A one mm diameter hole was drilled into the pipe and a sample grommet (Specialty Systems, Winnipeg, MB, Canada) was inserted into the hole. Insertion of the thermocouple through the sample grommet ensured firm positioning of the thermocouple at the geometric center of the pipe.

In addition to monitoring drawing temperatures during continuous freezing the flow rates of ice cream were also measured (Table 4.3). The flow rates were monitored manually 4 times during steady state freezing by weighing the amount of ice cream collected over a 30 second time period.

Figure 4.3:

Filling of 10 Litre Cylinders During Continuous Freezing of Vanilla Ice Cream



After filling the 2 L boxes, the packaged ice cream was placed into plastic milk crates each of which held 6 boxes (Figure 4.5). Manual transfer of ice cream from the continuous freezing room to the hardening room immediately followed the completion of each crate. Two 10 L cylinder pails were filled for each batch of ice cream and each cylinder was transferred separately to the hardening room immediately after filling. The cylinders measured 24 cm in diameter and 40 cm in height (Figure 4.3).

4.2.3 Hardening and Melting

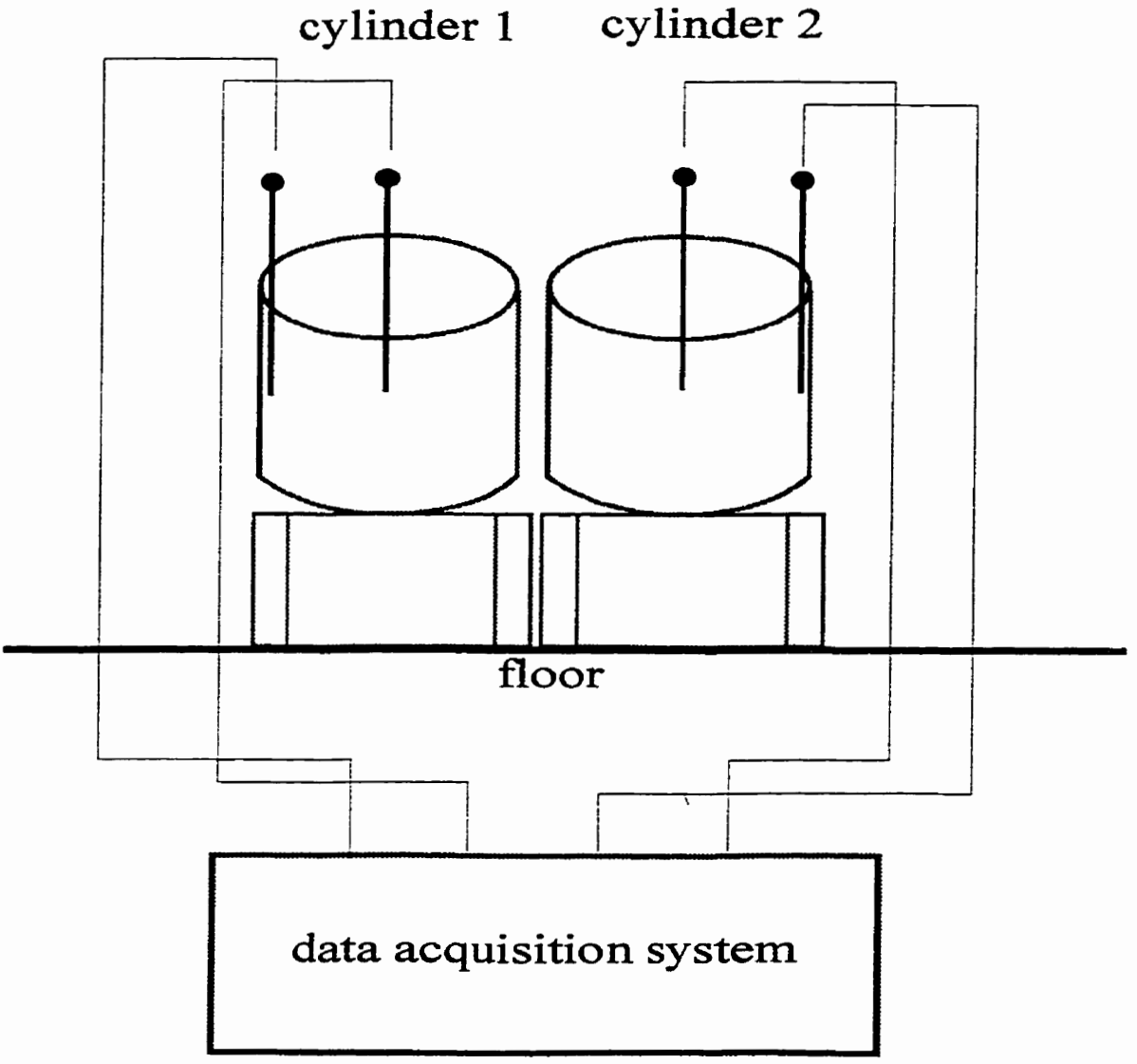
The room used for hardening packaged ice cream was a 3.84m x 2.83m x 2.14m (12'7"x 9'3.5"x 7'0") indirect-contact air-blast convection freezing chamber. Air flow within the freezer was 1.0-1.5 m/s and the defrost temperature cycle was -26°C to -32°C over a 15 minute time period with an overall average freezing chamber temperature of -31°C. At the completion of continuous freezing the data acquisition and thermocouple assembly were transferred from the continuous freezing room to an area immediately adjacent to the hardening room.

Within the hardening room, 4 stacks of ice cream were positioned approximately 1.22 m (4') from the cooling fans, 0.92 m (3') from the walk-in freezer entrance and 1.06 m (3.5') from either side wall. Each stack consisted of 3 full crates of ice cream and an empty crate. The empty crate was used to elevate the stack off the floor and therefore improve the cooling surface area of the ice cream. The 10 L cylinder pails were also elevated from the floor using an empty crate. Thermocouple probes were constructed using 0.25 mm copper tubing as housing for the thermocouple wire. The tubing was cut to specific lengths to ensure that thermocouple probes would measure temperatures at the geometric centres of the cylinders and 2 L boxes. Thermocouple wire was threaded through the copper tubing and firmly fastened using electrical tape so that only the tip of the wire was exposed at the end of the tubing.

For every batch of packaged ice cream, two thermocouple probes were inserted into each of the two 10 L cylinder pails and into four 2 L boxes. One thermocouple probe

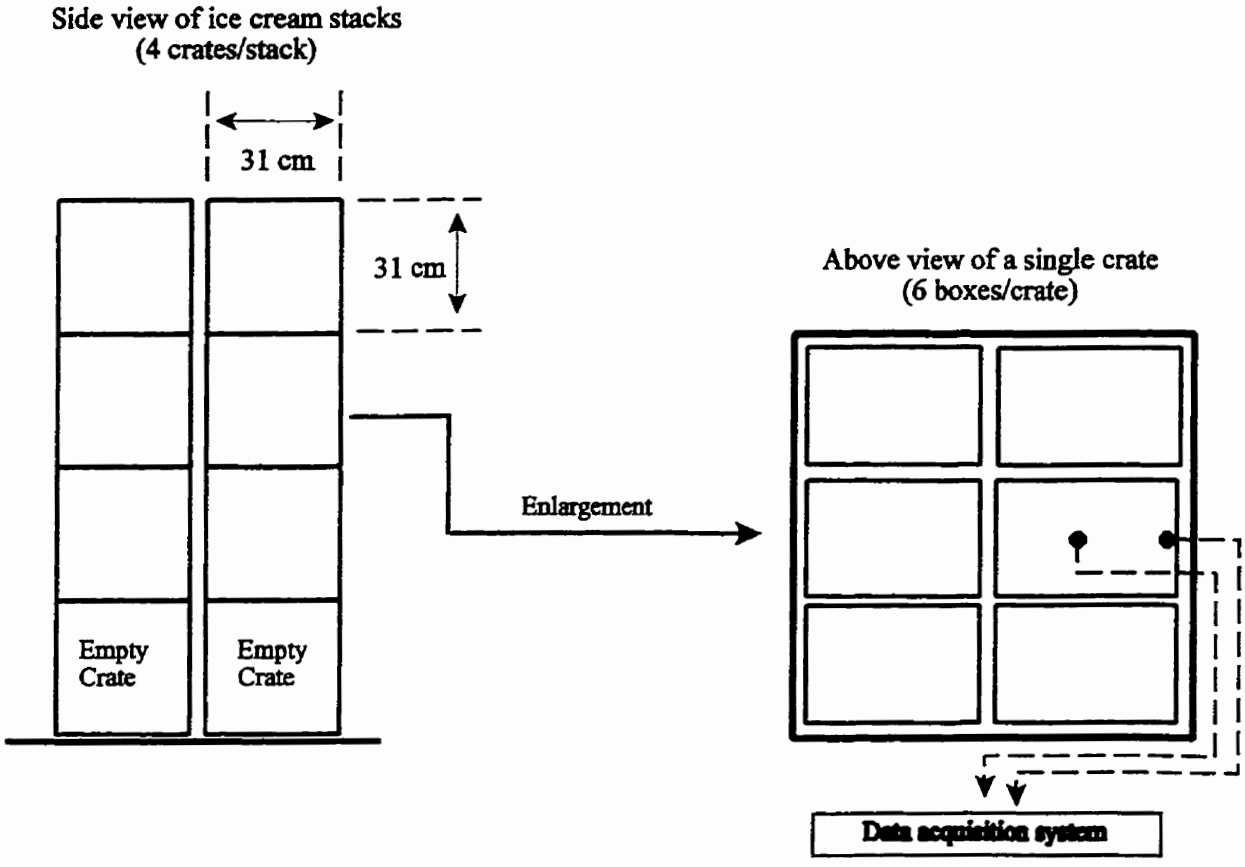
measured temperatures at the centre of a container and the second thermocouple measured temperatures immediately adjacent to the inside container surface (Figures 4.4 and 4.5).

Figure 4.4: Positioning of thermocouples during the hardening of ice cream in cylinders.



Of the four boxes monitored for each batch, two were located in the middle crate of a stack and the other two were located in the top crate of the same stack. To monitor cooling air temperatures during hardening, a thermocouple was positioned approximately 5 cm (2") above the centre of the 4 stacks of ice cream. Refer to Appendix 5 for related data and calculations.

Figure 4.5: Positioning of thermocouples during the hardening of ice cream in 2 L paper-board boxes and stacking of crates.



For melting analysis the frozen samples monitored during hardening were transferred with the thermocouples in place to a glass door cabinet (Coldstream, Winnipeg, MB, Canada). The cabinet, having cavity dimensions of 61cm x 114.3cm x 122cm (24"x 45"x 57"), minimized experimental error by maintaining ambient temperatures. A thermostat ensured that cabinet temperatures did not deviate from 21+/-1°C. In addition to monitoring temperatures in the boxes and cylinders having the thermocouples, the weight of liquid accumulated during melting for each experimental condition was measured. The bottom of one box was cut out using a utility knife and mounted on a screen (the openings were1.3cm x 1.3cm) above a beaker placed on a zeroed scale. Every 30 seconds the number of grams of melted ice cream was recorded.

4.2.4 DSC Testing

A DSC 7 Differential Scanning Calorimeter (Perkin-Elmer, Norwalk, CT, US.) was used for the melting and freeze-thaw stability analysis of treatment samples. Frozen samples of 20 to 25 mg were loaded into DSC pans. Sample pans were sealed and placed into the DSC 7 load cell. The load cell held the sample pan and an empty reference pan. The load cell was equipped with liquid nitrogen circulation and the scanning temperature range was -35°C to 5°C. At the beginning of each scan the cooling head instantly lowered sample temperatures to -35°C followed by controlled heating at 2°C/minute. The same heating rate was used by Goff et al. (1993) in their investigation of the low temperature stability of ice cream. For the freeze-thaw stability tests, after the initial scan was

complete two subsequent scans were conducted without re-loading fresh sample. Thus each of the samples used for freeze-thaw analysis were melted and re-frozen three times. Melting endotherms from the DSC experiments were analysed using the Perkin-Elmer 7 Series Thermal Analysis System. The melting values examined were peak temperature, ΔH and onset temperature.

4.3 Data Analysis

Two process trials were conducted for each treatment sample. The data from the two process trials for evaluation of continuous freezing, hardening and melting, were treated as duplicate trials as there were significant interactions between trial and treatment. Unlike the samples prepared for sensory testing, experimental error attributed to the modified starch used for both trials was negligible as the same supply of starch was used for all samples. The continuous freezing average drawing temperatures and flow rates, hardening time and the DSC values of enthalpy (ΔH), peak temperature and onset temperature, were analysed statistically using the Number Crunching Statistical Analysis software (J. L. Hintze Co., Kaysville, Utah, 1987). The melting time-temperature profiles, freeze-thaw stability and apparent thermal diffusivity, were not analysed statistically because of experimental error that occurred due to inadvertent environmental conditions.

For product freezing calculations the following average frozen product densities in kg/m^3 were used; 532.8 for regular fat, 537.3 for light, 544.4 for low fat and 557.2 for fat free. The average frozen product densities were based on the weight of the 2 L

containers used. The assumptions for calculations pertaining to the apparent thermal diffusivity were as follows: 1) for temperatures below zero the thermal conductivity of water was assumed constant at 0.57 W/m°C; 2) the specific heat of ash was assumed to be zero; and 3) the aforementioned densities were assumed to be constant over the entire hardening period. The calculation of thermal diffusivity followed the guidelines of Heldman (1992).

4.4 Results and Discussion

4.4.1 Continuous freezing

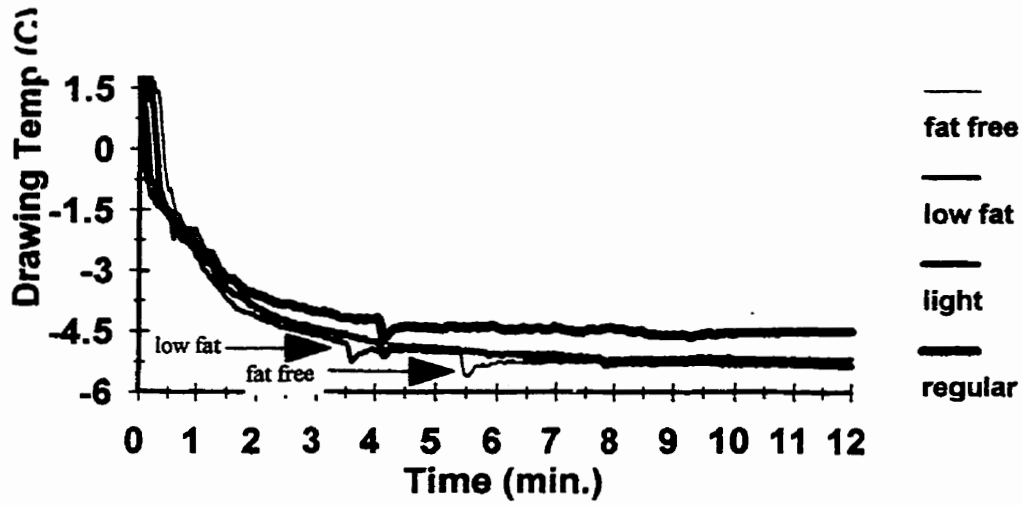
Goff and Sahagian (1996) stated that the initial freezing temperature of ice cream mix is normally about -2.5°C. During the initial freezing of ice cream mixes (Figure 4.6) the numerous plateaus noted in the time-temperature profile between -1.5°C and -3.0°C and the change in slope starting at -1.5°C provide an indication that initial freezing points for treatment samples were in the proximity stated by Goff and Sahagian (1996). During the work of Everington (1991), specific drawing temperatures during continuous freezing were achieved through manipulation of controls, however, in the present research drawing temperature was not purposely varied. The controls available to influence the process of continuous freezing are dasher speed, air intake and back pressure on the freezer barrel. The settings selected for dasher speed, air intake and back pressure(section 3.2.1), were typical of those used for a continuous freezer operating at approximately 75% capacity and freezing a regular fat ice cream mix to 100% overrun. Thus, to determine if the treatment ice cream mixes would react differently during continuous freezing, the controls were not adjusted and temperature data derived on this basis was a reflection of ice cream mix composition.

From the time-temperature patterns observed during continuous freezing (Figure 4.6), it is clear that ice cream of varied fat content can display different initial freezing properties. Of particular interest were the sudden decreases in temperature followed by small increases in temperature at 5.5, 3.5, 4.2 and 4.2 minutes for fat free, low fat, light and regular samples respectively. The fat free sample at 5.5 minutes showed the most

affect. It is possible that these thermal events represented significant points of crystallization followed by a partial release of latent heat. The numerous temperature fluctuations noted during the early stages of continuous freezing may signify nucleation since the enthalpy associated with the formation of molecular clusters of sufficient size to become stable nuclei is then released in the form of latent heat (Goff and Sahagian, 1996). It therefore appears that the modified starch fat replacer altered the initial ice crystallization processes. This, in theory, should affect the ice cream structure formed during manufacture and therefore the final product texture. Once steady-state continuous freezing conditions were established at the 7 minute mark the average drawing temperature decreased as fat levels decreased although only the regular fat sample showed a statistically significant difference (Table 4.2).

According to Farrall (1980), a typical commercial continuous freezer drawing regular fat ice cream at -5°C and 100% overrun, will have a throughput of approximately 165 gallons or approximately 580 kg of ice cream per hour. Even though these values greatly exceed the capacity of the freezing equipment used in the present study, this parameter was evaluated to demonstrate how ice cream mix composition might affect the flow rate of semi-frozen ice cream.

Figure 4.6: Comparison of continuous freezing time-temperature profiles at the initiation of freezing for ice cream of varied fat content.



The importance of steady state drawing temperatures, from a process economics perspective, is related to the refrigeration required to remove heat from mixes at different drawing temperatures. Marshall and Arbuckle (1996), listed the refrigeration requirements during the continuous freezing of full fat ice cream at -4.44°C and -5.56°C as being 25.00 kcal/kg and 30.83 kcal/kg of mix, respectively. Hence, even a change in drawing temperature of 1°C can represent an increase in energy requirements for refrigeration of 5 kcal/kg of mix.

Table 4.2: Average steady-state drawing temperatures during continuous freezing of ice cream samples.

Sample	average drawing temp. (°C)[1]	standard deviation
fat free	-5.31 a	0.04
low fat	-5.19 a	0.01
light	-5.08 a	0.13
regular	-4.52 b	0.34

[1] values within a column with no common letter are significantly different ($P < 0.05$)

Another important operational factor in ice cream production is the capacity of the continuous freezers being used. Continuous freezer capacities can range from 100 L/hour to over 3800 L/hour (Marshall, 1996). Flow rate data analysis showed a significant effect and a significant interaction between samples and trials. Statistically, the difference of 5 kg ice cream per hour observed between the fat free and regular ice cream was significant (Table 4.3).

Table 4.3: Comparison of flow rate data during continuous freezing.

Sample	flow rate (kg ice cream/hour)		standard error
	trial 1	trial 2	
regular fat	86.70 b	85.36 b	0.277
light	100.16 c	96.22 d	0.308
low fat	87.16 b	91.02 c	0.458
fat free	79.70 a	80.03 a	0.41
standard error	0.428	0.303	

values within a column with no common letter significantly differ ($P< 0.05$).
values within a row with no common letter significantly differ ($P< 0.05$).

The fat free samples displayed the lowest flow rate and light samples the highest in both trials. The continuous freezer operating parameters of rotor speed and back pressure outlined in the manufacture of ice cream (section 3.2.1) were selected to allow for comparison of freezing properties of each sample as opposed to being chosen to best suit each sample independently. It is also noteworthy that seldom will two continuous freezers display similar behaviour with regard to the freezing of ice cream mixes (Jimenez-Flores et al., 1993). As well, freezer operators will often make changes to parameters depending on how their freezers handle a mix. Thus, the values presented in Table 4.3 are not appropriate for comparison to flow rate values of other freezers.

The higher the solids content of ice cream mix, the lower the amount of water that will be converted to ice during continuous freezing. Even a difference in solids content of between 36% to 38% can affect texture control (Everington, 1991). Texture

may be affected because ice cream mixes containing different levels of water may freeze differently due to the size distribution of ice crystals. Thus, the lower levels of solids present in the fat free samples (Table 4.1) would contribute to a higher semi-solid ice cream viscosity because more water will be available to crystallize out of solution. As ice crystals form, the solids concentration and the viscosity of the unfrozen serum phase increases within the freezing barrel. Hence, the flow rate will decrease unless more energy is supplied from the equipment. Ice cream mixes containing regular levels of fat would require less energy from the equipment compared to a mix of less than regular fat. This is because a fatty film will form along the freezer barrel wall when freezing regular fat mix. For mixes of lowered levels fat levels, an aqueous film can form at the heat exchange surface which would increase the resistance to the dasher blades since freezing between the blades and the surface can occur. For non-regular fat samples, a relationship may exist between the lower average drawing temperatures (Table 4.2) and the lower flow rates noted during continuous freezing (Table 4.3).

4.4.2 Hardening and melting

4.4.2.1 Hardening

Some experimental error occurred during the hardening analysis because the product load within the freezer could not be held constant throughout the study. In a hardening room of small dimensions and only one source of cooling air the impact of altered air flow patterns due to a changing freezer load is magnified. Therefore, only data from boxes in the top crates were considered representative since considerable

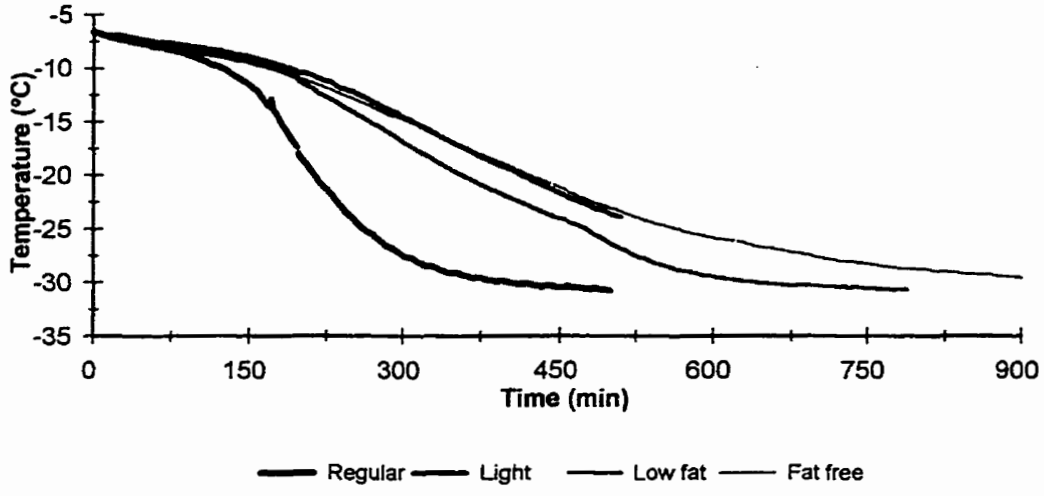
temperature variation was noted in boxes positioned in the middle crates of each stack. Accurate comparison of hardening profiles was difficult because temperature data could not be recorded during hardening until continuous freezing was complete. Hence, the cooling of samples within a process trial could not be monitored from the same starting temperature and time which is essential for legitimate comparison of cooling rates. In such cases, statistical analysis for comparisons between products would not be valid. Aside from the experimental shortcomings, the observations and discussion of cooling patterns during the hardening of samples is worthwhile.

Figures 4.7 and 4.8 contain data collected during the hardening of boxes located in two stacks from two separate process trials. For the 2 L boxes in process trial 1 (Figure 4.7), the cooling pattern for the regular fat ice cream differed greatly from ice cream of all other fat levels. Similar patterns were noticed for processing trial 2 (Figure 4.8). As pure components, the thermal conductivity of water (0.601 W/m•°C at 20°C) is approximately 3.5 times greater than that of fat (0.176 W/m•°C at 20°C), (Choi and Okos,1986). However, greater rates of heat transfer for ice cream of lower fat levels in comparison to regular fat ice cream should not be assumed. This is because the aqueous phase of frozen ice cream is not pure water or pure ice; it is an extremely high viscosity mixture of dissolved sugars and macromolecules.

The overrun of samples was not viewed as a significant variable (Table 4.1), hence based on thermal conductivity alone, the regular fat samples were expected to require more time to reach -18°C. This was not the case (Figure 4.7).The viscosity of the unfrozen phase is most likely a critical factor. In regular fat samples the unfrozen phase

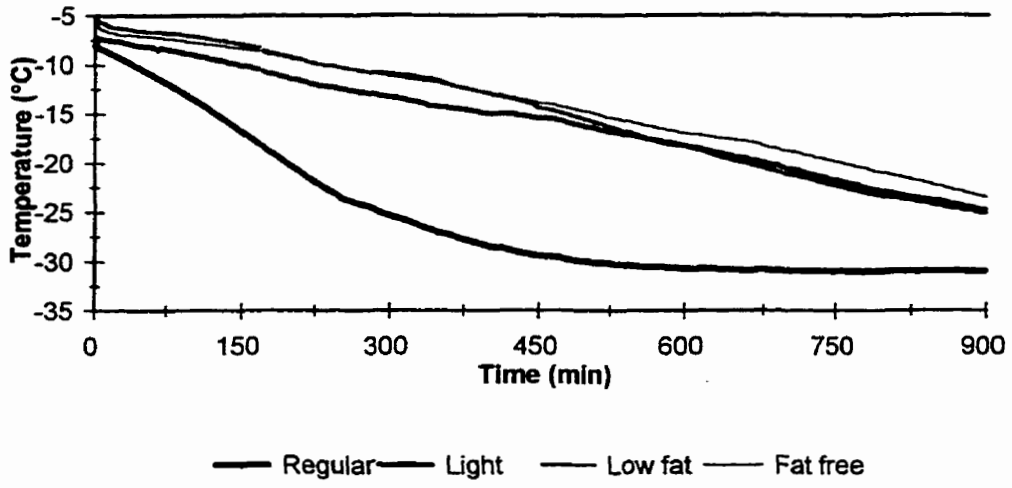
viscosity is expected to be the lowest due to the absence of a modified starch fat replacer. It is likely that the higher unfrozen phase viscosity of samples containing the fat replacer contributed to the slower rates of cooling noticed for all non-regular fat samples.

Figure 4.7: Hardening time-temperature profiles for ice cream in 2 L paper board boxes from processing trial 1.



Freezer load may partially explain the differences between process trials because reduced fat ice cream samples from process trial 1 required between 325 to 375 minutes to reach -18°C (Figure 4.7) whereas 600 to 650 minutes was required to reach the same temperature during process trial 2 (Figure 4.8) when the load in the hardening room was considerably higher.

Figure 4.8: Hardening time-temperature profiles for ice cream in 2 L paper board boxes in the top-center position from processing trial 2.



The hardening profiles for ice cream packaged in plastic 10 L cylinders were different from the profiles for ice cream packaged in stacked paper board 2 L boxes (Figures 4.9 and 4.10). The most notable difference was for the regular fat samples. For 2 L boxes there was a clear distinction between regular fat and lower fat ice cream samples but this was not the case for ice cream packaged in the 10 L cylinders. The velocity of cooling air around packaged ice cream is a critical factor during hardening (Marshall and Arbuckle, 1996). The air velocity recorded inside the walk-in hardening chamber was measured within the maximum air stream. Thus, the cylinders did not receive the convective benefit that boxes positioned in the top crates did. The shape of container and location in proximity to the cooling air stream were important factors because in the boxes, regular fat samples reached -18°C in under 200 minutes (Figure 4.7 and 4.8),

whereas the same product packaged in the cylinders required a maximum of approximately 425 minutes (Figures 4.9 and 4.10). Overall, despite the experimental inconsistencies it is clear that the level of fat in ice cream, the type of packaging and the location of packages within a hardening chamber are factors that influence the shape of time-temperature profiles during ice cream hardening.

Figure 4.9: Hardening time-temperature profiles for ice cream in cylinders from processing trial1.

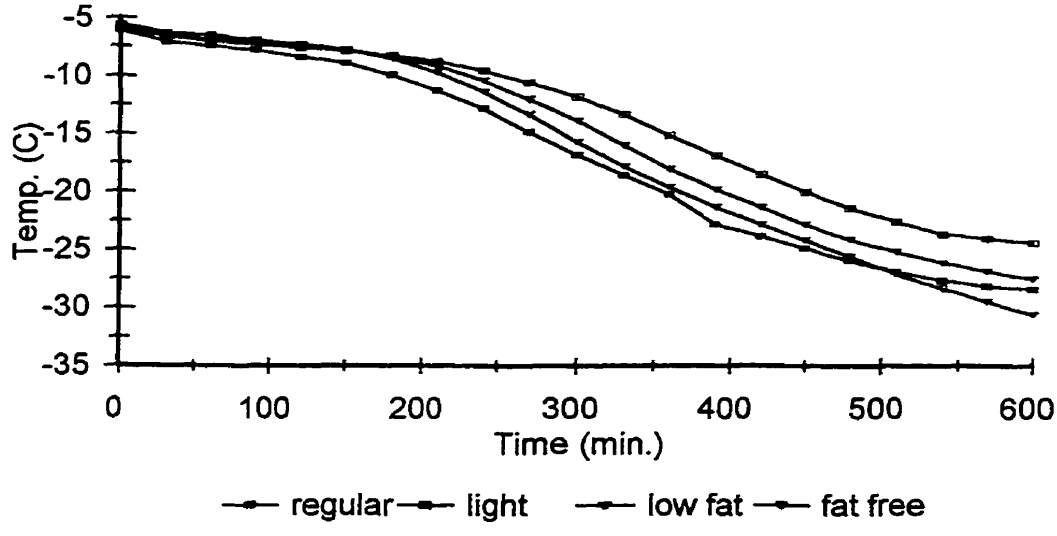
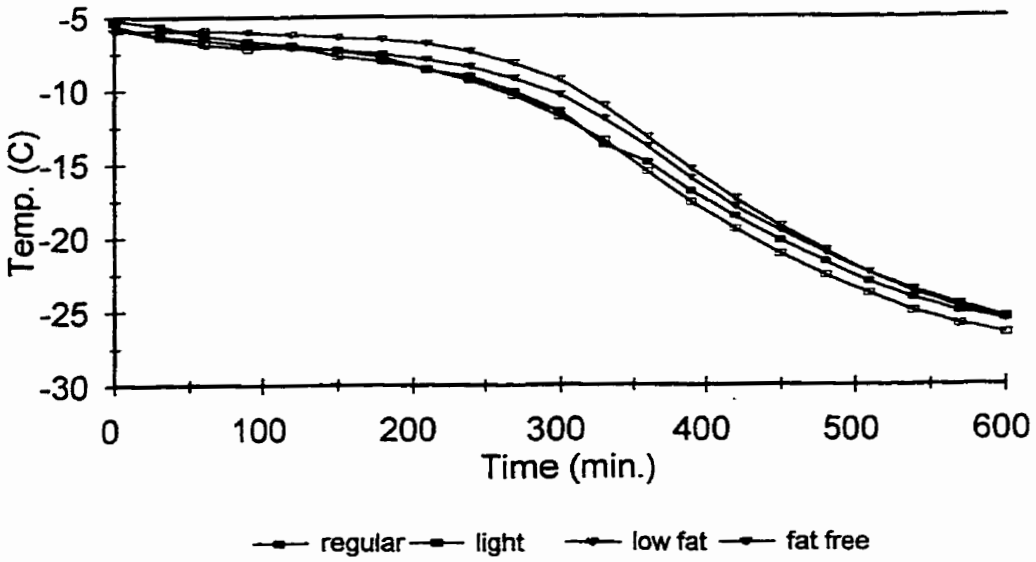


Figure 4.10: Hardening time-temperature profiles for ice cream in cylinders from processing trial 2.



4.4.2.2 Melting

Few differences were noticed in the melting time-temperature profiles for ice cream packaged in both the boxes and cylinders (Figures 4.11 through 4.14). Of interest is that the fact that the effect of package type and location noted during hardening was not as evident during melting. The hardening profiles for 2 L boxes (Figures 4.7 and 4.8) showed regular fat samples as being more rapidly cooled compared to samples of lower fat levels, this was not noted during the melting analysis since all samples displayed similar time-temperature patterns (Figures 4.11 through 4.14). The highly controlled testing environment for the melting analysis in comparison to the hardening tests, probably had a strong influence on the results.

Figure 4.11: Time-temperature profiles during the warming of ice cream packaged in 2 L paper board boxes during process trial 1.

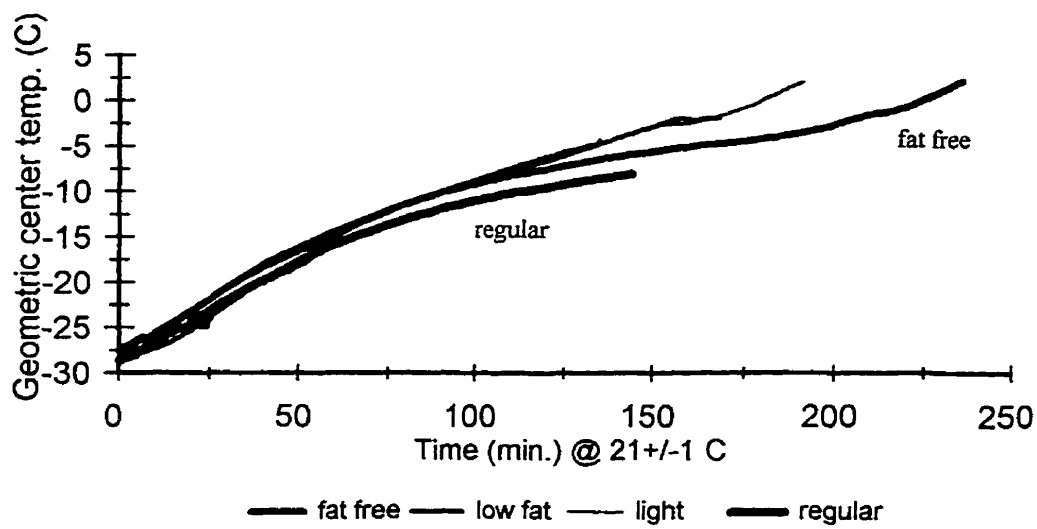


Figure 4.12: Time-temperature profiles during the warming of ice cream packaged in 2 L paper board boxes during process trial 2.

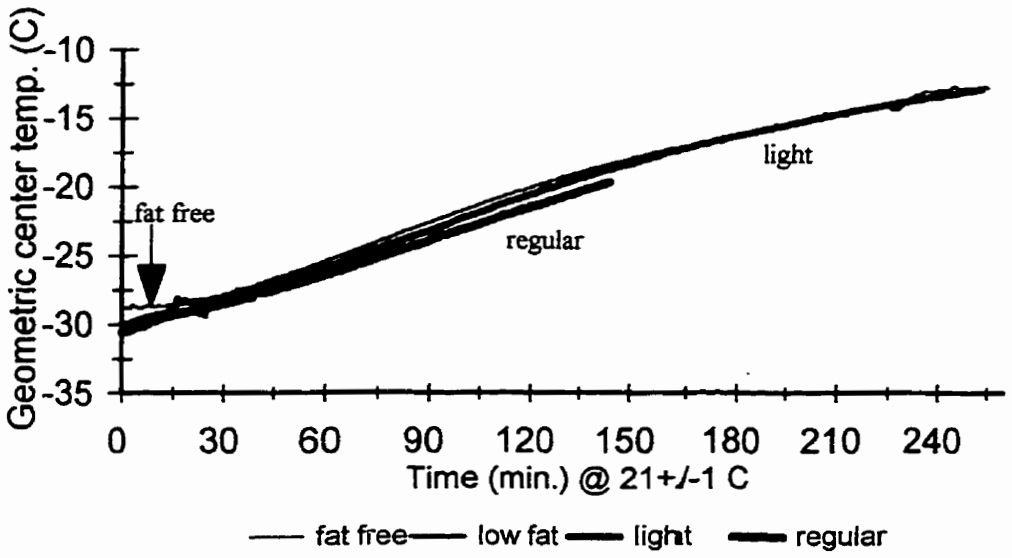


Figure 4.13: Time-temperature profiles during the warming of ice cream packaged in 10 L cylinders during process trial 1.

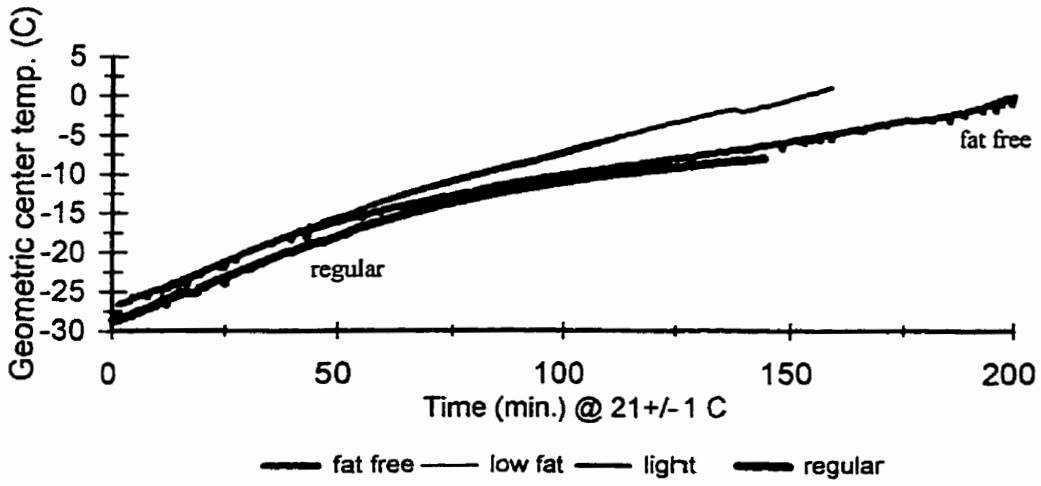
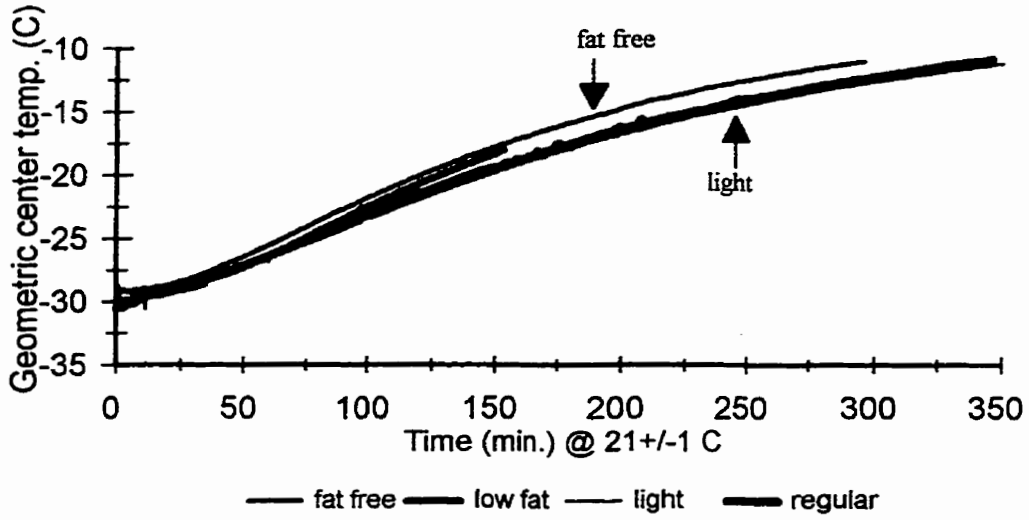


Figure 4.14: Time-temperature profiles during the warming of ice cream packaged in 10 L cylinders during process trial 2.



Unlike the warming time-temperature profiles, differences in melting behavior were found when the rate of meltdown was evaluated by weight vs time. This is related to the fact that the time-weight measurements are dependent on the physical-chemical properties of the ice cream whereas the time-temperature measurements reflect thermodynamic properties. Also, in comparison to the hardening evaluations, the melting analysis benefitted from a much more controlled testing environment and therefore much less experimental error.

In Figures 4.15 and 4.16 it is clear that fat free and low fat had similar melting rates but these differed from the light and regular fat samples which melted more slowly.

It was apparent that the level of milk fat had a direct affect on the rate of meltdown with the biggest difference occurring between the level of approximately 2.5% and 5% milk fat. The milk fat appeared to act as an adhesive within the structure of ice cream in that as the structure collapsed during meltdown the serum phase of ice cream was not readily released as was often the case in fat reduced ice cream products. This was particularly evident from visual observation where for regular fat samples, melted ice cream was released from the screen (4.2.3) intermittently in large clumps and, in between the release of large clumps, small drops of serum were released. For fat free, low fat and to a lesser extent light, this was not the case and meltdown occurred in a more linear fashion. It would appear as though for regular fat samples there was a clear distinction between the dispersed phase containing milk fat and the continuous serum phase. This was not observed during the meltdown of samples containing the fat replacer which implied that there was a closer association between milk fat and the aqueous serum phase. To further explore this observation, testing for fat in the melted serum and the un-melted semi-solid ice cream would be required.

Figure 4.15: Average melting rate comparison for ice cream in 2 L paper board boxes hardened in the top-center stack positions during process trial 1.

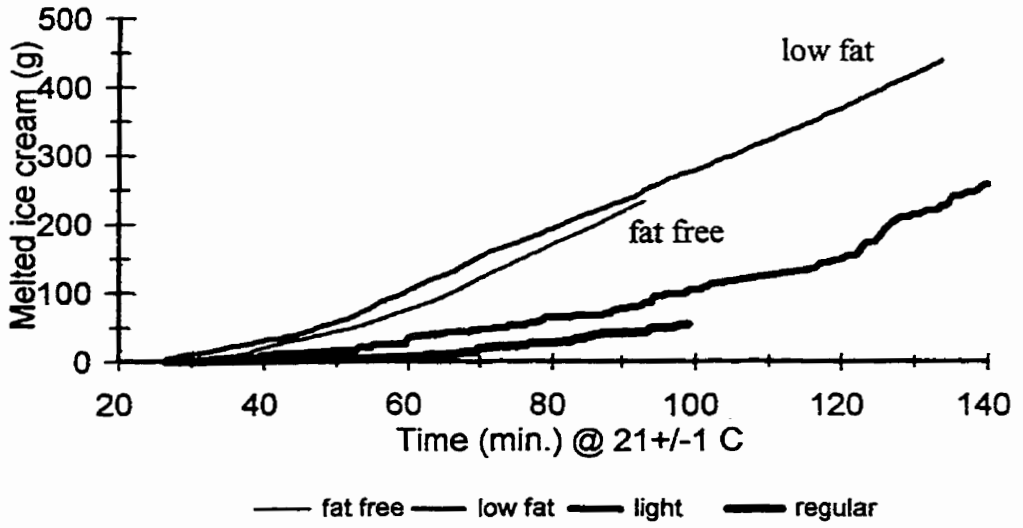
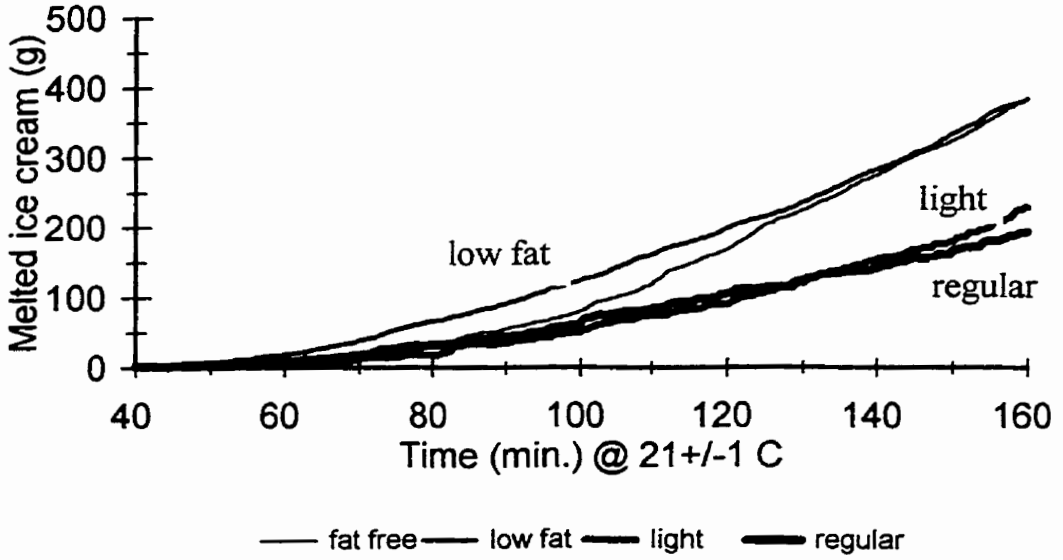


Figure 4.16: Average melting rate comparison for ice cream in 2 L paper board boxes hardened in the top-center stack positions during process trial 2.



Overall, the melting rate of fat free samples was viewed as similar to that of the low fat samples (Figures 4.15 and 4.16). However, under the conditions used for evaluation, the modified starch in the low fat samples was not effective in matching the melting behavior of the light samples. The melting behavior of light samples closely resembled that of the regular fat (Figures 4.15 and 4.16). According to the defects of melting quality illustrated by Marshall and Arbuckle (1996), the quality of the non-regular fat samples of this study can be described as somewhere between a foamy melt and a melt for which there is little or no criticism although the melt of fat free samples may also be classified as of low viscosity. Foamy melting quality is evident when large air bubbles do not collapse as the product melts and this is often attributed to highly surface-active mix constituents effective in maintaining a stabile foam (Marshall and Arbuckle, 1996). The latter authors referred to emulsifiers and egg yolk solids as examples of such surface-active components but it is conceivable that in our study the modified starch was the component contributing most to the stable foam noticed during meltdown.

4.4.3 DSC Testing

The glass transition temperature (Tg') for a concentrated frozen product solution such as ice cream may range between -23°C to -43°C (Levine and Slade, 1990). Goff et al. (1993) also noted significant transition temperatures in ice cream at approximately -30°C. Currently, researchers are uncertain whether these transitions represented a true glass transition or simply the onset of melting. If it is the latter, then maintaining storage

temperatures below -35°C to achieve the glassy state is not necessary. The transitions noted by the above researchers were not detected in the samples tested during this study.

For onset melting temperatures, the fat free samples of both trials were significantly lower than all other samples of higher fat content (Table 4.4) and even though the peak melting temperatures of the low fat samples were also the lowest, they were determined to be statistically similar to the light samples for both trials.

For ΔH, the low fat samples of both trials had significantly higher values than all other treatment samples. Greater ΔH values mean that more energy was absorbed by a sample for the physical structure of the sample to fully collapse and melt. Thus, it is possible that the concentration of fat in low fat ice cream permitted optimal interaction with the modified starch to yield a more stable crystallized ice cream structure in comparison with other levels of fat. It can be postulated that the structural stability of ice cream containing modified starch as a fat replacer will be highly dependent on the level of fat and possibly involve the interaction among the fat, modified starch and ice crystals. Overall, relationships between the onset of melting, peak melting temperature and ΔH values, were not strong.

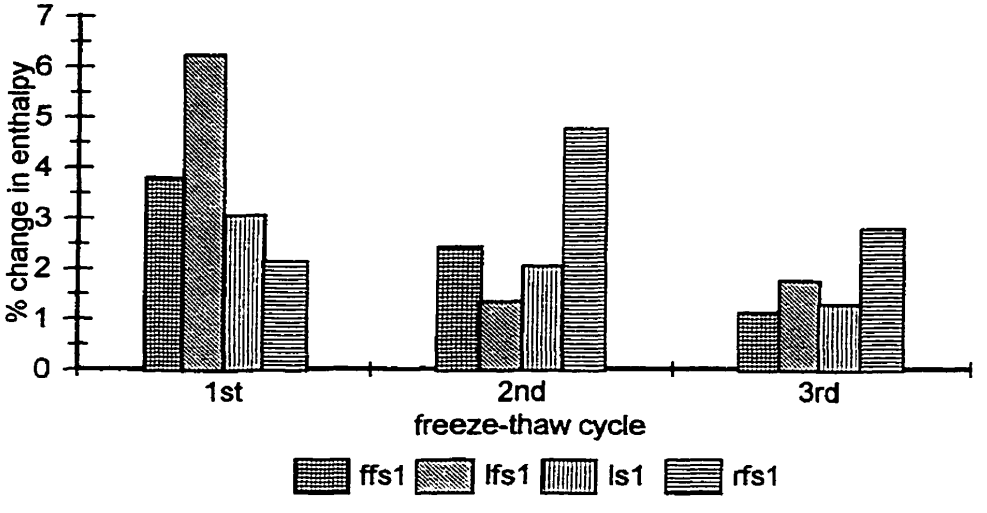
Temperatures associated with melting as determined by DSC analysis (Table 4.4) and the initial freezing patterns of samples (Figure 4.6) are not comparable because the agitation that occurs during continuous freezing does not occur during DSC analysis. The rapid agitation of continuous freezing enhances heterogeneous nucleation (Goff and Sahagian, 1996). Thus, an earlier release of latent heat is expected during agitated freezing tests as opposed to non-agitated freezing tests such as the DSC tests.

Table 4.4: Onset and peak melting temperatures and enthalpy (ΔH) of ice cream samples as determined by low temperature DSC.

Samples	Trial 1			Trial 2		
	Onset (°C)	Peak (°C)	ΔH (J/g)	Onset (°C)	Peak (°C)	ΔH (J/g)
fat free	-8.84 a	-5.06 a	53.21 a	-10.59 a	-5.08 a	68.01 b
low fat	-8.27 b	-4.05 c	85.32 c	-8.99 b	-4.34 b	80.68 c
light	-8.31 b	-4.86 ab	62.46 b	-8.34 c	-5.03 a	61.98 a
regular fat	-8.28 b	-4.67 b	64.24 b	-8.30 c	-4.43 b	68.63 b
standard error	0.105	0.084	1.04	0.107	0.135	1.6

values within a column with no common letter, significantly differ ($p<0.05$)

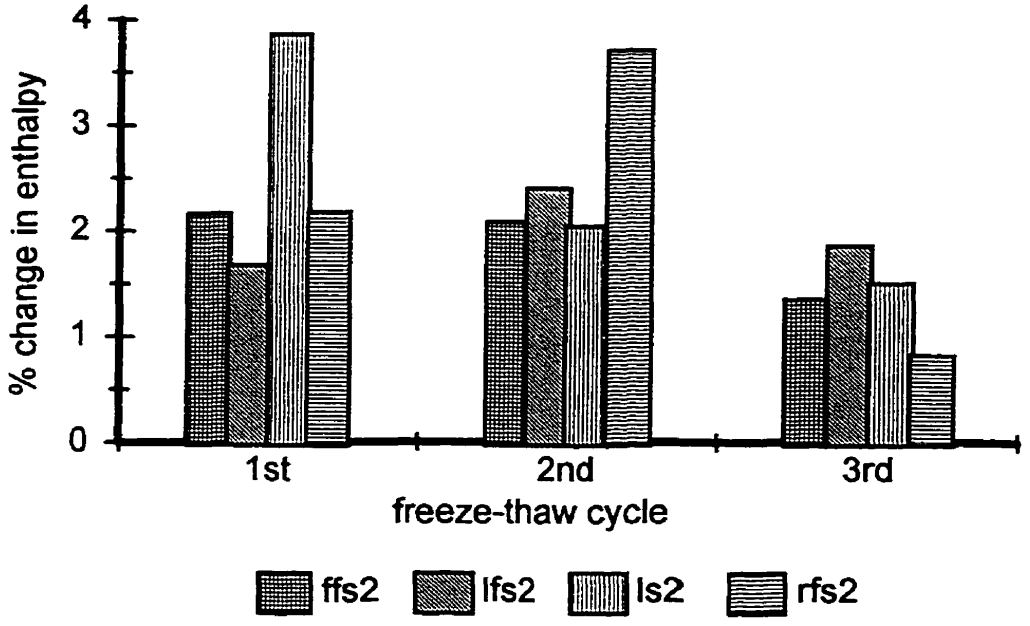
Figure 4.17: DSC assessment of freeze-thaw stability for samples prepared during sensory trial 1.



To evaluate freeze-thaw stability the percent change in melting enthalpy upon repeated DSC scanning of samples - without the use of fresh sample for each scan - was assessed. The melting enthalpy values are expected to decrease upon repeated freezing and thawing because after a sample is melted it will not re-freeze to its original crystalline structure. The sample is likely to re-freeze into a less structured crystalline network where less heat absorption is required for melting. In theory, samples which show little change in enthalpy upon repeated melting and re-freezing during DSC tests may also be stable against the temperature fluctuations during distribution and retail storage.

For trial 1, single freeze thaw cycles for the low fat samples show greater change in enthalpy than regular fat but the reverse was true after three freeze-thaw cycles (Figure 4.17). After three freeze-thaw cycles, the enthalpies for the reduced fat samples were similar although there were differences during the first two cycles. For trial 2 samples (Figure 4.18) the reduced fat samples showed less change than the regular fat samples after two freeze-thaw cycles however the reverse was true after three cycles. This evaluation technique did not seem to supply information valuable in predicting sensitivity to temperature fluctuations.

Figure 4.18: DSC assessment of freeze-thaw stability for samples prepared during sensory trial 2.



4.4.4 Apparent Thermal Diffusivity of Ice Cream during Hardening

The thermal properties of ice cream products are important to manufacturers in terms of end product quality and process energy expenditure. From a quality perspective, if fat reduced ice cream products have different thermal properties from regular fat products, the textures of the products will be different. For example, if fat reduced products take longer to freeze, a coarse texture can develop during hardening and storage due to the growth of larger ice crystals. Process energy expenditure is important because for every extra unit of time that a fat reduced product requires to be lowered to a

certain temperature, as compared to a regular fat product, the more energy that must be supplied to the cooling system responsible for the lowering of temperatures.

Thermal diffusivity is a thermal property which encompasses several critical properties which affect the freezing of ice cream. Properties which include product density, thermal conductivity and specific heat. The thermal conductivity (k) of a product provides, in quantitative terms, the rate at which heat will be conducted through a unit thickness of product and is thus described in J/s·m·°C or W/m·°C (Singh and Heldman, 1993). The thermal diffusivity (α)of a food material is a function of its thermal conductivity, density (ρ) and specific heat (C_p) because $\alpha = k / \rho * C_p$ and is expressed in $m^2 \cdot s^{-1}$.

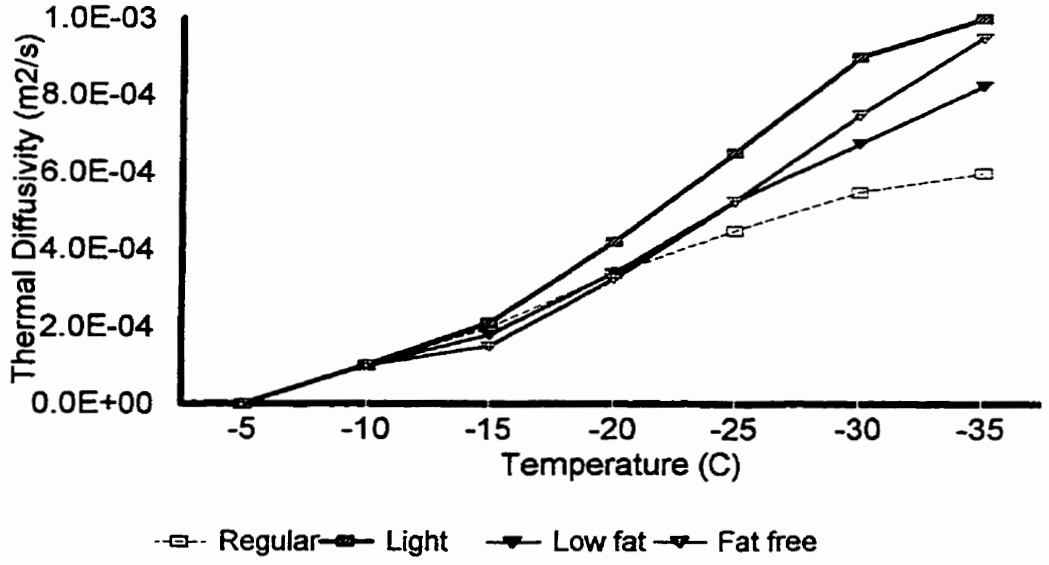
Clearly, ρ is an important factor and any conditions which may increase product ρ, such as lowering the fat content of a product, would be expected to decrease α. The average frozen product densities (Section 4.2) increased as the level of fat in formulations decreased. However, despite having the lowest density, the calculations did not demonstrate regular fat ice cream as being the most thermally diffuse substance (Figure 4.19). This may be related to the fact that all of the physical and thermal properties in ice cream can not be completely accounted for when deriving information on a semi-empirical basis. Relatively accurate estimates of the thermal properties of pure substances such as carbohydrate, protein, water, ice and air - all of which are ice cream components - are widespread in the food engineering literature. However, little information exists to provide a basis for assumptions on the thermal properties of the highly heterogeneous and concentrated unfrozen phase of ice cream. The unfrozen phase,

which in itself is a diverse mixture of pure substances, is extremely viscous at low temperatures which makes assumptions on its thermal properties difficult to develop. The complexity of the unfrozen phase in ice cream is probably an important factor contributing to poor correlations between calculated thermal properties and expected results. Overall, if thermal diffusivity was determined using a more non-empirical technique then the unexpected low diffusivity of the regular fat ice cream could be validated.

Factors which affect the ρ and therefore the α of frozen ice cream as well are air content or overrun and the ratio of water to ice. The α of air is $1.9*10^{-5}$ and the α of water is $1.4*10^{-7}$ $m^2 \cdot s^{-1}$ (Hayhurst, 1997). Thus, differences in overrun between samples (Table 4.1) would be expected to alter α to a greater extent than differences in water content. The water to ice ratio, however, is also a factor because the α of ice is approximately 9 times greater than the α of water (Franks, 1985). The differences in overrun did not appear to affect the calculated values for apparent thermal diffusivity (α_A) of treatment samples during hardening (Figure 4.19).

From drawing temperatures to approximately -17.5°C at the geometric center, all samples displayed similar patterns of increasing α_A with decreasing product temperature (Figure 4.19). At temperatures below approximately -17.5°C the α_A of low fat samples began to increase at a greater rate in comparison to other samples.

Figure 4.19: Apparent thermal diffusivity of ice cream during the hardening of samples from process trials 1 and 2 combined.



5 SUMMARY AND CONCLUSION

Based on the sensory data it is clear that a light ice cream that is equivalent to regular fat ice cream can be prepared using modified pea starch to replace the fat. While low fat or fat free ice creams were viewed to have similar properties, some of the attributes evaluated indicated there were differences between these two samples and the regular and light samples. This was particularly true for smoothness and mouth coating. In comparisons of the light ice creams to the low fat and fat free samples, similarities for the coldness, firmness, viscosity (trial 2) and smoothness, were demonstrated. Despite the similarities, the low fat and fat free ice creams did not reach the overall textural quality of the light ice cream. Differences in firmness and viscosity were dependent on the trial in that all samples in trial 1 had similar firmness values and all samples in trial 2 had similar viscosity data. Also for trial 2, the firmness of the low fat and fat free ice creams were similar to the light ice cream but different from the regular fat.

Instrumental firmness values also supported the conclusion that the light and regular fat samples were similar. Instrumental viscosity measurements were sufficiently sensitive to detect differences not noticeable to the trained panel. While the single point apparent viscosity data showed no trend in relation to the fat content, the consistency coefficients for samples with reduced fat content decreased with decreasing levels of fat. This would suggest that the factors contributing the viscosity are altered when the modified starch is included so that the influence of fat content is different from that in the regular fat sample.

For the continuous freezing properties, drawing temperatures and flow rates, the fat reduced samples were generally found to be similar to the regular fat ice cream. Interestingly, the light ice cream mixes demonstrated greater flow rates than the regular fat mixes during continuous freezing. Similar to the findings from both the sensory and instrumental texture analysis, the continuous freezing properties of fat free ice cream were not comparable to ice creams of higher fat content.

The time-temperature hardening profiles for 2 L boxes indicated that regular fat samples cooled at a more rapid rate than all other fat levels with light, low fat and fat free, each being viewed has having similar hardening patterns. The 10 L cylinder time-temperature profiles did not indicate regular fat ice cream to have a distinctly more rapid rate of cooling as was the case for the 2 L boxes. Clearly, factors other than ice cream composition played a significant role. Factors such as the package material and package dimensions undoubtedly contributed to the differences but likely of greater significance was the differences between package position within the hardening room in relation to the cooling air stream.

The melting properties as evaluated by the weight of melted ice cream vs time indicated that light ice cream was similar to the melting of regular fat ice cream than were the low fat and fat free ice creams for both process trials. The fat free ice creams were viewed as having melting properties comparable to low fat but not to the light or regular fat samples. The DSC findings for ΔH, onset and peak melting temperatures, did not show the same distinction of fat free and low fat from light and regular fat although some similarities were determined between the respective ice creams. The only

consistent finding between the two process trials was that in both cases the fat free ice creams were determined to have the lowest onset melting temperatures. The freeze-thaw analysis using DSC was largely inconclusive as to which samples might display the most stability although for both process trials the fat free samples demonstrated comparatively low percent changes in enthalpy.

The findings for thermal diffusivity did not appear to relate well to other freezing or melting results. It is probable that differences in the diffusivity of ice creams of varied fat content are only noticeable when very low temperatures are reached. Not until the temperatures at the geometric center of containers were below -18°C did differences between the diffusivity of ice creams and light ice cream in particular, appear evident. Difficulty in measuring the thermal properties of the unfrozen phase of ice cream at low temperatures and hence the lack of information from which assumptions can be based, were also detriments to generating accurate comparisons for diffusivity.

Overall, the research objectives fulfilled during this study were as follows. First, a sensory ballot for descriptive analysis of new and complex ice creams was developed and effectively utilized. Second, a modified starch fat replacer in light ice cream prepared under commercial-like process conditions was demonstrated to closely mimic the properties of regular fat ice cream during sensory, instrumental, freezing and melting analysis. Clearly, the ability to produce an ice cream with a reduced level of fat has been established but to generate a product that gives consistently good results with a fat content of less than 5%, requires further experimentation.

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APPENDIX 1

Submission for Ethical Review of Research Involving Human Subjects

1. Title:

Sensory Evaluation of Fat Reduced Ice Cream Products

2. Researchers:

D. Aime (graduate student), Dept. of Food Science; L. Malcolmson, D. Ryland, Department of Foods and Nutrition.

3. Purpose:

To evaluate the flavor and textural quality of fat reduced ice cream products.

4. Subjects:

A group of 10-12 people will be selected for training.

5. Risks, Benefits and Remuneration:

Ice cream samples of varying formulations will be evaluated for flavor and textural attributes. Subjects will be screened using a questionnaire to determine if they have any food allergies, food biases or if they are currently taking any medication which may influence their judgements. If for any of these reasons, subjects have to be eliminated from the panel, they will be notified in writing stating their unsuitability for participation in this particular study but will be invited to reply to future requests for panelists.

Panelists will benefit from this project by gaining skills in the area of sensory evaluation. Specifically, panelists will learn about flavor and texture discrimination techniques and protocols, and their abilities to make such judgements. Panelists will be rewarded with a $20 gift certificate after all of the sessions have been completed.

6. Procedures:

Preliminary: A letter with an explanation of the study (enclosed), a consent form (enclosed), a questionnaire (enclosed), and a timetable will be mailed to potential panelists in the Faculty of Human Ecology and other interested individuals.

Training: Panelists will undergo a training period which will involve: assessment of identified texture standards, direction and discussion on the protocol of texture and flavor evaluation, and agreement, through discussion, on different ice cream attributes and practice in judging the intensity of these coded samples. A minimum of seven 30 minute sessions will be required.

Testing: In each test session, the trained panelists will evaluate the intensities of attributes in a maximum of four ice cream samples. Panelists' results will be replicated and 2-4 test sessions will be required. The test site will be the computerized George Weston Limited Sensory and Food Research Center in room 400 of the Human Ecology building.

7. Procedure to obtain consent:

Written consent will be obtained prior to training.

8. Confidentiality:

Participants will be asked to sign a consent form which assures confidentiality. During training, the protocol involves personal declaration of scores in round-table discussions to reach consensus on methods of testing, on standards and reference samples, and on the distinction among possible attributes. Results from the study will be given as mean values and will not be reported by individuals' names nor will names be associated with the results. All data are retained in a locked filing cabinet in the laboratory with limited access.

Panelist Questionnaire
Ice Cream Evaluation

THIS INFORMATION WILL REMAIN STRICTLY CONFIDENTIAL

Name: _____

1. Have you participated on sensory evaluation panels before?

   Yes____ No____ If Yes,

   a) What product(s) did you evaluate?

   _____
   _____

   b) Was training part of the evaluation procedure?

   Yes ____ No ____ If Yes, please indicate for which product(s).

   _____
   _____

2. Are you allergic to any food products?

   Yes ____ No ____ If Yes, please note them below.

   _____

3. Are there any foods specifically, or food flavors generally that you prefer not to evaluate?

   _____

4. Do you take any medications which affect your senses?

   Yes ____ No ____

5. Do you have any dental work that may affect your ability to evaluate texture?

   Yes ____ No ____

6. Do you expect to be away for two or more consecutive weekdays prior to April 30/96?

   Yes ____ No ____ If Yes, please list them.

   _____

APPENDIX 2

TO: G. Sevenhuysen, Chair, Ethics Committee

FROM: L. Malcolmson, Foods & Nutrition Department

DATE: April 1, 1996

SUBJECT: Ethics Approval - Sensory Evaluation of Fat Reduced Ice Cream

Further to your memo of March 29th, please be advised that we have made the following changes as requested by the committee:

1. The following sentence has been added to the consent form:

   "Individual results declared during training will be kept confidential."

2. In the confidentiality section of the proposal, the statement "All data are retained in a locked filing cabinet in the laboratory with limited access." has been changed to "All data are retained in a locked filing cabinet in the laboratory with limited access by only the researchers."

cc. D. Aime, Food Science
D. Ryland

APPENDIX 3

DATE: 1 April, 1996

TO: Dr. L. Malcolmson, Foods and Nutrition

FROM: G. P. Sevenhuysen, Chair Ethics Review Committee

RE: Ethics Review: Sensory evaluation of fat reduced ice cream products, D. Aime and L. Malcolmson.

The Ethics Committee has reviewed the proposed research procedures you submitted on 22 March 96 and the update you provided on 1 April 96. The procedures meet ethical guidelines and the Committee approves the research procedures.

APPENDIX 4

CONSENT FORM

ICE CREAM EVALUATION

I agree to take part in the sensory evaluation of ice cream products which involves assessing their textural and flavor properties. Additional products may be assessed if found useful in describing the sensory properties of the ice cream samples.

I understand that this study will take place over a 1 month period and that remuneration will only be granted upon completion of the entire testing period.

I understand that results generated from this study will not be reported by individuals' names nor will any names be associated with the results. Any personal data will remain strictly confidential and will be destroyed upon completion of the thesis.

I agree to keep confidential the individual results that participants will declare during training.

I also understand that I am free to withdraw from the study provided that I notify the experimenter.

Name (please print) _____

Signature _____

Date _____

Daytime Telephone Number _____

University Address _____

APPENDIX 5

Table 5A.1: Analysis of variance for coldness (process trial 1).

source of variation	df	SS	MS	F	
				calculated (p</=0.01)	tabular (p</=0.01)
total	71	268.70			
treatments	3	39.96	13.32	4.01	4.41
panelists	8	59.34	7.42	2.23	3.08
replication	1	0.35	0.35	0.10	7.44
tr x p	24	52.77	2.20	0.66	2.38
error	35	116.28	3.32		

Table 5A.2: Analysis of variance for firmness (process trial 1).

source of variation	df	SS	MS	F	
				calculated (p</=0.01)	tabular (p</=0.01)
total	71	427.24			
treatments	3	85.61	26.54	6.94	4.41
panelists	8	64.66	8.08	1.96	3.08
replication	1	4.20	4.20	1.02	7.44
tr x p	24	128.76	5.36	1.30	2.38
error	35	144.01	4.11		

Table 5A.3: Analysis of variance for viscosity (process trial 1).

source of variation	df	SS	MS	F	
				calculated (p</=0.01)	tabular (p</=0.01)
total	71	349.20			
treatments	3	117.33	39.11	13.59	4.41
panelists	8	48.41	6.05	2.10	3.08
replication	1	1.00	1.00	0.35	7.44
tr x p	24	81.70	3.40	1.18	2.38
error	35	100.75	2.88		

Table 5A.4: Analysis of variance for smoothness (process trial 1).

source of variation	df	SS	MS	F	
				calculated (p</=0.01)	tabular (p</=0.01)
total	71	563.15			
treatments	3	289.41	96.47	36.32	4.41
panelists	8	49.76	6.22	2.34	3.08
replication	1	0.00	0.00	0.00	7.44
tr x p	24	131.01	5.46	2.06	2.38
error	35	92.96	2.66		

Table 5A.5: Analysis of variance for mouth coating (process trial 1).

source of variation	df	SS	MS	F	
				calculated (p</=0.01)	tabular (p</=0.01)
total	71	397.16			
treatments	3	99.37	33.12	10.83	4.41
panelists	8	113.37	14.17	4.63	3.08
replication	1	0.31	0.31	0.10	7.44
tr x p	24	77.02	3.21	1.05	2.38
error	35	107.09	3.06		

Table 5A.6: Analysis of variance for coldness (process trial 2).

source of variation	df	SS	MS	F	
				calculated (p</=0.01)	tabular (p</=0.01)
total	71	363.56			
treatments	3	15.53	5.18	1.83	4.41
panelists	8	147.37	18.42	6.52	3.08
replication	1	3.56	3.56	1.26	7.44
tr x p	24	98.16	4.09	1.45	2.38
error	35	98.93	2.83		

Table 5A.7: Analysis of variance for firmness (process trial 2) .

source of variation	df	SS	MS	F	
				calculated (p</=0.01)	tabular (p</=0.01)
total	71	500.56			
treatments	3	148.46	49.49	8.96	4.41
panelists	8	46.43	5.80	1.05	3.08
replication	1	4.21	4.21	0.76	7.44
tr x p	24	108.06	4.50	0.81	2.38
error	35	193.40	5.53		

Table 5A.8: Analysis of variance for viscosity (process trial 2).

source of variation	df	SS	MS	F	
				calculated (p</=0.01)	tabular (p</=0.01)
total	71	382.54			
treatments	3	75.14	25.05	5.71	4.41
panelists	8	53.37	6.67	1.52	3.08
replication	1	0.50	0.50	0.11	7.44
tr x p	24	99.92	4.16	0.95	2.38
error	35	153.61	4.39		

Table 5A.9: Analysis of variance for smoothness (process trial 2).

source of variation	df	SS	MS	F	
				calculated (p</=0.01)	tabular (p</=0.01)
total	71	434.72			
treatments	3	74.59	24.86	7.84	4.41
panelists	8	101.96	12.75	4.02	3.08
replication	1	1.42	1.42	0.45	7.44
tr x p	24	145.77	6.07	1.92	2.38
error	35	110.98	3.17		

Table 5A.10: Analysis of variance for mouth coating (process trial 2).

source of variation	df	SS	MS	F	
				calculated (p</=0.01)	tabular (p</=0.01)
total	71	335.15			
treatments	3	83.40	27.80	14.58	4.41
panelists	8	77.69	9.71	5.09	3.08
replication	1	4.55	4.55	2.39	7.44
tr x p	24	102.78	4.28	2.25	2.38
error	35	66.72	1.91		

NOTE TO USERS

The diskette is not included in this original manuscript. It is available for consultation at the author's graduate school library.

Appendix 6

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