Utilization of Commercial Pea Protein Isolate and Commercial Hydrogenated Canola Oils in the Development of a Non-Dairy Frozen Dessert

by

Albert Shiu Man Chan

A thesis
presented to the University of Manitoba
in partial fulfillment of the
requirements for the degree of
Master of Science
in
Food Science

Winnipeg, Manitoba

ISBN 0-315-63309-3

Canada

UTILIZATION OF COMMERCIAL PEA PROTEIN ISOLATE AND COMMERCIAL HYDROGENATED CANOLA OILS IN THE DEVELOPMENT OF A NON-DAIRY FROZEN DESSERT

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ALBERT SHIU MAN CHAN

A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

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ABSTRACT

Commercial pea protein isolate (PPI) prepared from yellow field peas (Pisum sativum L.) and blends of commercial hard (H) and soft (S) margarine oils (Canola) in various weight ratios were used as the sources of protein and fat, respectively, in the development of a non-dairy frozen dessert. Four PPI levels (3.5%, 5.0%, 6.5% and 8.0%) and five oil blends (%H/%S: 30/70, 40/60, 50/50, 60/40 and 70/30) were selected for developing the product formulation. All the frozen desserts were evaluated by a sensory panel using a nine-point hedonic scale for their overall acceptability and to identify the optimum oil blend/PPI level combination. It was found that a formulation containing by weight 10.50% fat, 3.50% PPI, 11.00% sugar, 11.00% glucose solids, 0.35% emulsifier/stabilizer and 63.65% water yielded a frozen dessert which was more preferred to the others as judged by the sensory panel. The optimum composition of the oil blend contained 60% hard and 40% soft margarine oil. The solid fat index of this oil blend at 10°C, 21.1°C and 33.3°C were 24.29, 13.20 and 2.97, respectively. The frozen desserts made with oil blends containing less than 50% hard margarine oil scored significantly lower than the most acceptable one. The use of PPI levels exceeding 5.0% resulted in frozen desserts that were significantly less acceptable than the most preferred one. This indicated that 5.0% was the maximum level of PPI which could be used in the manufacture of a satisfactory product.

ACKNOWLEDGEMENTS

I wish to thank Dr. Ronald Roy Pereira for his guidance and patience throughout this study, and his understanding and encouragement in my times of trouble. I would also like to express my gratitude to the following individuals who have made valuable contributions to this study: Dr. Sue Arntfield for performing the DSC analysis, George Davidson of Canada Packers, Inc. for carrying out the test for Solid Fat Index, Dr. Costas Biliaderis for the interpretation of the viscometry data, Gregg Morden and Val Huzel of the Soil Science Department for their assistance in the Kjeldahl analysis, Blaine Snell for photography in the melting quality study, Linda Neden of the Statistical Advisory Service for her advice on the analysis of the sensory evaluation data, Paul Stephen for the abundant supply of computer units, and the staff and students of the Departments of Food Science and Foods and Nutrition for their participation in the sensory panels. For their encouragement, I am grateful to Dr. Don Murray, Dr. Greg Blank, Dr. Costas Biliaderis and Arnie Hydamaka.

On a personal note, my sincere appreciation goes to my friends, both within and outside the department, who helped me through some very painful and trying times. To Francis, Philip, Hansen, Eva, Sue-Ellen, Lucia, Lucinda, Rick, Janine, Maureen, Pamela, Bill, Vien, Georgina, Mickey, Norman, Diana, Chris and Joe, I thank them all for making my burden more endurable. Finally, my deepest gratitude resides with my

parents, to whom I owe everything. I thank them for their unfailing faith and support through the years, and above all, for setting to me an example of commitment and perseverance in the face of adversity.

DEDICATION

To My Parents

and

To World Peace

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Chapter I

INTRODUCTION

Many dairy-like food products such as margarine and non-dairy coffee creamers have been developed over the years by the food industry utilizing materials of plant origin. The development of such products is in response to several factors. First of which is the rising costs and limitations on supply of dairy ingredients which prompted the food industry to turn to other sources of supply (Simmons et al., 1980). Second, the economics, availability, functional and nutritional properties offered by plant materials made potential product development possible (Morr, 1979; Rajor et al., 1983). Lastly, consumer demands for lower-priced and convenient food products, advances in food science technology and the increasing popularity of non-dairy products also promoted this trend (National Dairy Council, 1983; Lawhon et al., 1980).

In addition to these reasons, various segments of the population constitute a market for such products. One such segment is made up of individuals who are intolerant to lactose and/or milk proteins. Lactose intolerance is a common adverse reaction to cows' milk (Taylor and Cumming, 1985). Malabsorption of lactose due to a deficiency in the enzyme lactase in the human host may frequently lead to gastrointestinal discomfort and other symptoms (Taylor, 1986; Sandine and Daly, 1979). Nearly 70% of the world's adult population is lactase-deficient, however, such individuals may or may not develop the symptoms of lactose

intolerance (Savaiano and Levitt, 1987). Another commonly reported adverse reaction is cows' milk allergy (Emerson and Johnson, 1985). Bovine milk contains 18 to 25 proteins that are antigenic and can provoke allergic reactions in humans (Taylor, 1986). The prevalence of cows' milk allergy has been estimated as 0.3-7.5% of the population (Emerson and Johnson, 1985; Taylor, 1986).

Another group is comprised of individuals who are concerned with saturated fat intake in their diets. World-wide interest in physical fitness (Lusas and Rhee, 1986) and the recognition of the possible link between coronary heart disease and saturated fat intake in the diet (Porter, 1980) have raised consumer awareness in dietary planning in North America. Although dairy products are not the only foodstuffs which contain saturated fat and cholesterol, some have been targeted as undesirable. Such public attitude is reflected by the Agriculture Canada (1986) food consumption statistics between 1978 and 1985. A steady decline in consumption is shown in some dairy products such as homogenized whole milk (down from 42.70 to 31.87 L/person/year) and butter (dropped from 4.47 to 3.39 kg/person/year). An opposite trend, however, is observed in low-fat products such as partly skimmed 2% milk (up from 51.29 to 60.96 L/person/year) and skim milk (rose from 3.75 to 4.31 L/person/year).

Individuals who are unable to consume dairy products due to religious or ethical reasons make up the third group. Jewish dietary laws, for instance, prohibit the consumption of dairy food and meat food at the same meal (Fram, 1974; Sacharow, 1974). Vegetarianism, whether it is based on religion, ethics, health concern or personal reasons, may also occasionally exclude the use of food of animal origin (Simoons, 1982).

The rising numbers of these individuals represent a steadily growing market sector which the food industry has come to recognize. In order to meet the needs and demands of these consumers, increasing effort has been channelled into the development of new food products by the food industry. The dairy sector, for instance, has put forth many new products or substitutes for traditional products. Some examples are lactose-reduced milk, calorie-reduced ice cream, Nutri-whip and non-dairy frozen desserts. Of particular interest is the non-dairy frozen desserts because plant proteins and oils are usually utilized in these products to partially or completely replace milk proteins and butterfat. One such products which gained wide commercial success in the U.S. in the mid-1980's was Tofutti, an ice cream-like frozen dessert which contained soy protein and soy oil (Shurtleff and Aoyagi, 1985).

Due to the interest shown towards these non-dairy frozen desserts, an investigation was conducted to determine the feasibility of utilizing other sources of plant protein and oil for the development of such a product. Commercial pea protein isolate and commercial margarine oils (hydrogenated Canola oils) were used in this study for several reasons. These ingredients were selected for several reasons. First, green peas was the most widely cultivated horticultural crop in Manitoba (Agriculture Canada, 1986). If this trend continues, and since the manufacturer of the pea protein isolate is a Manitoba-based company, a steady supply of this relatively new plant protein isolate should be available if demands increase. Thus far, pea protein has been used as a meat extender in sausage (Delaquis, 1983) and as a protein fortifier for cereal products such as bread (Grant, 1983). Second, Canola is the most

important oilseed crop in Canada since it accounted for approximately 62% of the total vegetable oil production in July of 1989 (Statistics Canada, 1989). At present Canola oil is widely used as shortening oil, salad oil and in margarine production. Any attempts to develop more means of utilizing these domestic products are apparently important and logical in economic terms. Finally, at the academic level, this project is undertaken since no research has thus far been conducted to investigate the feasibility of developing a non-dairy frozen dessert based on hydrogenated Canola oils and pea protein isolate.

Chapter II

LITERATURE REVIEW

2.1 CLASSIFICATION OF FROZEN DESSERTS

Among the many types of frozen dessert available in North America, some can be grouped under the broad category of ice cream and related products. These include ice cream, frozen custard, ice milk, sherbet, water ice, frozen confections, and mellorine- and parevine-type products (Arbuckle, 1986). The latter two resemble ice cream and may be regarded as its imitations.

In the U.S., dairy-like foods which resemble or substitute for traditional dairy foods are referred to as imitation or substitute dairy products by the FDA definition (National Dairy Council, 1983). The imitation label generally implies nutritional inferiority. Dairy-like products are commonly manufactured by partially or completely replacing the milk proteins and/or fat with their vegetative counterparts. They are not considered as dairy products and can be divided into two categories: non-dairy and filled products. Filled products such as mellorine and coffee creamers are basically manufactured by combining non-fat milk solids with vegetable fat (Rahman, 1974; Weiss, 1983), whereas non-dairy products such as parevine and non-dairy whip toppings do not contain any dairy ingredients.

2.2 BACKGROUND OF THE USE OF PLANT PROTEINS AND/OR OILS IN THE MANUFACTURING OF DAIRY-LIKE PRODUCTS

The history of the use of vegetable proteins and oils in food production has been a long one. Tofu, for instance, a soybean product developed by the Chinese nearly two millenia ago, has remained in their diet until today. A margarine which contained predominantly coconut and palm kernel oils had appeared on the market by the turn of the century (Pritchett, 1974). In modern times, the interest in plant materials originated from the effort in the 1960's to combat global hunger problems (Lusas and Rhee, 1986). Some dairy-like products were proposed or developed as part of an effort to alleviate the extent of hunger and malnutrition in third world countries. Swaminathan and Papria (1967) gave details of the preparation of oilseed- and nut-based milk substitutes in the hope of overcoming milk shortage and improving the nutrition of the very young in developing countries. Chandrasekhara et al. (1971) developed Miltone, a toned milk product prepared by mixing peanut protein isolate with buffalo or cow's milk in an attempt to extend the milk supply for children in India. In the early 1970's, a whey-soy drink mix was also developed for preschool feeding programs in developing countries sponsored by U.S. aid (Wilding, 1979). The mix was made up of sweet cheese whey solids (41.7%), full fat soy flour (36.9%), soybean oil (12.3%), corn syrup solids (9.1%), and was supplemented with vitamins and minerals. Also in the 70's, Sosulski et al. (1978) experimented in formulating imitation and blended milk products based on legume protein isolates. Their study evaluated the protein isolates prepared by alkaline extraction and acid precipitation from ten legume species, including field pea, for their performance as the protein

source in imitation milks. However, all the imitation milks were significantly inferior to cow's milk in flavour and odour.

Currently, there are many dairy-like products on the market. Some widely known examples are coffee creamers and non-dairy whip toppings. These fabricated products contain vegetable fat and the protein usually used is sodium caseinate or isolated soy protein (Kolar et al., 1979). Soy-based infant formulas have been used as milk replacements for infants allergic to milk proteins (Thomson, 1979). Commercial production of sterilized and packaged soya milk in Hong Kong has been a successful venture since 1945 (Jonas, 1975; Steinkraus, 1978). Imitation and substitute cheeses containing vegetable fat have gained substantial popularity in the early 1980's in the U.S. (National Dairy Council, 1983). Commercial butter containing vegetable oil is currently produced in Sweden, Finland, Australia, the U.K., Switzerland, Japan, Canada and the U.S. (Madsen, 1985). Margarine, a butter-like product made from vegetable oil, has also gained a strong foothold in the market. Also available are ice cream-like products such as parevine and mellorine. Parevine is a non-dairy frozen dessert which is devoid of dairy and meat ingredients (Arbuckle, 1969). Mellorine is a filled product which resembles ice cream or ice milk (Weiss, 1983). Shurtleff and Aoyagi (1984) published the production methods for many soymilk products, some of which are manufactured commercially. Some examples are soymilk ice cream, soymilk mayonnaise, soy dressings, soy chip dip, soy popsicles, soy shakes, soymilk yoghurt and soymilk cheeses.

2.3 USE OF PLANT PROTEINS AND FATS IN THE DEVELOPMENT OF ICE CREAM-LIKE PRODUCTS

This section reviews some of the recent research conducted on the use of plant protein and/or fat in the manufacture of imitation ice cream.

2.3.1 Use of Plant Proteins in Ice Cream-Like Products

Soy protein has been utilized extensively in the food industry. Some attempts have been made to explore the possibility of utilizing other plant proteins. Lawhon et al. (1980) attempted to partially substitute membrane-produced oilseed isolates for milk-solids-not-fat at levels from 20% to 80% in soft-serve frozen desserts. The study found that soy , peanut and cottonseed storage protein isolates at substitution levels of 60%, 60% and 20%, respectively, did not cause any loss in the overall acceptability of the frozen desserts.

Cottonseed protein and soy protein ingredients were tried by Simmons et al. (1980) to partially replace the milk-solids-not-fat at levels from 5% to 80% in soft-serve frozen desserts. Cottonseed and soy flours, and soy protein concentrate were found to affect the overall acceptability of the frozen desserts at 40% substitution level and higher. Soy protein isolate at 80% substitution affected the overall acceptability of the final product. Glandless cottonseed storage protein isolate showed no significant effects on the acceptability of the final product and these researchers concluded that it might be used to substitute up to 80% of the milk-solids-not-fat in soft-serve frozen desserts.

El-Deeb and Salam (1984) used defatted glandless cottonseed flour, defatted soybean flour and faba bean flour to partially substitute milk-solids-not-fat in ice cream mixes. Their results showed that faba bean flour could be used at the 10% level to replace milk-solids-not-fat without adversely affecting the quality of the ice cream. Vanilla and cholocate ice cream with acceptable qualities could be made with defatted glandless cottonseed flour at 10% and 15%, respectively. The chocolate flavour was more effective than the vanilla in masking the defects in flavour and therefore permitted a higher substitution level. However, soybean flour incorporation was only successful at 10% substitution level. Higher levels resulted in flavour defects in the ice cream.

In India, a soft-serve ice cream was developed using soybean and buttermilk as part of an effort to provide lower-priced nutritious foods to the populace (Rajor and Gupta, 1982; Rajor et al., 1983). The soft ice cream mix was prepared by incorporating hydrogenated vegetable oil and sugar into a soybean-buttermilk slurry. The slurry was manufactured by grinding previously soaked, blanched and dehulled soybean in fresh sweet-cream buttermilk. The optimal mix formulation contained 9% fat, 15% sugar and a slurry with a soy solids to buttermilk solids ratio (on a fat-free basis) of 1.3:1.

Another Indian research group attempted to manufacture ice cream by incorporating groundnut protein isolate (Gabriel et al., 1986). Their study revealed that replacement of milk-solids-not-fat up to 40% did not affect the sensory qualities of the final product which was reported to contain more protein and cost less to produce.

2.3.2 Use of Vegetable Fats/Oils in Ice Cream-Like Products

Partial substitution of milk fat by vegetable fat in ice cream manufacturing has been tried in several studies. Youssef et al. (1981) substituted the fat in fresh cream with anhydrous butteroil, cottonseed and corn oils in ice cream production. Anhydrous butteroil at a substitution level of 50% did not affect the flavour, body and texture of the ice cream. Substitution level of 25% for cottonseed and corn oils was recommended as the upper limit at which no adverse effect was noticeable in the final product.

Partial replacement of milk fat with hydrogenated vegetable oil in ice cream making was attempted by El-Deeb et al. (1983). Their results showed that substitution of milk fat by hydrogenated oils decreased the overrun, the score on body and texture, and the rate of melting of the ice cream. Substitution levels higher than 10% in vanilla mix imparted an off-flavour to the ice cream. However, chocolate was found to be more effective than vanilla in improving the flavour of mixes containing hydrogenated oils. The researchers concluded that up to 35% of milk fat could be replaced by hydrogenated oils in chocolate ice cream with no adverse effects on the product quality.

Laustsen (1985) and Lautsen (1986) reported that two specialty vegetable fats, Polawar E 31 and Confao 5, were developed in Denmark. Polawar E 31 was a fat based on fractionated palm kernel oil. The nature of Confao was not disclosed. Laustsen (1985) claimed that these specialty fats offered lower prices, uniform quality, longer shelf life, improved consistency at room temperature, and neutral colour and taste.

Suggested applications of these fats were in filled milk, filled cream, filled coffee cream, yoghurt and ice cream.

2.3.3 Mellorine and Parevine

Mellorine and parevine are commercial ice cream-like products which are legally available only in some of the states in the U.S. Mellorine was first granted a legal status in Texas in 1951 and its sales are only permitted in several states (Borgstrom, 1976). The sales of mellorine are prohibited in Canada. Mellorine is a filled product in which milkfat has been replaced, in whole or in part, with vegetable fat (Shurtleff and Aoyagi, 1985). Regular mellorine contains a minimum of 6-10% fat while the low-fat version contains a minimum of 3-4%. Refined and hydrogenated vegetable fats are used in imitation ice cream, a mellorine-type product. The fats may be that of coconut, soybean, corn, cottonseed, or their combinations (Arbuckle, 1986). A typical formulation of imitation ice cream (mellorine) is shown in Table 1.

Parevine is a non-dairy frozen dessert which does not contain milk and meat products, or any of their derivatives (Arbuckle, 1969). However, eggs and egg products are permitted. Parevine is not federally regulated in the U.S., however, state standards do exist (Shurtleff and Aoyagi, 1985). The non-dairy frozen desserts permitted to be sold in Canada are in essence parevine-type products.

A variation of parevine is the all-vegetable frozen dessert. All the ingredients in this type of products are of plant origin. Typical formulations of parevine and all-vegetable frozen dessert are shown in Table 2 and Table 3, respectively.

TABLE 1

Typical Formulation of Imitation Ice Cream (Mellorine).

Constituents	Percentage
Water	60.60
Milk-solids-not-fat	12.00
Sucrose	12.00
Vegetable fat	10.00
Corn syrup solids	5.00
Stabilizer	0.30
Emulsifier	0.10
Vitamins A and D	optional
Total solids	39.40

Source: Arbuckle (1986).

TABLE 2

Typical Formulations of Parevine.

Constituents	Economy Mix #1 (%)	Medium Mix #2 (%)	Deluxe Mix #3 (%)
Water	68.00	67.00	64.50
Vegetable fat (pure)	10.00	10.00	10.00
Sugar	15.00	16.00	16.00
Whole egg solids or dry whole eggs	---	4.50[1]	9.00[2]
Low D.E. corn syrup solids or hydrolized cereal solids	3.00	2.00	---
Vegetable protein	2.00	---	---
Microcrystalline cellulose	1.50	---	---
Stabilizer	0.35	0.35	0.35
Salt	0.15	0.15	0.15
Total solids	32.00	33.00	35.50

Source: Arbuckle (1986).
1 Can be replaced by using 18 fresh whole eggs per 100 lb of mix.
2 Can be replaced by the use of 26 fresh whole eggs per 100 lb of mix.

TABLE 3

Formulations of All-vegetable Frozen Dessert.

Ingredients	2% fat mix (%)	4% fat mix (%)	10% fat mix (%)
Water	67.50	67.25	66.70
Corn sweetener (36 D.E.)	14.00	13.00	10.00
Fructose (5/S)	14.00	12.00	10.00
Vegetable fat	2.00	4.00	10.00
Soy protein	2.00	4.00	3.00
Stabilizer/emulsifier	0.50	0.45	0.30
Total solids	32.50	32.75	33.30

Source: Arbuckle (1986).

2.4 INGREDIENTS IN ICE CREAM AND NON-DAIRY FROZEN DESSERTS

Ice cream is a frozen foam prepared by simultaneous aeration and freezing of a pasteurized mix. The basic components of the unflavoured mix are milk-solids-not-fat (proteins), milkfat, sweeteners, emulsifiers and stabilizers (Table 4). Canadian federal standards (Food and Drugs Act, 1982) require that an ice cream mix must have a minimum total solids of 36% and a fat content of 10%, or 8% if chocolate syrup is added. This section will discuss the functions and sources of these ingredients.

TABLE 4

Approximate Composition of Different Grades of Ice Cream.

Ice cream Grade	Constituents (%)				
	Milkfat	MSNF	Sugar	Stabilizers/ Emulsifiers	Approximate total solids
Economy	10.0 12.0	10.0-11.0 9.0-10.0	15.0 13.0-16.0	0.3 0.2-0.4	35.0-37.0
Trade Brand	12.0 14.0	11.0 8.0-9.0	15.0 13.0-16.0	0.3 0.2-0.4	37.5-39.0
Deluxe	16.0	7.0-8.0	13.0-16.0	0.2-0.4	40.0-41.0
Premium- Super premium	18.0-20.0 20.0	6.0-7.5 5.0-6.0	16.0-17.0 14.0-17.0	0.0-0.2 0.25	42.0-45.0 46.0

Source: Arbuckle (1986).

2.4.1 Protein

2.4.1.1 Milk Proteins

Bovine milk is composed of water, fat, protein, lactose and minerals (Table 5). The constituents other than water and fat are collectively referred to as milk-solids-not-fat (MSNF). These materials are also termed skim milk solids or serum solids. Milk-solids-not-fat in the form of nonfat dry milk contains approximately 3.0% moisture, 0.9% fat, 37.0% protein and 51% lactose (Arbuckle, 1986). The most important components of MSNF are the milk proteins, namely the casein and whey proteins.

Of all the proteins in milk, casein accounts for approximately 80% (Brunner, 1978). This protein contains many components, but αs_1-, αs_2-, ß- and k-caseins have been identified as the major ones (Dalgleish, 1982).

TABLE 5

Approximate Composition of Bovine Milk.

Components	Percentage
Water	87.43
Fat	3.70
Protein	3.50
Lactose	4.90
Minerals	0.70
Solids-not-fat	9.10

Source: Henderson (1971).

Casein exists in milk as colloidal particles termed micelles (Fox and Mulvihill, 1982). The micelles vary from 20 to 300 nm in diameter (Schmidt, 1980) and assume a highly porous and hydrated spherical structure (Schmidt and Morris, 1984). This structure is an aggregate of numerous submicelles which range from 10-20 nm in diameter (Morr, 1985). The submicelles are in turn made up of molecules of the different caseins ie. αs_1-, αs_2-, β- and k-caseins. Both the micelles and submicelles are not static structures. There are continuous exchange reactions between micelles and serum submicelles (Schmidt and Morris, 1984); and between submicelles and serum casein molecules (McMahon and Brown, 1984).

All casein monomers are low in molecular weight in comparison to other food proteins. In general the casein polypeptide chain possesses a fair number of uniformly distributed proline residues which limits the α-helix or β-sheet formation (Modler, 1985) and this results in an open random coil structure (Morr, 1982). The polypeptide chains contain very

few sulphydryl groups and do not rely on disulphide linkages to provide structural stability (Dalgleish, 1982). This also renders casein a high degree of heat stability. Clusters of acidic (carboxyl and ester phosphate) and hydrophobic residues are distributed unevenly along the polypeptide chains, leading to the formation of distinctive hydrophilic and hydrophobic regions (Morr, 1982; Kinsella, 1984). This molecular arrangement gives the molecule its amphiphilic properties.

Whey or serum proteins make up 20-25% of the total proteins in milk (Borst, 1978). The two principal fractions of whey proteins are ß-lactoglobulin and α-lactalbumin which constitute 70-80% of this protein group.

In milk, ß-lactoglobulin exists as a dimer with a molecular weight of approximately 36,000 (Lim, 1980). Each monomer contains two disulphide bonds and one free sulphydryl group (Kilara and Sharkasi, 1986), and the two monomers are joined by disulphide linkages (Schmidt and Morris, 1984). It is because of the presence of the sulphydryl groups that ß-lactoglobulin is sensitive to heat denaturation and intermolecular interaction (Morr, 1985). Beta-lactoglobulin has a compact and rather spherical structure which owes it to a relatively low proline content that permits a substantial helical content in the conformation (Lim, 1980; Morr, 1982). Acidic and basic residues, as well as hydrophobic and hydrophilic ones, are uniformly distributed along its polypeptide chain (Evans, 1986). The result is the lack of amphiphilic properties in the molecule.

Alpha-lactalbumin is a very compact, nearly spherical single-chain globulin with a molecular weight of approximately 16,000 (Schmidt and Morris, 1984). Alpha-lactalbumin contains four intramolecular disulphide bonds and no sulphydryl groups, it is therefore less susceptible than ß-lactoglobulin to heat denaturation (Schmidt and Morris, 1984; Kinsella, 1984).

2.4.1.2 Functions and Sources of Milk Proteins in Ice Cream

The proteins in the MSNF serve several functions in ice cream. The most obvious one is their high nutritional qualities (Swartz and Wong, 1985) which increase the nutritional value of ice cream. Casein, due to its amphiphilic properties, acts as an emulsifying agent and helps to stabilize the oil in water emulsion of ice cream (Julien, 1985). The milk proteins also act as stabilizers as they are able to hold water through hydration (Hamilton, 1983). The results are an increase in the mix viscosity and the retardation of the forming of large ice and lactose crystals during the freezing process and during storage. The increased viscosity improves the whipping quality of the mix, and once foaming begins the entrapped air bubbles are stabilized by a layer of fat which may have complexed with denatured milk proteins (Berger et al., 1972b). The presence of large ice and lactose crystals in ice cream gives the product an undesirable texture which is manifested by an icy, gritty and sandy mouthfeel. On the whole, the milk proteins in the mix give body, structure and consistency to the finished ice cream.

The lactose and minerals in the MSNF also serve some functions in ice cream. Lactose, though not a potent sweetening agent, nevertheless contributes a small degree of sweetness to ice cream. But crystalliza-

tion of lactose during the freezing process due to excessive amounts of lactose; and during storage because of fluctuating temperatures gives the finished ice cream a sandy texture. The minerals, on the other hand, help to enhance the flavour of ice cream. Both the lactose and the minerals also depress the freezing point of the mix (Iversen, 1983), although not to the extend as shown by the sugars in the mix.

In the production of ice cream, milk is commonly used as a dispersion medium for other ingredients. Milk also provides some of the MSNF required in the ice cream mix. About 10-11% of MSNF is needed in a typical ice cream mix in order to produce a good ice cream (Rothwell, 1984). Since milk contains only 9% of MSNF, the use of a concentrated source(s) of MSNF is necessary in order to reach the desired levels. These sources include buttermilk, nonfat dry milk/skim milk powder, whole milk powder, condensed/evaporated milk, whey protein powder/ concentrate and caseinates.

2.4.1.3 Pea Proteins

Peas (Pisum sativum L.) belong to the family Leguminosae (Pomeranz, 1985). The general composition of peas is shown in Table 6.

Pea seed protein is composed of mainly globulins and a smaller fraction of albumins. The albumins account for 13-14% of the total protein (Grant et al., 1976) and are largely of cytoplasmic origin (Pate, 1977). Pea albumins consist of many subunits which range from 18,000 to 90,000 daltons in molecular weight (Mosse and Pernollet, 1983). The albumins contain more sulphur amino acid residues than the globulins.

TABLE 6

General Composition of Peas.

Constituents	Percentage
Water	78.2
Protein	5.8
Fat	0.4
Carbohydrates	8.1
Fiber	5.6
Organic acids	0.19
Ash	0.7

Source: Wills et al. (1984)

The globulins are storage proteins predominantly located in the cotyledons (Pate, 1977). They account for nearly 80% of the total protein in mature pea seeds (Boulter, 1983). Three types of these globulins have been recognized thus far: legumin, vicilin and convicilin (Boulter, 1983).

2.4.1.4 Manufacture of Pea Protein Preparations

Pea protein preparations can be conventionally manufactured by either dry or wet process. In the dry process as described by Sosulski and Sosulski (1986), dehulled pea seeds are reduced by pin milling to a flour of desired particle size which is then separated into a protein-rich and a starch-rich fraction by air-classification. The starch fraction is reclassified to separate the residual protein which is combined with the first protein fraction to yield pea protein concentrate. The wet processing method is a slightly more complicated procedure (Sumner et al., 1981 Sosulski and Sosulski, 1986). In general, the proteins are

extracted from pea flour under alkaline conditions. Non-protein materials are removed and extracted for residual proteins. The protein extractions are combined and centrifuged to separate the starch. By adjusting the purified protein extraction to pH 4.5 with acid, the proteins are precipitated and then separated from the whey. To prepare a salt of the protein (proteinate) the curd is neutralized with an alkali (usually NaOH) and then dried. If an isoelectric protein isolate is desired, the curd is redissolved in alkali, reprecipitated with acid, washed and then dried.

The commercial PPIs' used in this study were prepared from the seeds of yellow field pea (Pisum sativum L. var. Century or var. Trapper) by Woodstone Foods Ltd., Portage la Prairie, Manitoba, using an acid extraction method patented by Nickel (1981). Due to the proprietary nature of the process, detailed information on the manufacturing process is not available. Briefly, dehulled peas are wet-milled in water to give a slurry from which the proteins are extracted by lowering the pH to 2.5-3.0 with acid. The solubilized proteins are then separated from the non-protein materials, precipitated at pH 4.5, neutralized and spray-dried.

Due to the severe extraction conditions, the structure of the proteins which influences the functionality of the protein isolate can be drastically altered. One analytical method which evaluates the extent of denaturation as a reflection of the functional integrity of a protein extraction is Differential Scanning Calorimetry (DSC). This method was also used in this research to determine the severity of denaturation of the pea protein isolate. It is therefore relevant to briefly review the principles of this method in the following section.

2.4.1.5 Differential Scanning Calorimetry (DSC)

Differential scanning calorimetry (DSC) is a thermoanalytical technique which measures the thermal energy absorbed or released when a substance/system undergoes a change in state, be it as the result of a physical or chemical process (Wright, 1982). In the operation of DSC, a sample and a thermally inert reference material are maintained in the same thermal environment while heat is applied to both at a programmed rate (Sleeter, 1985). The thermal energy absorbed or evolved i.e. an increase or decrease in the enthalpy by the sample causes its temperature to exceed (exotherm) or lag (endotherm) that of the reference. Such a differential heat flow is recorded as ΔT (temperature difference) or millicalories per second as a function of the temperature program range or time and is normally shown as a peak on a thermogram.

The DSC thermogram directly yields some important information concerning a given sample. Readily obtainable from the thermogram is the enthalpy change (ΔH) associated with the transition (Wright, 1982). The area under the peak is directly proportional to the enthalpic change and the direction of the peak indicates whether the transition is endothermic or exothermic (Biliaderis, 1983). A downward peak indicates an endothermic process while an upward one depicts an exothermic process (Arntfield and Murray, 1981).

The temperature at which a transition takes place is also shown directly on the thermogram. This temperature is commonly indicated by the peak maximum temperature which has been denoted by the symbols Td, T'm, Tm, Td and Tmax (Wright, 1982). In the case of proteins, this is referred to as the denaturation temperature.

Processing conditions such as temperature, pH and ionic strength influence the molecular conformation of protein molecules and thus determine the degree of denaturation of the protein preparation. Partial denaturation of a protein resulted from processing will be reflected by the lowering of the ΔH while complete denaturation will not yield an endothermic transition (Biliaderis, 1983).

2.4.2 Fat

2.4.2.1 Milkfat

Cow's milk contains an average of 3.70% fat (Henderson, 1971). The fat exists in milk in the form of globules held in a state of emulsion (oil in water). The size of the fat globules ranges from 0.1 to 10 um in diameter and varies with the breed of cow, stage of lactation and individual cow (Atherton and Newlander, 1977). The globules are enclosed by a thin membrane known as the milk fat globule membrane (MFGM). This membrane is approximately 10 nm thick and is composed of proteins, phospholipids, glycoproteins, triglycerides, cholesterol, enzymes and other components (McPherson and Kitchen, 1983). The MFGM functions as a barrier which protects the milkfat from the action of milk lipase and as a natural emulsifier that maintains the fat globules in the aqueous phase. Nevertheless, fat globules tend to cluster because of the protein agglutinins on the MFGM surface and separate from the milk serum due to gravity and difference in density i.e. creaming.

The creaming phenomenon can be retarded by means of homogenization. The process reduces the fat globules to less than 1 um in diameter which largely eliminates the tendency of creaming. However, the reduction of fat globule size results in a tremendous expansion in surface area and

the original MFGM materials are no longer adequate to surround all the newly formed fat particles. As a result, MFGM fragments and the milk proteins adsorbed onto the fat particle surface and form the new (artificial) membrane which is less prone to clustering. In ice cream mixes, the added emulsifiers are also a component of this new membrane. Its formation and composition are results of random interactions among the materials surrounding each fat globule as it is formed (Berger and White, 1976a). Upon cooling, the membrane moves into a more stable state through structural rearrangements.

Milkfat is a diverse mixture of glycerides of fatty acids (Atherton and Newlander, 1977). The physical properties of milkfat therefore depend on the proportions and properties of the component fatty acids. The proportions of the fatty acids and triglycerides are in turn strongly influenced by factors such as feeding conditions and lactation stage (Frede et al., 1985). Several hundred of fatty acids have been identified in milkfat but only ten make up the majority (90%) of the fatty acid composition (Munro and Illingworth, 1986) and have significant influence on the behaviour of the fat (Rajah, 1986). These include five short chain saturated fatty acids (4:0, 6:0, 8:0, 10:0 and 12:0), three long chain saturated fatty acids (14:0, 16:0 and 18:0) and two long chain monoenoic fatty acids (18:1, cis- and trans-) (Munro and Illingworth, 1986).

Milkfat has a wide melting range instead of a sharp melting point due to its heterogeneous composition (Mortensen, 1983). At or above 40°C milkfat exists as a liquid, and as a solid at or below -40°C. Within this temperature range, milkfat contains both solid and liquid fats.

The melting range of milkfat can be divided into three regions: <0°C, 0°-20°C, and >20°C (Munro and Illingworth, 1986). Table 7 shows the concentration and composition of the milkfat in each region.

TABLE 7

Concentration and Composition of Milkfat in Each Melting Range Region.

Melting Range (°C)	Concentration (%)	Composition
<0	35 - 40	low molecular weight unsaturated triglycerides
0 - 20	45 - 50	low molecular weight saturated triglycerides or high molecular weight monoene triglycerides
>20	10 - 15	high molecular weight saturated triglycerides

Source: Munro and Illingworth (1986).

2.4.2.2 Functions and Sources of Milkfat in Ice Cream

Milkfat plays several roles in ice cream. The most important one is to impart the unique rich, creamy flavour to the product (Potter, 1980). The characteristic milkfat flavour is such a complex phenomenon that thus far it has been impossible to duplicate. Milkfat also improves the body and texture of ice cream as the fat crystals play an integral part in the structure of ice cream. The lubricating effect of fat in the mouth also contributes a smooth texture to ice cream (Berger and White, 1979). A high-fat ice cream is remarkably smoother than one with less fat (Fouts and Freeman, 1948). But fat is a foam depressant, high levels of fat and excessive churning of fat during the freezing process impair the whipping quality of ice cream mixes (Berger et al., 1972a).

In nutritional terms, milkfat is a source of calories, fatty acids and four fat-soluble vitamins.

As indicated earlier, milk serves as a source of MSNF. However, liquid whole milk also contains an average of 3.70% milkfat. This fat must be taken into consideration when formulating an ice cream mix. In Canada, the legal minimum fat content of plain ice cream mixes is 10%. Other sources of milkfat must therefore be furnished in order to meet this requirement. These sources include fresh cream, frozen cream, plastic cream, butter and anhydrous milkfat.

2.4.2.3 Sources and Composition of Canola Oil

The name "Canola" is a registered trademark of the Canola Council of Canada (Ackman, 1983). The name is used to designate newly developed rapeseed (Brassica napus and Brassica campestris) cultivars that are low in both erucic acid (<5% of total fatty acids) and glucosinolates (<3 mg equivalents of 3-butenyl isothiocyanate per gram of oil-free dried meal) (Boulter, 1983). These cultivars are also termed as "double-low" because they contain low quantities of the two aforementioned factors. Canola oil is the oil extracted from the whole seeds of such rapeseed cultivars. Between 1971 and 1981, six rapeseed varieties of the Canola type had been licensed. These included four varieties of Brassica napus (Tower, Regent, Altex and Andor) and two of Brassica campestris (Candle and Tobin), all of which is characterized by a high oil content (>40%, dry basis) (Daun, 1983). Almost all of the rapeseed grown in Canada is of the Canola type (Boulter, 1983). In July of 1989, Canola accounted for about 62% of the total vegetable oil production in Canada (Statistics Canada, 1989).

The Canola oil used in margarine production requires it to be specifically formulated in order to render the end product the desired characteristics. Margarines made with pure Canola oil have been reported to develop a grainy or chalky texture after a few months of storage because of the fine crystal structure of Canola oil (Anon., 1981). Such defects can be rectified by blending Canola oil with other oils of varying hardness to improve the smoothness of margarine. The base oils for hard (print or stick) and soft (tub) margarines are therefore made by blending base stocks whose number and sources vary among margarine manufacturers (Teasdale and Mag, 1983). Tables 8, 9 and 10 show the solid fat index of some of these base stocks and the formulae for hard and soft margarine oils.

TABLE 8

Solid Fat Index of Hydrogenated Canola Oil, Hydrogenated Soybean Oil and Palm Oil Used as Ingredients for Formulating Hard and Soft Margarine Base Oils.

	Hydrogenated Canola Oil				Hydrogenated Soybean Oil		Palm Oil
Oil Stock	C1	C2	C3	C4	SB4	SB5	
Temperature (°C)	Solid Fat Index (ml/kg)						
10	4	12	38	50	50	60	22-28
21.3	2	5	20	40	40	45	15-20
33.3	0	0	2	15	15	30	7-10

Source: Teasdale and Mag (1983).

The composition of Canola and high erucic acid rapeseed (HEAR) oils is shown in Table 11. Canola oil is characteristic among vegetable oils in two respects. First, the levels of the major saturated fatty acids,

TABLE 9

Formulae for Hard (Print) Margarine (PM) Oils.

	Types of Print Margarine (PM)							
Ingredient (%)	PM1	PM2	PM3	PM4	PM5	PM6	PM7	PM8
Liquid Canola oil	---	---	---	---	---	---	20	50
C1	60	60	51	51	---	55	45	---
C2	---	---	---	---	65	---	---	---
C3	---	---	---	---	---	20	---	---
C4	40	---	---	34	35	---	---	---
SB4	---	40	34	---	---	25	---	---
SB5	---	---	---	---	---	---	35	50
Palm Oil	---	---	15	15	---	---	---	---

Source: Teasdale and Mag (1983).

TABLE 10

Formulae for Soft Margarine (SM) Oils.

	Types of Soft Margarine (SM)			
Ingredient (%)	SM1	SM2	SM3	SM4
Liquid Canola oil	80	---	---	68
C1	---	85	75	---
C4	---	15	---	---
SB5	20	---	25	17
Palm oil	---	---	---	15

Source: Teasdale and Mag (1983).

palmitic and stearic, which amount to 5-6% (Ackman, 1983), are the lowest among the major edible oils (Downey, 1983). Second, the mono-unsaturated fatty acid content is quite high (ca. 60%) with oleic (18:1) being the predominant species (Ackman, 1983). This phenonmenon is the result of the inability of low erucic acid rapeseed (LEAR) plants to

synthesize erucic acid (22:1) from oleic acid which is consequently accumulated (Downey, 1983). However, hydrogenated Canola oils are used in the formulation of margarine oils. As hydrogenation lowers the unsaturated fatty acid content of an oil, the margarine oils will as a result contain different proportions of these fatty acids.

TABLE 11

Major Fatty Acids of Canola oil and High Erucic Acid Rapeseed (HEAR) Oil.

Fatty acids	Canola oil (%)	HEAR oil (%)
Palmitic (16:0)	2- 5	3- 5
Stearic (18:0)	1- 3	1- 3
Oleic (18:1)	53-58	18-27
Linoleic (18:2)	19-23	14-18
Linolenic (18:3)	8-12	8- 9
Gondoic (20:1)	1- 2	12-14
Erucic (22:1)	<1- 4	25-45

Source: Teasdale and Mag (1983).

2.4.2.4 Solid Fat Index (SFI)

The Solid Fat Index (Method Cd 10-57) of the American Oil Chemists' Society (AOCS) has been widely accepted as an empirical tool to characterize fats according to their solid-liquid contents (Walker and Bosin, 1971). This method is a dilatometric technique which measures the change in volumes as stabilized fats expand or contract when being melted or solidified at a given temperature (Rossell, 1986). In the AOCS method, solid fat indices are determined at 10.0°C, 21.1°C, 26.7°C, 33.3°C and 37.8°C to characterize shortenings and margarine oils. SFI

is expressed in units of milliliters solid fat per kilogram of fat (ml/kg). SFI values range from 0 for fully liquid oils to 80-100 for nearly solid fats.

SFI is an indicator of the amount of solid fat present in a fat sample (Waddington, 1986) or is used to indicate the extent of crystallization of fats and oils (Birker and Padley, 1987). It does not measure the true solids content of a fat which can be determined by Differential Scanning Calorimetry or Nuclear Magnetic Resonance Spectroscopy (Walker and Bosin, 1971). SFI is also not an indicator of the melting point of a fat as the relationship between SFI and melting point is dependent on the nature of the fat in question (Weiss, 1983).

2.4.3 Sources and Functions of Sweetening Agents

The Canadian Food and Drug Regulations (1982) dictate that ice cream shall be sweetened with sugar, liquid sugar, invert sugar, honey, dextrose, glucose, corn syrup solids, or any combination of these sweeteners. In practice, the most widely used ice cream sweetening agent is the combination of sugar(sucrose) and corn syrup solids (Julien, 1985). The following discussion will therefore focus on these two sweeteners.

2.4.3.1 Sources of Sucrose and Corn Syrup Solids

Sucrose is a dissacharide composed of a molecule of glucose and fructose. The sources of sucrose are cane and beet. Some advantages of using sucrose in ice cream are its availability, simple production methods, relative low cost and long history of use (Inglett, 1981). Sucrose can be used in either a syrup or granular form. Granulated

sugar must contain a minimum of 99.8% sucrose as required by the Canadian Food and Drug Regulations (1967).

Corn sweeteners are manufactured by converting corn starch molecules to fragments of different chain lengths through hydrolysis by acid, acid-enzyme and enzyme processes (Hobbs, 1986; Newsome, 1986). Corn syrup (glucose syrup) and dried corn syrup (dried glucose syrup) must have a minimum of 20 dextrose equivalent (D.E.) as required by the Canadian Food and Drug Regulations (1984). Dextrose equivalent is an indicator of the extent to which starch has been converted to glucose (Hobbs, 1986). It measures the percentage of reducing sugars, calculated as dextrose, based on total dry substance (Hoynak, 1974). Corn syrups in liquid or dry form are commonly classified according to their D.E. values (Julien, 1985): low conversion (30-35 D.E.), medium conversion (~50 D.E.), and high conversion (≥60 D.E.). The properties of corn syrups are determined by the degree of hydrolysis of corn starch i.e. D.E. (Goff et al., 1983). As the D.E. value increases, the glucose content increases while the content of water-binding dextrins decreases. In other word, with increasing D.E., corn syrups become sweeter and more effective in lowering the freezing point of the mix but less effective in imparting viscosity to it. Low and medium D.E. corn syrups are usually used in ice cream manufacture.

2.4.3.2 Functions of Sweeteners

The obvious role of sweeteners in ice cream is to give sweetness and to enhance flavour. Sweeteners are also a major and economic source of solids which, if adequate in quantity, give body and a fine texture to

ice cream (Fouts and Freeman, 1948). A good average ice cream contains 14-16% of sweeteners. Further, sweeteners lower the freezing point of ice cream mixes to prevent them from becoming a rigid frozen mass inside the freezer (Potter, 1980). Sweeteners also improve the texture of the finished ice creams by controlling the amount of ice crystals formed during freezing and storage (Harper and Shoemaker, 1983). But excessive amounts of sugar in the mix will impair its ability to absorb air during the freezing process.

As mentioned earlier, a combination of sucrose and corn syrup solids is widely accepted as a sweetening agent in ice cream production. The purpose of this practice is to partially replace sucrose with corn sweeteners. Between one-quarter to one-third of the sweetening agents in ice cream can be corn sweeteners (Arbuckle, 1986). There are two reasons for such practice. First of which is to increase the total solids of the mix without increasing its sweetness and at the same time lower the cost of the mix (Mahdi and Bradley, 1969). Corn syrups are ideal for this purpose because they are less sweet and are compatible with sucrose and food flavours used in ice cream manufacture (Pomeranz, 1985). Second, the use of lower D.E. corn syrups helps to control sucrose crystallization (Hoynak, 1974), increases the mix viscosity which in turn gives a firmer and smoother ice cream (Goff et al., 1983). Ice cream containing corn syrups also show increased resistance to heat shock during storage and more uniform melting (Pomeranz, 1985).

2.4.4 Functions and Sources of Stabilizers

2.4.4.1 Functions of Stabilizers

Stabilizers used in ice cream production are generally hydrophilic colloids or hydrocolloids, commonly known as gums (Sharma, 1981). Gums are usually high molecular weight polysaccharides that dissolve or disperse in water to give a thickening and/or gelling effect (Igoe, 1982). This phenomenon is due to the ability of gums to bind and immobilize large amounts of water (Andreasen, 1985). Stabilizer gums are used in very low quantities but are effective in performing several important functions in ice cream. First of which is to stabilize the oil/water emulsion in ice cream mix (Glicksman, 1984). This is made possible by: (i) the ability of stabilizers to increase the viscosity of the aqueous phase, thereby lowering the frequency of collision of the emulsion droplets that results in agglomeration and (ii) the film-forming properties of some gums which enable their molecules to surround the fat globules to form a barrier against coalescence.

The second function of stabilizers in ice cream is to retard the growth of lactose and ice crystals during storage. Tipson (1956) theorized that a stabilizing agent can inhibit ice crystal growth by: (i) adsorbing on ice crystal surfaces to prevent further expansion, (ii) limiting the mobility of free water by its water-binding properties, (iii) complexing with crystallizing materials, and (iv) enhancing the solubility of crystalline materials. The size and number of lactose and ice crystals can increase during prolonged storage. Fluctuations in storage temperatures cause ice cream to thaw and re-freeze, resulting in the formation of large ice crystals. Substantial amounts of large ice crystals in ice cream give the product an undesirable coarse texture.

Furthermore, the presence of excessive lactose crystals in ice cream is responsible for a sandy and gritty texture. This is best controlled by limiting the amount of MSNF used in the ice cream mix as it is the major source of lactose in ice cream, as well as, preventing temperature fluctuation during storage.

Lastly, stabilizers impart viscosity to the mix. An increase in viscosity facilitates the incorporation and retention of air during the freezing process and also improves the body and the melting qualities of the finished ice cream (Cottrell et al., 1980).

Blends of gums are widely used in ice cream mixes as they are found to be more effective due to synergism than individual gums to provide stabilization (Glicksman, 1985).

Combined and integrated emulsifiers and stabilizers are also popular in the ice cream industry for two reasons (Nielsen, 1978). First, a combined emulsifier and stabilizer system is likely to eliminate the defects of individual components or improve the overall performance of the system through synergism. Second, the use of integrated emulsifiers and stabilizers simplifies the production process and improves its efficiency.

2.4.4.2 Sources of Stabilizers

Stabilizer gums can be classified by chemical nature or by source (Graham, 1978). On the basis of chemical nature, gums can be categorized as anionic, cationic, or neutral. When classified by source, gums can be grouped as plant exudates, seed gums, seaweed extract, plant

extract, cellulose derivatives, microbial gums, proteins and synthetic gums.

2.4.4.3 Rheology

Since hydrocolloids alter the rheological properties of the system in which they are dispersed or dissolved, it is appropriate to briefly review the concepts of rheology. By definition, rheology is the study of deformation and flow (Dickinson and Stainsby, 1982). Although the science of rheology encompasses both solids and fluids, the rheology of the latter will be discussed because only liquid samples were tested for their rheological properties in this research. Viscometry and oscillatory testing are two methods of investigation which can be carried out to study the rheological behaviour of fluids. Only viscometry will be discussed briefly because the frozen dessert mixes in this research were not subjected to oscillatory testing.

Viscometry measures the viscosity, which is the internal friction or the resistance to flow, of a fluid (Glicksman, 1982). Some concepts are fundamental to the understanding of viscometry: shear stress, shear strain, shear rate and shear viscosity (Morris, 1984). The force per unit area applied laterally to a sample is known as shear stress which has units of Pascal (Pa). The amount of deformation of the sample induced by the applied force is called shear strain which is dimensionless i.e. without units. Shear rate is the rate of strain (strain per unit time) and is expressed in reciprocal time (s^{-1}). The shear viscosity of the sample is the ratio of shear stress to shear rate and has units of Pascal seconds (Pas). Plotting shear stress against shear

rate yields a flow line on the plot (a rheogram). This line can be linear or curvilinear. On this basis, fluids can be classified as Newtonian or non-Newtonian (Mohsenin, 1978).

In Newtonian (or ideal) fluids the shear stress is directly proportional to the shear rate. This relationship is demonstrated by a linear flow line which passes through the origin. The viscosity of a Newtonian fluid is constant and is sometimes referred to as absolute viscosity. The shear stress of non-Newtonian fluids, on the other hand, is not directly proportional to the shear rate (Glicksman, 1982). The viscosity varies with the shear stress or shear rate and may be time-dependent. The flow line is curvilinear and the viscosity at any point on the curve (called the apparent viscosity) is the slope of a line connecting that point and the origin (Mohsenin, 1978). Non-Newtonian fluids fall into five categories: pseudoplastic, dilatant, Bingham plastic, thixotropic and rheopectic materials. The apparent viscosity of the latter two is time-dependent, but such a relationship does not exist for the others.

Pseudoplastic and dilatant flows are two opposite phenomena (Dickinson and Stainsby, 1982). A pseudoplastic (shear-thinning) fluid decreases in apparent viscosity with increasing shear rate. This constrasts with a dilatant (shear-thickening) material whose apparent viscosity increases with increasing shear rate.

A Bingham plastic is a fluid which will not flow unless a minimum force (the yield stress) is applied to overcome the initial resistance (Glicksman, 1982). The flow follows a Newtonian pattern i.e. a linear flow line once it has commenced.

Thixotropic and rheopectic flows are pseudoplastic and dilatant in nature, respectively, except that their rheological behaviour is influenced by time (Mohsenin, 1978). Thixotropic fluids thin out as the shear rate increases, however, the original viscosity is restored if a period of rest is permitted. In a rheopectic flow, the fluid thickens with increasing shear rate, but the original viscosity is also restored after a period of rest.

2.4.5 Functions and Sources of Emulsifiers

2.4.5.1 Functions of Emulsifiers

An emulsion is a dispersion of at least two immiscible liquids, one of which being dispersed in another in the form of droplets or globules (Christiansen, 1985). The dispersed liquid is usually referred to as the dispersed or internal phase, while the other liquid is the closed, continuous or external phase (Schneider, 1986). The emulsion system is very unstable due to the surface tension between the two phases. If allowed to stand the dispersed phase will rapidly coalesce and separate from the continuous phase i.e. the breakdown of the emulsion.

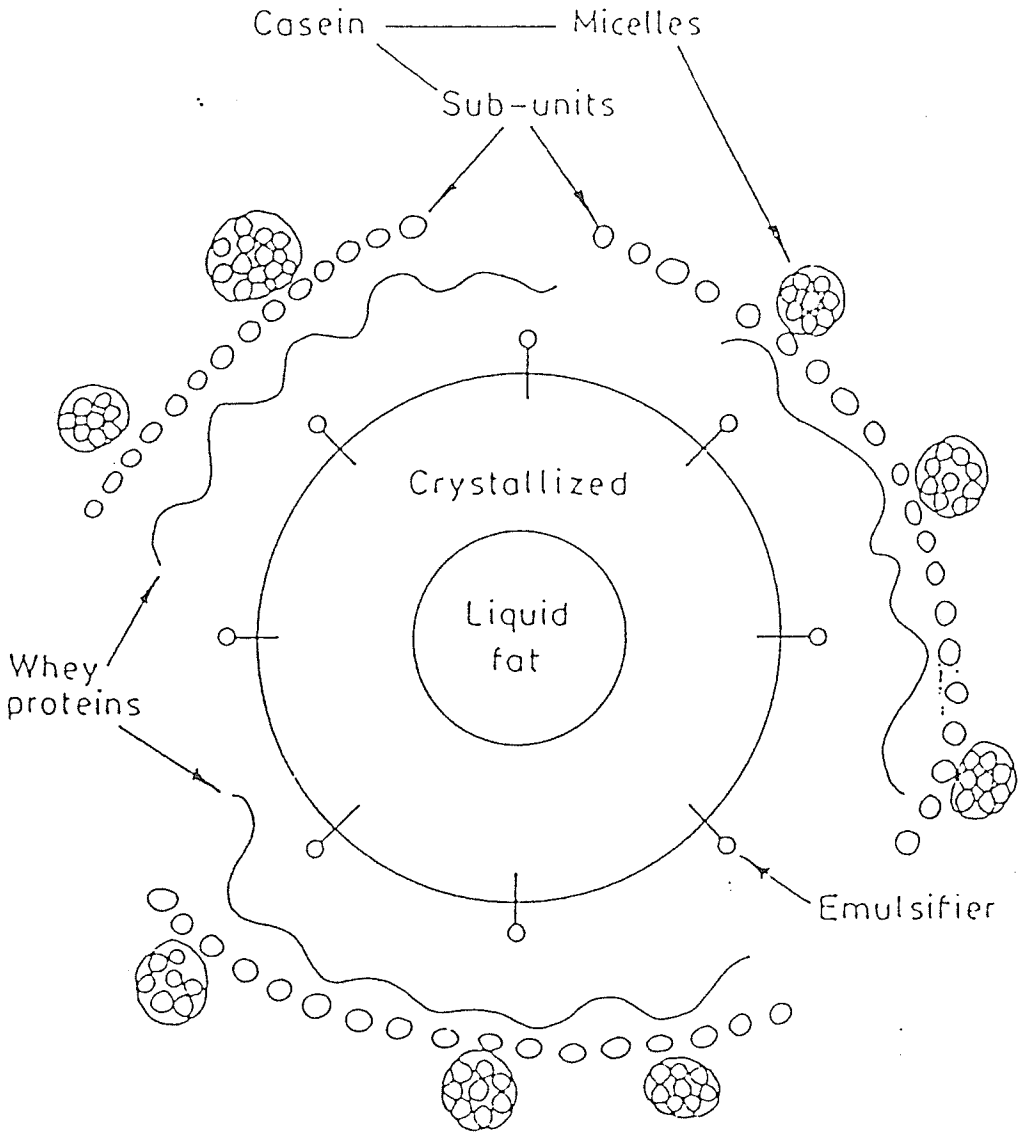
In order to prevent phase separation, emulsifiers are introduced into the system. Emulsifiers are interfacially active substances capable of reducing the surface tension at the interfacial region and thus allow the droplets to remain dispersed in the continuous phase. This capability is due to the hydrophilic-lipophilic nature of an emulsifier molecule which permits it to position itself at the interface. Two modes of action of emulsifiers have been suggested (Fisher and Parker, 1985): (i) once settled in the interfacial layer, the emulsifier

molecules provide electrostatic or steric forces which repel emulsion droplets from one another and (ii) some emulsifiers form liquid crystalline multilayers at the interface to prevent the coalescence of emulsion droplets.

Emulsifiers in ice cream, ironically, are not used primarily to provide emulsion stability. The oil in water emulsion in the ice cream mix prior to freezing is largely stabilized by the milk proteins and stabilizers, although the emulsifiers do provide additional stabilizing effect and improve the extent of fat dispersion in the mix (Flack, 1983b). The major function of emulsifiers is to promote and control the destabilization or de-emulsification of the milkfat globule membrane formed during homogenization when the mix is being frozen (Gregory, 1982). Figure 1 shows the orientation of emulsifier molecules in homogenized ice cream mix. Other important functions of emulsifiers in ice cream are to promote fat-protein interactions, to facilitate air incorporation, to impart dryness at extrusion, to impart smoothness and consistency, to increase resistance to shrinkage and to improve melting properties (Nielsen, 1978).

Figure 1: Milkfat Globule Membrane in Homogenized Ice Cream Mix.

Source: Flack (1983a).


Casein
Micelles
Sub-units
Crystallized
Liquid
fat
Whey
proteins
Emulsifier

2.4.5.2 Sources of Emulsifiers

Emulsifiers are classified according to their electrical charge or solubility properties (Schneider, 1986). Emulsifiers can be anionic, cationic, amphoteric or non-ionic if categorized by electrical charge. When solubility is used as the classification criteria the hydrophilic-lipophilic balance (HLB) index is often used.

Commercial emulsifiers for food use can be either natural or synthetic, but the synthetic types are used predominantly. Emulsifiers fall into several categories: lecithin, monoglycerides and derivatives, propylene glycol esters, polyglyerol esters, sorbitan and polysorbate esters, and surcose esters (Weiss, 1983).

2.5 PROCESSING STEPS OF ICE CREAM MANUFACTURE

Ice cream is produced by the simultaneous freezing and aeration of a liquid mix base. The preparation of this mix begins with blending of ingredients, follows by pasteurization, homogenization, cooling and aging. The mix is then flavoured, frozen, packaged and hardened. The functions of each processing step are discussed briefly as follows.

2.5.1 Blending of Ingredients

The first step of ice cream manufacture is to prepare a mix base by blending the ingredients in proportions as determined by the desired formula. Blending is carried out in a tank or vat in which the liquid ingredients are held. The dry ingredients are incorporated while the liquids are agitated and heated. To aid dissolution and dispersion, the

dry materials can be either premixed or sifted to avoid clumping prior to blending (Arbuckle, 1986). The temperature at which the solid ingredients are added depends largely on their properties.

2.5.2 Pasteurization

Pasteurization of the mix is required by law to render the product free from pathogenic organisms. Ice cream mixes are usually pasteurized by the continuous high-temperature-short-time (HTST) or the holding method (Julien, 1985). In the continuous HTST pasteurization, the mix is heated to at least 80°C for 25 sec in Canada. The holding or batch method requires the mix to be heated to a minimum of 69°C and held at that temperature for not less than 30 min. Pasteurization offers benefits other than rendering the mix safe for consumption. The keeping quality of the mix is improved due to a reduced microbial load. The heat treatment also furthers the dissolution and hydration of the ingredients, this in turn promotes their uniform distribution and interactions.

2.5.3 Homogenization

The principal objective of homogenizing the mix is to produce a uniform and stable emulsion. Homogenization breaks up the fat globules into much smaller ones (<2 um in diameter), thereby increasing the total surface area onto which the stabilizing materials (mostly caseins) can adsorb. This results in a fine dispersion of emulsified fat globules which greatly enhances the stability and thus the life span of the emulsion.

Homogenization is accomplished by forcing the mix under pressure through a small adjustable valve called the homogenizing head (Gravlund, 1984). Fat globules are disintegrated by shear force, turbulence, cavitation and ultrasonic vibration as they pass through the valve system of the homogenizer (Rees, 1974; Reuter, 1978). The temperature and pressure at which homogenization is carried out largely determine the effectiveness of the operation. Best results of homogenization are obtained at temperatures which milkfat is in the liquid state (Rees and Pandolfe, 1986). Homogenization pressures vary with the type of homogenizing valve and mix composition. In general, the required homogenizing pressure decreases with increasing fat content in the mix (Mitten and Neirinckx, 1986). Ice cream mixes should be homogenized in a two-stage operation in order to give proper viscosity control. After passing the homogenizing valve under high pressures the disintegrated fat globules tend to form clusters which will impart excessive viscosity to the mix. The clusters are dispersed if the mix is passed through a second valve in series with the first one at lower pressures (Rees, 1974; Brennan, 1974). Ice cream mixes are usually homogenized at pasteurization temperatures and at pressures of 2500-3000 psi on the first stage and 500 psi on the second (Arbuckle, 1986).

Homogenization also serves some other functions in addition to stabilizing the emulsion. This process improves the distribution of mix ingredients and promotes the interactions among emulsion components. Ice cream made from a homogenized mix is smoother in texture because small fat globules allow the incoproration of fine air cells and also obstruct the formation of large ice crystals (White, 1981). The fat in a homogenized mix is less prone to churning during the freezing process,

this in turn improves the whipping quality of the mix and results in a smoother ice cream (Thomas, 1981).

2.5.4 Aging

After pasteurization and homogenization, mixes are cooled to $\leq 4^{0}C$ to control microbial growth and to induce proper crystallization of the liquid fat. It was mentioned earlier that milk fat is a diverse mixture of glycerides of fatty acids (Atherton and Newlander, 1977). As temperature is lowered, the high melting glycerides solidify at the fat globule surface to form a shell surrounding a still-liquid core of low-melting glycerides (Evans, 1986). The crystallization of fat is important because the degree of fat churning in the freezer increases when the liquid fraction in the fat is high (Berger and White, 1971). Excessive churning of fat impairs the whipping quality of the mix and causes defects such as fat and ice separation, buttery texture and resistant to melt with leakage of serum.

The cooled mix is held at the cooling temperatures for 4 to 24 h before the freezing process. This holding period is known as aging during which some changes take place in the mix. The most important of which is the continuation of fat crystallization and the adsorption of milk proteins onto the fat globules (Mitten and Neirinckx, 1986). The milk proteins and the stabilizers also become fully hydrated, and the emulsifiers orientated at the fat-serum interface during this period. At this stage, the artificial fat globule membrane assumes its final form (Figure 1). The overall result in the mix is a stable emulsion which has increased viscosity and improved whipping properties.

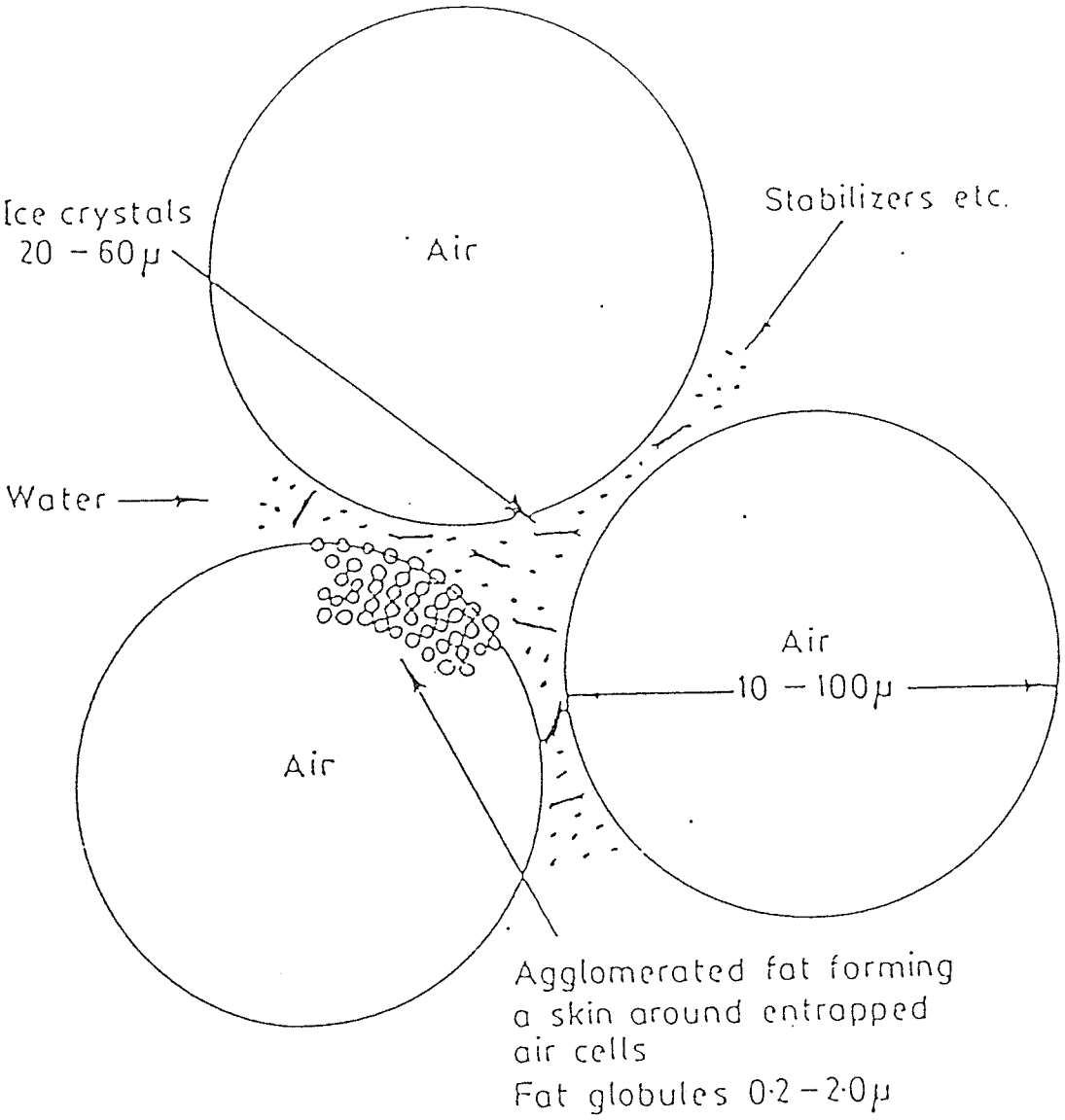
2.5.5 Freezing

The purpose of freezing is to produce a stable foam through partial destabilization of the ice cream mix (Dickinson and Stainsby, 1982). Freezing is accomplished with ice cream freezers which can be divided into two basic types, the batch and the continuous freezer (Hall et al., 1986). Both types of freezer are usually consisted of a horizontal tubular freezing chamber fitted with a motor-driven scraper/dasher to aid freezing and aeration. The batch freezer can only process a definite amount of mix at a time and aeration is done at atmospheric pressures. In the continuous freezing, ice cream is fed to the freezer at a steady rate and is frozen and aerated under pressure. The major advantages of the continuous freezer over the batch freezer are: (i) a lower freezing temperature and a shorter freezing time, (ii) more accurate control of the freezing process and thus a more uniform finished product, and (iii) improved efficiency and economics of plant operations.

The freezing process may be regarded as a structurization process (Monzini and Maltini, 1983) through which the liquid mix is transformed into a complex system composed of liquid, solid and gaseous phases (Keeney, 1982). Structurally, ice cream is a partly frozen foam in which air is dispersed in the form of tiny bubbles (air cells) in a concentrated and unfrozen solution (continuous phase). In this solution are dissolved sugars and salts; colloidal milk proteins and stabilizers; solidified fat, lactose and ice crystals (Arbuckle, 1986). Figure 2 shows a schematic representation of ice cream structure.

Figure 2: A Schematic representation of the Structure of Ice Cream.

Source: Flack (1983a).



At −20°C (−4°F)
85 – 90% of the water
is frozen

Several important changes which take place in the mix during the freezing process to give ice cream its unique structure are the freezing of water, aeration and partial destabilization or de-emulsification of fat. As liquid water in the mix is frozen into ice crystals, the dissolved materials become increasingly concentrated in the unfrozen portion of the mix, lowering the freezing point continuously. The liquid mix is therefore gradually turned into a viscous plastic mass instead of a frozen solid throughout the freezing process (Thomas, 1981). This is important in the aeration of the mix because Hall et al. (1986) indicate that the mix only incorporates air readily at a temperature of about $-5^{0}C$. This suggests that a partially frozen mix is more effective in trapping air than the unfrozen mix. The incorporated air causes an increase in the volume of the frozen mix. This phenomenon is known as the overrun which is defined as the volume of ice cream obtained in excess of the volume of the mix (Arbuckle, 1986). Overrun is expressed in percentage.

A partial destabilization of the fat is essential in the retention of air in the mix. During the freezing process, some fat globules are ruptured by the combined effect of low temperature and agitation (Berger and White, 1979). The liquid fat in these disrupted globules leaks out and acts like a cement which binds other fat globules together to form a skin that encloses and stabilizes the entrapped air cells (Berger et al., 1972b). This effect also strengthens the structure between the air cells (the lamellae).

2.5.6 Hardening

After ice cream has been extruded from the freezer and packaged, it is immediately stored at temperatures between -20^0 and -30^0C for hardening (Julien, 1985). This practice is extremely important since it is at this stage that ice cream aquires it definite structure and becomes sufficiently strong to be handled. During hardening, more water will be frozen into ice crystals until the concentration of the solutes in the continuous phase elevates to such an extent that freezing can no longer occur. Up to 95% of the water in ice cream is frozen at the hardening temperatures (Monzini and Maltini, 1983). At this point the structure of ice cream beocmes rigid. In order to avoid coarseness and iciness in the ice cream, hardening should be carried out rapidly so as to prevent the formation of large ice crystals.

2.5.7 Melting Quality Defects of Ice Cream

The melting behaviour of ice cream can be used as an objective criteria in determining the effects of formulation and processing conditions on the quality of ice cream. Since the melting behaviour of the frozen desserts was also studied in this research, the melting quality defects will be briefly reviewed. These defects have been covered extensively by Nelson and Trout (1965) and Arbuckle (1986).

A high quality ice cream should melt readily at room temperature. The melted ice cream should be a smooth and homogeneous liquid which resembles the original mix. The most common defects in the melting quality of ice cream are: does-not-melt, foamy, watery, whey leakage and curdy.

2.5.7.1 Does-Not-Melt

The does not melt or slow melting defect is indicated by an ice cream which retains or tends to retain its shape or is slow to melt when allowed to stand at room temperature. Factors which are responsible for this defect are excessive viscosity in the mix resulting from high fat content, improper homogenization, overstabilization and slow cooling; low extrusion temperature from continuous freezers, and high freezing point. This defect is often associated with a soggy, gummy, doughy or sticky body.

2.5.7.2 Foaminess

A foamy or frothy meltdown is shown by the presence of numerous fine air bubbles in the completely melted ice cream. This defect is caused by excessive overrun, large air cells, large amount of egg solids, excess emulsifiers or gelatin in low-solids mixes and high mix viscosities.

2.5.7.3 Watery

A watery meltdown is characterized by rapid melting that yields a thin, watery liquid. The common cause of this defect is a low solids content in the mix. A coarse, weak body may accompany a watery meltdown.

2.5.7.4 Whey Leakage

Whey leakage or wheying-off is shown by a watery liquid seeping out of the ice cream during melting. Major causes of this defect are poor quality ingredients, improperly balanced mixes and ineffective stabilization. Whey leakage is closely associated with curdiness.

2.5.7.5 Curdiness

The curdy meltdown is characterized by a feathery scum on the surface of the watery melted ice cream and the presence of fine particles in this liquid. This defect is a result of protein destabilization in the ice cream caused by excess acidity, imbalanced salt content, excessive homogenization pressures, melting and refreezing in the freezer, prolonged low temperature storage and shrinkage of ice cream.

Chapter III

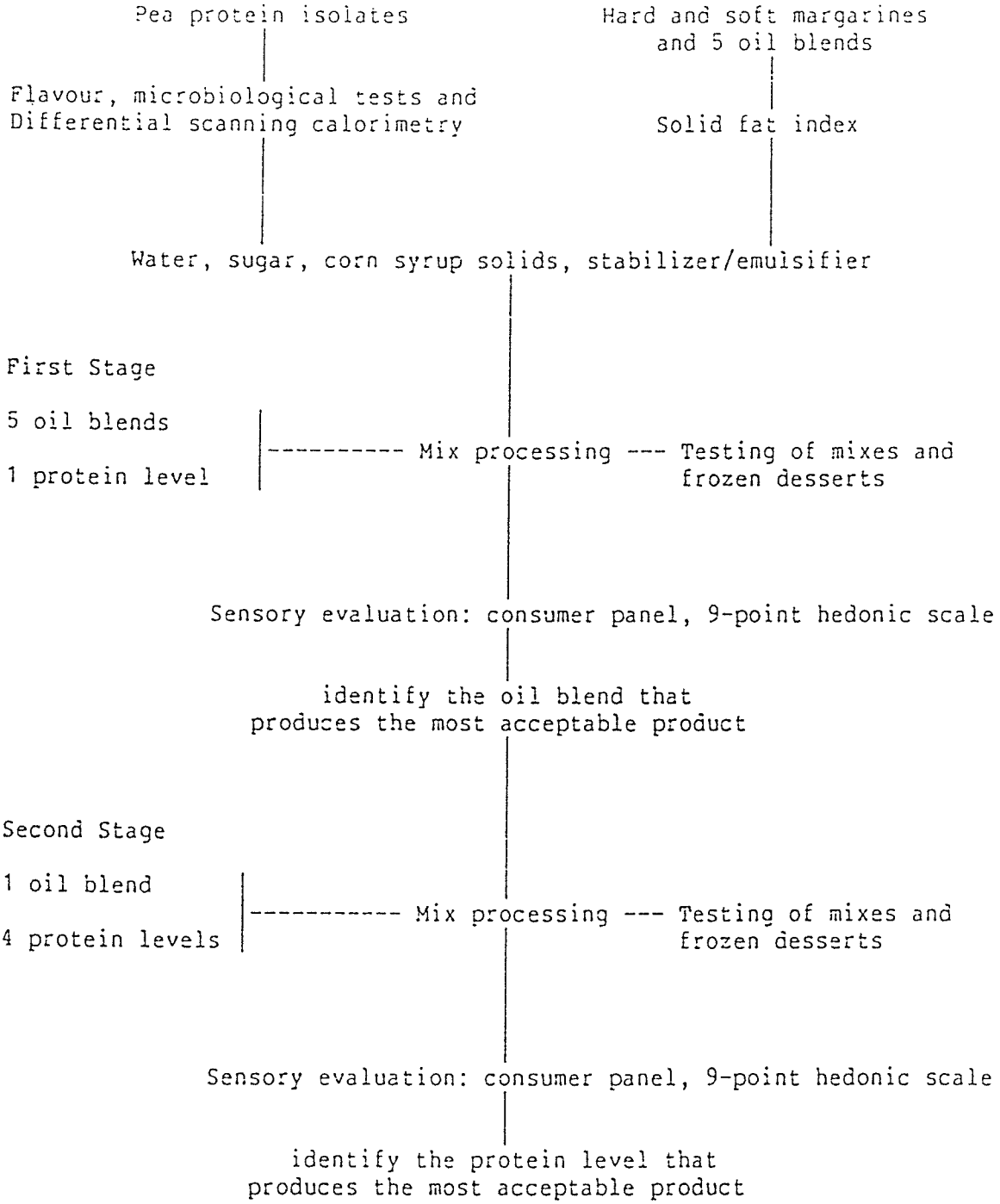
METHODS AND MATERIALS

3.1 INTRODUCTION

The objective of this research was to develop a non-dairy frozen dessert with acceptable sensory qualities using commercial pea protein isolate and margarine oil blend as the sources of protein and fat, respectively. Other ingredients used include water, sugar, glucose solids, flavouring materials and stabilizer/emulsifier.

The research was divided into two phases in order to arrive at an oil blend/protein level combination which would result in an acceptable non-dairy frozen dessert, as determined by sensory evaluation. The content of sugar, corn syrup solids, flavouring materials and stabilizer/emulsifier remained constant among batches of non-dairy frozen dessert throughout the entire research. Two variables, the fat composition which was manipulated by blending hard and soft margarine oils in various weight proportions, and the protein level were studied for their effects on the quality and acceptability of the final products. A schematic layout of the research is shown in Figure 3.

Figure 3: Schematic Presentation of the Research Plan.


Pea protein isolates
Hard and soft margarines and 5 oil blends
Flavour, microbiological tests and Differential scanning calorimetry
Solid fat index
Water, sugar, corn syrup solids, stabilizer/emulsifier
First Stage
5 oil blends
1 protein level
Mix processing
Testing of mixes and frozen desserts
Sensory evaluation: consumer panel, 9-point hedonic scale
identify the oil blend that produces the most acceptable product
Second Stage
1 oil blend
4 protein levels
Mix processing
Testing of mixes and frozen desserts
Sensory evaluation: consumer panel, 9-point hedonic scale
identify the protein level that produces the most acceptable product

The first stage of the research was aimed at identifying a margarine oil blend which was able to create an acceptable frozen dessert. Five oil blends were used to process the frozen desserts. The oil blend which resulted in the most acceptable final product was identified by subjecting the frozen desserts to a sensory panel. This oil blend alone was to be used in the processing of frozen desserts in the next phase of the research.

The goal of the second stage of the investigation was to determine a protein level which would result in an acceptable frozen dessert. Batches of frozen dessert were processed at four protein levels. The most acceptable protein level was identified by subjecting the frozen desserts to a sensory panel.

Prior to stage one of the research, the pea protein isolates were tested for their flavour and microbiological quality. The extent of denaturation of the pea protein isolates was measured by Differential Scanning Calorimetry (DSC). Both the hard and soft margarine oils and all the oil blends made up of the two were measured for their solid fat indices. The non-dairy frozen dessert mixes were tested for their microbiological quality, pH, titratable acidity, fat content, protein content, total solids, stability and rheological properties. The frozen products were evaluated for their overrun, sensory quality, melting quality and microstructure.

3.2 TESTING OF THE PEA PROTEIN ISOLATE

The pea protein isolates (PPI) used in this research were obtained from Woodstone Foods, Portage la Prairie, Manitoba. Four grades of PPI are generally manufactured by the company: Woodstone Gold, Propulse 985B, Propulse 985R and Propulse 980. The four grades of PPI were manufactured for various applications. Primary use of each grade of PPI, as recommended by the manufacturer, was Woodstone Gold in diet and health foods; Propulse 985B in baking; Propulse 985R in replacing other proteins; and Propulse 980 in animal feed.

Samples taken from three grades of PPI (Gold, Propulse 985B and Propulse 985R) were tested for their flavour, microbiological quality and the extent of denaturation. Chemical analyses were not performed on the PPI samples. However, information regarding the chemical composition of the PPI was obtained from the company (Table 12).

TABLE 12

Typical Chemical Composition and Microbiological Quality of Four Grades of Pea Protein Isolate.

	Pea Protein Isolate			
	Gold	Propulse 985B	Propulse 985R	Propulse 980
Moisture, %	5.0	5.0	6.0	6.0
pH (10% solution)	6.5	6.5	6.5	6.5
Protein, %[1]	85.0	83.0	81.0	80.0
Fat, %[2]	3.0	2.0	3.5	N/A
Ash, %[2]	4.0	N/A	4.5	N/A
Crude fibre, %[2]	0.5	0.4	0.5	N/A
Standard Plate Count (organisms/g)	<50,000	<50,000	<50,000	<50,000
Coliforms	-ve	-ve	-ve	-ve
Salmonella	-ve	-ve	-ve	-ve

Source: Woodstone Foods Ltd., Portage la Prairie, Manitoba.
1 %Protein = % Kjeldahl nitrogen x 6.25, dry weight basis.
2 dry weight basis.
N/A measurements not available.

3.2.1 Flavour

A flavour evaluation was carried out to determine the acceptability and the difference in the flavour of the three grades of PPI (Gold, Propulse 985B and 985R). For this purpose a sensory panel consisted of 16 judges using a 9-point hedonic scale was employed. A 10% slurry of each grade of PPI was prepared by heating the appropriate quantity of PPI in deionized water to a temperature of 79.4°C (175°F) and maintained at such for 30 min with constant stirring. The pasteurized slurries were cooled and stored at 4°C in sealed flasks for not more than 24 h before the taste panel began.

The panel was carried out in a panel room under red lighting to eliminate the effect of colour on the panelists' performance. The slurry of each grade of PPI was assigned a 3-digit random number. Approximately 20 ml of the slurry was poured into a paper cup labelled with the corresponding 3-digit number. A set of samples in random order was presented to each panelist. The panelists were instructed to chew a piece of unsalted cracker and rinse their mouths with water between samples. The analysis of variance was used to determined the presence of difference among samples.

3.2.2 Microbiological Tests

The PPI samples were tested for Standard Plate Count (SPC) and the presence of Coliforms and Salmonella. Standard plate count and the Presumptive test for coliforms were carried out as outlined in the Standard Methods for the Examination of Dairy Products (APHA, 1978). Difco SPC agar and Violet Red Bile (VRB) agar were prepared according to manufacturer's instructions. Eleven grams of PPI sample were weighed aspectically into a dilution bottle containing 99 ml sterile buffer solution and mixed thoroughly. Dilution factors of 1:2 and 1:10 were used for both tests. Plates were poured in duplicates and incubated at 32°C for 48 h for SPC and at 32°C for 24 h for the presumptive coliform test. Typical coliforms colonies on the VRB plates were transferred to 2% Brilliant Green Lactose Bile Broth and incubated at 32°C for 48 h. Lack of gas production indicated a negative test.

The presence of Salmonella in the PPI samples was detected by the AOAC method (AOAC, 1984) with modifications. Twenty-five grams of PPI

samples were aseptically weighed into a blender jar containing 225 ml of sterilized Nutrient Broth. The contents of the jar were blended thoroughly using an Osterizer blender. The jar was then incubated at 35°C for 24 h. One ml of the jar contents was transferred to a tube of Selenite Cystine Broth and a tube of Tetrathionate Broth which were incubated at 43°C for 24 h. A loopful of each of the two broths was streaked onto the surface of one plate of Brilliant Green Sulfadiazine agar and one plate of Salmonella Shigella agar. The plates were incubated at 35°C for 24 h and examined for suspicious colonies. Suspected colonies were inoculated onto Triple Sugar Iron agar slant and Lysine Iron agar slant and incubated at 35°C for 24 h. Colonies from positive slants were tested with the API 20E system (API Produits de Laboratoire Ltee, St. Laurent, Quebec) to determine their identity.

3.2.3 Differential Scanning Calorimetry (DSC)

The degree of denaturation of the PPI samples was determined by DSC. Each PPI sample was first freeze-dried and then used to prepare a 20% (w/w) slurry in water. A 10 to 15 mg sample of the slurry was weighed into a tared DSC pan which was then hermetically sealed. A Dupont Model 9900 thermal analyzer with a Model 910 DSC cell base and pressure DSC cell was used in the test. The sealed DSC pan was heated from 25° to 120°C in the cell at a rate of 10°C/min. The measurements were processed by the DSC standard analysis software. Downward peaks indicate an endothermic process. The temperature of denaturation (Td) equals the peak temperature. The enthalpy of the reaction is calculated from the peak area with the equation:

$$\Delta H = (A/MCP)\ (60BE\Delta qs)$$

where: ΔH = enthalpy of the reaction ($mcal \cdot mg^{-1}$)
A = area (in^2)
M = sample mass (mg)
C = sample concentration (% w/w)
P = protein concentration of sample (%)
B = time base ($min \cdot in^{-1}$)
E = cell calibration coefficient
Δqs = Y axis range ($mcal \cdot s^{-1} \cdot in^{-1}$)

3.3 SOLID FAT INDEX

The physical characteristics of the fat samples involved in this research were studied by measuring their solid fat index (SFI). The AOCS Official Method Cd 10-57 (AOCS, 1974) was used for this purpose. The work was performed by the chemical laboratory of Canada Packers Inc., Winnipeg. Instead of measuring the solid fat indices at five different temperatures (10°, 21.1°, 26.7°, 33.3° and 37.8°C), as outlined in the method, only three (10°, 21.1° and 33.3°C) were used routinely by the laboratory. This practice is common in the oils and fats industry as Allen (1982) pointed out that most margarine and shortening manufacturers have made modifications of the lengthy official method to suit quality control purposes. The use of these three temperatures has been generally accepted (Weiss, 1983).

3.3.1 Sample Preparation

Hard (print or stick) margarine (20 kg blocks) and soft (tub) margarine (13 kg plastic tubs) were purchased from Canada Packers Inc., Winnipeg for this study. The formulation of the hard margarine oil was PM5 (Table 9) and that of the soft margarine oil was SM2 (Table 10). The margarines were first melted to recover the oil fractions. Oil

samples were collected and treated for moisture removal before being tested or used to prepare various oil blends for testing. A milkfat sample was also prepared from a commercial butter in an identical manner and subjected to the test.

3.3.1.1 Melting of Margarine

The soft margarine was melted by placing the tubs in a hot water tank thermostatically maintained at 60°C (140°F). The tubs remained inside the tank for 5 h with periodic checking to ensure complete melting and separation of the aqueous phase. The aqueous phase had to be removed since it usually contains milk or whey solids, salt, and flavour (Teasdale and Mag, 1983) which may provide unwanted interference in the assessment of the quality of the finished frozen dessert. The oil was then collected in sanitized plastic containers, sealed and refrigerated. Approximately 700 ml of the well-mixed oil was collected separately for further study.

Unlike the soft margarine, each block of hard margarine was packaged in a paper carton, therefore its melting had to be done in a different manner. A block of hard margarine was heated in a stainless steel steam vat which had been sanitized with a 200 ppm chlorine solution and thoroughly drained. The margarine was heated slowly with agitation to 60°C to ensure complete melting. The oil was allowed to cool and separate from the non-fat materials. The clear oil was then decanted carefully into a sanitized plastic tub, sealed and refrigerated. Approximately 700 ml of the well-mixed oil was collected separately in a 1000-ml Erlenmyer flask for testing and the preparation of oil blend samples.

3.3.1.2 Moisture Removal

Each margarine oil sample collected after the melting step was transferred into a 1000-ml glass beaker on a hot plate with stirrer capability. The oil was heated to a temperature of 60°C and two teaspoonfuls of diatomaceous earth (obtained from the Chemical Lab of Canada Packers, Winnipeg) were blended in. The oil and diatomaceous earth mixture was agitated for 15 min before the latter was removed by filtration using Whatman No. 42 filter paper. The filtrate was then used to prepare various oil blends.

3.3.1.3 Preparation of Oil Blend Samples

The two types of margarine oil and five oil blends prepared from the two and a butterfat sample were tested for SFI. The oil blends of 100 g each were made up of the hard (H) and soft (S) margarine oils in the following proportions by weight: 30%-70% (HS 37), 40%-60% (HS 46), 50%-50% (HS 55), 60%-40% (HS 64) and 70%-30% (HS 73). These oil blends were chosen because preliminary studies showed that non-dairy frozen dessert made from PPI and pure hard or soft margarine oil did not possess acceptable quality. All oil samples were kept in 250-ml glass bottles sealed with plastic caps and stored under refrigeration until testing.

3.4 PROCESSING OF NON-DAIRY FROZEN DESSERT MIXES

Plain (unflavoured) non-dairy frozen dessert mixes were prepared by blending and pasteurizing the ingredients, followed by homogenization, cooling, and aging. The aged mixes were flavoured immediately before the freezing process. All cleaned equipment and utensils involved in the processing of the mixes were sanitized with a 200 ppm chlorine solution and drained thoroughly prior to use.

Twenty kg duplicate batches were processed using each oil blend in the first stage of the research. The mixes and the resultant frozen desserts are designated by the code of the oil blend they contained. The basic formulation of the mixes is shown in Table 13.

In the second stage, the mixes were prepared in 20 kg duplicate batches at four protein levels of 3.5% (P 35), 5.0% (P 50), 6.5% (P 65) and 8.0% (P 80). These batches of mix and the resultant frozen desserts will be hereafter referred to by the respective codes designated in the parentheses. Only the oil blend which resulted in the most acceptable frozen dessert in the first stage, as judged by a sensory panel, was used in this stage. The formulation used was modified from the one shown in Table 13. With the levels of sugar, glucose solids, fat and stabilizer/emulsifier maintained as in Table 13, the water content in each batch was adjusted to correspond to the PPI level so that the total percentage of ingredients remained at 100.

Since the processing steps, conditions and equipment for the non-dairy frozen dessert were identical to those for ice cream, one 20 kg batch of ice cream mix was processed as to familiarize with the produc-

TABLE 13

Basic Formulation of the Non-Dairy Frozen Dessert Mixes.

Ingredient	Percentage	Source
Water	62.15	
Sugar, fine granulated	11.00	Manitoba Sugar Co., Winnipeg, Manitoba.
Glucose solids[1] (39-43 D.E.)	11.00	Casco Inc., Toronto, Ontario.
Fat	10.50	Canada Packers Inc., Winnipeg.
Pea protein isolate (powder) (Woodstone Gold)	5.00	Woodstone Foods, Portage la Prairie, Manitoba.
Stabilizer/emulsifier (Beatamix 1143)[2]	0.35	Germantown Manufacturing Ltd., Scarborough, Ontario.
Total	37.85	

1 Contains 18.4% monosaccharides, 14.2% disaccharides, 12.5% trisaccharides and 54.9% higher saccharides.
2 Contains mono- and di-glycerides, cellulose gum, guar gum, polysorbate 80 and carrageenan.

tion procedures and equipment involved. The formulation of the ice cream mix used was obtained from the University of Manitoba Dairy Pilot Plant (Table 14).

TABLE 14

Formulation of an Ice Cream Mix, 10% B.F.

Ingredient	Percentage	Source
Milk, 3.3% B.F.	55.93	University of Manitoba
Cream, 42% B.F.	21.80	Dairy Pilot Plant
Sugar, fine granulated	12.75	Manitoba Sugar Co., Winnipeg, Manitoba.
Skim milk powder, spray-dried	4.68	Modern Dairies, St. Claude, Manitoba.
Glucose solids[1] (39-43 D.E.)	4.50	Casco Inc., Toronto, Ontario.
Stabilizer/emulsifier (Beatamix 1143)[2]	0.30	Germantown Manufacturing Ltd., Scarborough, Ontario.
Salt	0.04	
Total	100.00	

1 Contains 18.4% monosaccharides, 14.2% disaccharides, 12.5% trisaccharides and 54.9% higher saccharides.
2 Contains mono- and di-glycerides, cellulose gum, guar gum, polysorbate 80 and carrageenan.

3.4.1 Pasteurization

All dry ingredients were blended into the water in a sanitized stainless steel steam vat (Groen Mfg. Co., Illinois) with a capacity of 40 kg. Heat and agitation were slowly applied until all materials were dissolved. The oil was added when the vat contents reached a temperature of 48.9°C (120°F). The mix was pasteurized at 79.4°C (175°F) for 30 min with constant gentle agitation.

3.4.2 Homogenization

Homogenization of the pasteurized mix was performed with a Cherry Burrell Stellar Series 200 Superhomo homogenizer. The mix was homogenized at pressures of 2000 psi on the first stage and 500 psi on the second. The homogenized mix was collected in a sanitized stainless steel milk can.

3.4.3 Cooling and Aging

Cooling of the mix was done by immersing the milk can into a water tank with circulating cold water. The mix was gently agitated to facilitate cooling to a temperature of 26.7°C (80°F) or below. The can was then sealed and kept in a cold room at 4.4°C (40°F) for further cooling. Its contents were stirred every 20 min to aid the cooling process. The mix, when reached a temperature of 4.4°C (40°F), was allowed to age overnight at the same temperature.

3.4.4 Freezing

Prior to freezing, 15 kg of the aged mix was coloured and flavoured with 1.4 kg of butterscotch sundae topping (Bowes Co. Ltd., Toronto) and 40 ml of butterscotch flavour (Givaudan Ltd., Toronto). Preliminary work showed that butterscotch was an acceptable flavour for the type of non-dairy frozen dessert being studied. Freezing was carried out in a Cherry Burrell Fr 40-B Duo-Dash batch freezer. The frozen mix was packaged into six 2 L paper cartons which were then weighed and stored in an ice cream hardening room at -34°C. One dozen of 150 ml styrofoam cups

were also filled with the frozen mix and kept frozen at the hardening temperature for the study of the microstructure of the frozen desserts. Overrun of the frozen mix was calculated using the formula of Arbuckle (1986):

$$\% \text{ Overrun} = \frac{\text{weight of 2 L of mix} - \text{weight of 2 L of frozen mix}}{\text{weight of 2 L of frozen mix}} \times 100$$

3.5 TESTING OF THE MIXES

Mixes were tested for their pH, titratable acidity, total solids, microbiology, stability, fat content, protein content and viscosity. Samples were collected after the cooling stage and kept refrigerated for not more than 24 h before being tested.

3.5.1 Titratable Acidity and pH

The titratable acidity and pH in the mixes were determined by the modified procedures of the Standard Methods for the Examination of Dairy Products (APHA, 1978). Thirty six grams of mix were weighed directly into a tared 100-ml glass beaker. The pH of the mix was measured by a Corning pH meter.

Titratable acidity of the mix was determined after the pH measurements were taken. Thirty-six ml of boiled and cooled deionized water was added and then blended in with a magnetic stirrer bar. Twelve drops of 1% alcoholic phenolphthalein solution were dispensed by an eye dropper and mixed into the diluted mix. The beaker contents were titrated to the phenolphthalein end point of pH 8.3, as monitored by the

pH meter, using certified 0.1 N sodium hydroxide solution (BDH) dispensed by a Kimax Nafis acidometer. The titratable acidity was obtained by dividing the acidometer reading by 4.

3.5.2 Total Solids

Total solids of the mixes were determined by the AOAC method (AOAC, 1984). Approximately 1-2 g of mix was weighed directly into an aluminum drying dish (5 cm diameter) which had been heated in an oven at 100°C for 15 min and subsequently cooled in a dessicator. The sample inside the dish was spread over the entire bottom of the dish and then dried on a steam bath for 30 min before being transferred into a forced air oven for drying at 100°C for 3.5 h. Percentage total solids was calculated by the following formula:

$$\% \text{ Total Solids} = \frac{\text{residue weight}}{\text{sample weight}} \times 100$$

3.5.3 Microbiological Tests

The mixes were tested for standard plate count and the presence of coliforms. Standard Plate Count method and the Presumptive test for Coliforms using Violet Red Bile agar as described in the Standard Methods for the Examination of Dairy Products (APHA, 1978) were used. Eleven grams of mix were transferred asceptically into a dilution blank bottle containing 99 ml of sterilized buffer solution. Difco Standard Plate Count agar and Violet Red Bile agar were prepared according to manufacturer's instructions. Dilution factors of 1:10 and 1:100 were

used for the standard plate count. Duplicate plates were incubated at 32°C for 48 h before reading. Dilution factors of 1:2 and 1:10 were used in the presumptive test for coliforms. The plates were incubated at 32°C for 24 h. Suspicious colonies were inoculated in 2% Brilliant Green Lactose Bile Broth and incubated at 32°C for 48 h and examined for gas production. All media, glassware and dilution blanks were routinely sterilized in an autoclave at 121°C for 15 min at 15 psi pressure and cooled before use.

3.5.4 Stability Test

The procedure used was described in the Methods of Analysis of Milk and Its Products (Milk Industry Foundation, 1959). Five ml of mix was placed in a test tube, followed by the addition of 5 ml of alcohol solution. The alcohol solution was made up by diluting 72 ml of 95% ethanol to a volume of 100 ml with deionized water. The tube contents were mixed by gently inverting the tube several times. Instability of the mix was indicated if flakes of curd appear.

3.5.5 Fat Content

The Pennsylvania test outlined in the Standard Methods for the Examination of Dairy Products (APHA, 1978) was used to determined the fat content of the mixes. Nine-gram, 50% cream test bottles were used instead of the ice cream test bottle, as outlined in the method.

3.5.6 Protein Content

The nitrogen content of the mixes was measured by the Kjeldahl method (AOAC, 1984) with modifications. The digestion catalysts listed in the method were replaced by 2 Kjeltab tablets (Fisher Scientific). Digestion was proceeded as described in the method. The digested materials were cooled, diluted with 300 ml of distilled water and made alkali by the addition of 50 ml of certified 10 N sodium hydroxide solution (Fisher Scientific) prior to distillation. Approximately 200 ml of distillate was collected in a 500-ml Erlenmyer flask containing 50 ml of 1.0% boric acid with methyl red and bromocresol green added as pH indicators. The distillate was titrated with 0.1 N sulphuric acid. The nitrogen content was calculated as follows:

$$\%N = \frac{(\text{ml acid added} - \text{ml acid blank}) \times \text{normality of acid} \times 14.007}{\text{weight of sample (mg)}} \times 100$$

3.5.7 Viscometry Studies

The study of viscosity of the mixes was carried out by a Bohlin VOR rheometer system (Bohlin Reologi, Lund, Sweden). The system was connected to a Bohlin temperature control unit (Type 200123), a compressed air supply (2 bar), a Data Train DC-200S monitor screen, an IBM personal computer (Model 5150), and an Epson FX-85 printer. Test parameters were selected from the rheometer software. Viscosity measurements of the mixes were taken using the C25 concentric cylinder system at 20°C and the torque element setting at 95.8 g·cm. Approximately 11 ml of sample was introduced into the concentric

cylinder unit. The sample was subjected to every second one of the 48 shear rates within a range of 0.03682 to 1465 s^{-1}, both inclusive. The sensitivity was set at 1X. Initial delay time, constant delay time and integration time were set at 30 s, 5 s and 5 s, respectively. One measurement was taken at each shear rate.

3.6 TESTS PERFORMED ON THE FROZEN DESSERTS

3.6.1 Sensory Analysis of the Frozen Desserts

Frozen desserts from each stage of the research were evaluated by a sensory panel using a 9-point hedonic scale (Larmond, 1982). Panelists were staff members and graduate students from the departments of Foods and Nutrition and Food Science of the University of Manitoba. Fifty-three panelists participated in the first panel and forty eight in the second.

Each panel was carried out in a panel room under red lighting to eliminate the effect of colour on the panelists' performance. Each sample of the frozen desserts was assigned a 3-digit random number. Approximately 50 g of frozen dessert was placed in a styrofoam cup labelled with the corresponding 3-digit number. A set of samples in random order was presented to each panelist. Five non-dairy frozen dessert samples were tested in the first panel and four in the second. Panelists were instructed to chew a piece of unsalted cracker and rinse their mouths with water between samples. The samples were allowed to be swallowed.

Several statistical methods were used to analyze the data from each panel. The presence of differences among samples and among judges was detected by the analysis of variance. The significance of the variations among the samples was determined by the Tukey test (O'Mahony, 1986). In order to confirm whether there was a general agreement among panelists upon the ranking of the samples in each panel and to establish a reliable order of preference, the Kendall's coefficient of concordance was used (Gibbons, 1971).

3.6.2 Melting Quality of the Frozen Desserts

The arrangement and procedures for the recording of the melting behaviour of the frozen desserts are described as follows. Approximately 50 g of forzen dessert was placed in a plastic petri dish. Frozen desserts from the same trial of each stage of the research were lined up against a black background and were allowed to melt at room temperature. Photographs of the dish contents were taken at twenty-minute intervals in an one-hour period, beginning at zero minute. A Nikon camera with a 24 mm wide-angle lens and Kodak Ektachrome ED 135-20 slide film were used for the photography. Lighting was provided by four Sylvania B2 Superflood EB W bulbs, two on each side of the background. The lamps which generated heat were activated only when photographs were being taken in order to avoid possible accelerated melting of the dish contents.

3.6.3 Microstructure of the Frozen Desserts

Frozen dessert samples were sliced into sections of 8-10 um thick at -30°C using an American Optic Model 851c Cryo-Cut II Cryostat Microtome. Tissue-Tek embedding medium (Miles Scientific) was used for mounting. Each sample section was transferred onto a glass slide chilled inside the microtome and a chilled glass slide cover slip was placed on top of the specimen. The slide was then placed on a cooling stage located on top of the viewing stage of a Zeiss Universal transmitted-light reserach microscope. The cooling stage was a sealed hollow brass square (approximately 6.5 cm by 6.5 cm and 1 cm thick) with an opening in the center which allows the passage of light through the specimen. Two nozzles located on one edge of the square were used to connect the stage to a Haake F3-C digital refrigerated bath and circulator via two rubber tubings. The coolant, a 50/50 mixture of automotive engine antifreeze and distilled water, was cooled to -15 to -20°C and circulated inside the cooling stage to prevent rapid melting of the specimen. The structure of the speciment was photographed by a 35 mm camera attached to the microscope using Kodak Ektachrome ED 135-20 slide film.

Chapter IV

RESULTS AND DISCUSSION

4.1 RESULTS OF TESTS PERFORMED ON THE PEA PROTEIN ISOLATES.

4.1.1 Flavour Evaluation of PPI

On a scale of one to nine (dislike extremely to like extremely), the average scores for the three grades of PPI tested: Gold, 985B and 985R were 3.69, 3.69 and 3.38, respectively (Appendix A). These scores indicated the general acceptability of the PPI slurries by the panelists ranged from dislike slightly to dislike moderately. However, the flavour evaluation did not point out which aspect(s) of the PPI slurries was objectionable to the judges. The average scores for the PPI slurries were low perhaps because rather concentrated (10%) PPI slurries were used for flavour evaluation. This concentration was used because the manufacturer's guidelines suggested that a 10% PPI solution was bland in flavour. The undesirable qualities of the PPI, on the contrary, became acute at this concentration and were readily detected and penalized by the panelists.

However, the PPI levels used in preparing the non-dairy frozen desserts were lower (3.5%, 5.0%, 6.5% and 8.0%). Therefore if the 10% PPI slurry had been found acceptable in its sensory qualities, the use of these concentrations would not then be expected to pose any problem in the flavour of the frozen desserts. In addition, the frozen desserts were completely different food systems in which the presence of other

ingredients i.e. sweeteners, fat, emulsifiers, stabilizers and flavouring materials may conceal or modify the shortcomings of the PPI. Consequently, these average scores may not be regarded as a definite guide to the performance of the PPI with respect to flavour in food applications.

Analysis of variance did not reveal any significant difference in the general acceptability between the three grades of PPI at the 5% significant level (Appendix A). As a result, Woodstone Gold PPI was selected for this research because it was indicated by the manufacturer as the premium grade.

4.1.2 Microbiological Tests of PPI

These tests were carried out to assess the general microbiological quality of the PPI and to ascertain that these products were free of pathogenic organisms. The presence of Salmonella was not detected in any sample (Table 15). A negative presumptive test for coliforms was also noted for all the protein isolates. There were, however, variations in the Standard Plate Count results. One batch of the Gold grade, the 985B grade and the 985R grade PPI showed counts in conformance to the <50,000 organisms/g value as suggested by the manufacturer's typical analysis (Table 12). Two batches of the Gold grade PPI, on the other hand, gave counts exceeding 50,000 organisms/g. These counts are not significant since they are in the same log cycle as the manufacturer's standard (Table 12). It is likely that the high counts were contributed by the manufacturing process during the drying and packaging operations.

TABLE 15

Results of Microbiological Tests of PPI.

	Sample				
	Gold				
	G 20	G 38	G 87	985 B	985 R
SPC (CFU/g)	7,300[1]	53,000	60,000	34,000	7,200
Coliforms Count (organisms/g)	<1	<1	<1	<1	<1
Salmonella[2]	-ve	-ve	-ve	-ve	-ve

1 Average of results from duplicate plates.
2 Performed in duplicates.

4.1.3 DSC Analysis of PPI

The denaturation temperatures (Td) and enthalpies (ΔH) of the PPI are shown in Table 16. Bhatty (1982) cited that DSC analysis of pea proteins isolated by the salt solubilization method of Murray et al. (1978) showed a Td of approximately 90°C and ΔH of 4.0 - 4.5 cal/g. All the PPI samples tested had slightly lower Td but much lower ΔH readings, implying that they were severely denatured. It may be speculated that the cause of denaturation is the harsh treatment that the proteins received during the isolation process (Section 2.4.1.4).

Denaturation of proteins significantly affect their functional properties. Of particular interest to this research are the solubility and emulsifying properties of the PPI. Voutsinas et al. (1983) found that the solubility of PPI decreased with increasing heating time at 80°C as the proteins became progressively denatured. The emulsifying activity of the protein isolates also showed a similar trend. This is in agree-

ment with the suggestion of Kinsella (1982) that the solubility of proteins was crucial to their emulsifying ability. It is because a protein which stabilizes an emulsion does so by forming a film at the interfacial region. High solubilities therefore permit rapid migration of large amounts of protein molecules to the interface to effect stabilization.

Despite the extent of denaturation shown in the PPI tested, the frozen dessert mixes containing these proteins showed satisfactory stability. The alcohol coagulation test failed to induce destabilization of any of the mixes (Table 17). This is because the pea proteins were not the only source of stabilization in the mixes. Other ingredients such as the stabilizers, emulsifiers and glucose solids also contributed to emulsion stability which was further enhanced by the homogenization process. This may also be illustrated by the disappearance after homogenization of a very thin film of oil which tended to collect on the surface of the mixes during pasteurization as agitation was slowed down or ceased. Oil separation in the homogenized mixes was not observed even after the aging process.

TABLE 16

Results of DSC Analysis of PPI.

Sample	Td[1] (°C)	ΔH[2] (cal/g protein)
Gold: G 20[4]	83.75[3]	0.32[3]
G 38[5]	81.73	0.51
G 87[6]	63.51	0.39
985 B	86.03	0.59
985 R	85.47	0.32

1 Denaturation temperature.
2 Denaturation enthalpy.
3 Average of duplicate measurements.
4 Used in Trial 1 of stage one.
5 Used in Trial 2 of stage one.
6 Used in both trials of stage two.

TABLE 17

Alcohol Coagulation Test Results on the Non-Dairy Frozen Dessert Mixes from the Two Stages of the Research.

	Results	
Sample	Trial 1	Trial 2
HS 37	-ve[1]	-ve
HS 46	-ve	-ve
HS 55	-ve	-ve
HS 64	-ve	-ve
HS 73	-ve	-ve
P 35	-ve	-ve
P 50	-ve	-ve
P 65	-ve	-ve
P 80	-ve	-ve

1 A negative result was indicated by the absence of flakes/curds in the mix/alcohol mixture; result of duplicate observations.

4.2 SOLID FAT INDEX OF THE MARGARINE OIL BLENDS

The Solid Fat Index (SFI) values at 10°C and 21.1°C were seen to increase with increasing proportions of hard margarine oil in the oil blends (Table 18). However, at 33.3°C the SFI values fluctuated. They should have followed a similar trend as observed at the other two temperatures. Further, the SFI values of the soft margarine oil at 10°C and 21°C, and that of the hard margarine oil at 10°C exceeded the usual SFI range aimed for by the production line. Such anomalies may be contributed by: (i) errors made during testing or (ii) the altered crystallization/melting behaviour caused by variations in the oil manufacturing process.

TABLE 18

Solid Fat Index of Soft and Hard Margarine Oils, Margarine Oil Blends and Butterfat.

	Solid fat index		
Sample	10°C	21.1°C	33.3°C
S (normal range)[1]	10-14	6-9	2-4
S	14.21[2]	9.28	3.56
HS 37	20.16	10.89	3.26
HS 46	20.93	11.28	3.32
HS 55	22.07	11.91	3.39
HS 64	24.29	13.20	2.97
HS 73	25.05	13.33	2.91
H	29.55	14.96	2.99
H (normal range)[1]	26-28	13-15	2-3.5
Butterfat	36.60	21.10	4.25

1 Source: G. Davidson (Personal communication).
2 Result of a single measurement.

In order to explain the relationship between the oil blend composition and the SFI values, the crystallization behaviour of the margarine oils must be understood. The soft margarine oils were formulated to give a low degree of crystallization i.e. low SFI values at refrigeration temperatures so that a spreadable margarine can be obtained, whereas the hard margarine oils were formulated so as to yield a firm product. A progressive increase of hard margarine oil content in the oil blends is therefore matched by an increase in SFI values - a rise in the degree of crystallization at a given temperature.

Berger and White (1971) pointed out that excessive churning of the fat caused by over destabilization of the oil/water emulsion would impair the whipping quality of ice cream mixes and adversely affect the quality of the finished products. One of the factors which promotes churning is the presence of soft fat (low in crystallinity) in the emulsion. Such fat contains a greater liquid oil content which is conducive to excessive churning. This phenomenon is also seen in the non-dairy frozen dessert mixes. It is probable that a similar influence of fat crystallinity on fat destabilization in ice cream mixes may have also existed in the frozen dessert mixes during the freezing process.

It is logical to suggest that the excessive fat destabilization in the frozen desserts can perhaps be managed by the use of vegetable fats which show crystallization behaviour similar to that of milkfat. But this may not be feasible. It is because even though vegetable oil can be hydrogenated to such an extent that it becomes similar to milkfat in the SFI profile (oil stock C3, Table 8), the oil is processed as an ingredient in formulating margarine oils (Tables 9 and 10) and is not available in the market place. This research, on the other hand, was

aimed at utilizing only commercially available materials for the development of a non-dairy frozen dessert. Further, it was found in the preliminary studies that frozen desserts prepared with pure hard margarine oil were not judged as acceptable by a taste panel. The use of oils with higher SFI values is not likely to improve the quality of the frozen desserts.

4.3 RESULTS OF TESTS PERFORMED ON THE FROZEN DESSERT MIXES

4.3.1 Microbiological Tests

These tests were carried out to ensure that the mixes were produced under sanitary conditions. All the Standard Plate Counts were low (Tables 19 and 20). The coliforms test also showed negative results for all samples. These results conformed to the Canadian Food and Drug regulations (1982) of a standard plate count of less than 100,000 organsims/g and a coliforms count of less than 10 organisms/g. The test results also indicated that the pasteurization process was effective in controlling the bacterial content of the mixes and that the subsequent processing steps had been carried out with proper sanitation measures.

TABLE 19

Results of Standard Plate Count (SPC) and Presumptive Coliforms Test of the Non-Dairy Frozen Dessert Mixes made with Five Different Margarine Oil Blends.

	SPC (CFU/g)			Coliforms Count (organisms/g)		
Sample	Trial 1	Trial 2	mean	Trial 1	Trial 2	mean
HS 37	1,600[1]	1,400	1,500	<1	<1	<1
HS 46	1,400	1,300	1,400	<1	<1	<1
HS 55	1,400	2,100	1,800	<1	<1	<1
HS 64	1,400	1,400	1,400	<1	<1	<1
HS 73	1,500	1,700	1,600	<1	<1	<1

1 Average of duplicate plates.

TABLE 20

Results of Standard Plate Count (SPC) and Presumptive Coliforms Test of the Non-Dairy Frozen Dessert Mixes Prepared at Four Different PPI Levels.

	SPC (CFU/g)			Coliforms Count (organisms/g)		
Sample	Trial 1	Trial 2	mean	Trial 1	Trial 2	mean
P 35	1,600[1]	2,000	1,800	<1[1]	<1	<1
P 50	2,600	3,000	2,800	<1	<1	<1
P 65	1,700	2,100	1,900	<1	<1	<1
P 80	2,400	1,700	2,100	<1	<1	<1

1 Average of duplicate plates.

4.3.2 pH and Titratable Acidity

No references were found in the literature regarding the pH and titratable acidity of non-dairy frozen dessert mixes containing PPI and canola oil. However, the ingredients of these mixes are similar to those used in ice cream mixes except that the protein and fat are from

plant sources. Therefore, factors which influence the pH and titratable acidity of ice cream mix may also be applicable to the mixes in this research. Arbuckle (1986) pointed out that an increase in MSNF content raises the titratable acidity and lowers the pH of ice cream mix. Milk components which contribute to the acidity are the proteins, mineral salts and dissolved gases. But the bulk of the acidity in milk is attributed to the phosphates and caseins (Riel, 1985). An ice cream mix containing 10% fat and 10 to 11% MSNF (Table 4) will have an acidity between 0.180 and 0.198%, and a pH of 6.32 to 6.31 (Arbuckle, 1986).

The pH of the frozen dessert mixes was likely to be influenced by the PPI and, to a lesser extent, the water which may have contained minerals and dissolved gases used in preparing the mixes (Tables 21 and 22). Further, residual acid or alkali in the PPI from the manufacturing process (Section 2.4.1.4) may have also affected the pH of the mixes. This factor may help to explain the consistency of the pH readings within each trial and the discrepancies between the two trials in stage one of the research (Table 21) because the PPI used in each trial were not from a common lot. It may also explain the difference in the pH readings between the mixes of stage one and two. Pea protein isolate from a different batch was used during stage two and hence there was no difference in the pH readings between trials (Table 22). Such confusion stems from the fact that a large quantity of PPI from a common lot could not be secured to meet the needs of the entire research.

In milk, the majority of its titratable acidity is attributed to the phosphates and caseins (Riel, 1985). The principal source of acidity of the frozen dessert mixes would therefore be the pea proteins since they

TABLE 21

pH and Titratable Acidity of the Non-Dairy Frozen Dessert Mixes made with Five Different Margarine Oil Blends.

	pH			Titratable acidity (%)		
Sample	Trial 1	Trial 2	mean	Trial 1	Trial 2	mean
HS 37	6.35[1]	6.10	6.23	0.11[1]	0.13	0.12
HS 46	6.35	6.10	6.23	0.11	0.13	0.12
HS 55	6.35	6.10	6.23	0.11	0.13	0.12
HS 64	6.40	6.10	6.25	0.11	0.13	0.12
HS 73	6.35	6.10	6.23	0.11	0.13	0.12

1 Average of duplicate measurements.

TABLE 22

pH and Titratable Acidity of the Non-dairy Frozen Dessert Mixes Prepared at Four Levels of PPI.

	pH			Titratable acidity (%)		
Sample	Trial 1	Trial 2	mean	Trial 1	Trial 2	mean
P 35	6.70[1]	6.80	6.75	0.06[1]	0.06	0.06
P 50	6.80	6.80	6.80	0.07	0.08	0.08
P 65	6.70	6.80	6.75	0.10	0.10	0.10
P 80	6.70	6.70	6.70	0.13	0.13	0.13

1 Average of duplicate measurements.

were the only mix component capable of reacting with alkali to a great extent. This is because proteins are amphoteric in nature. If any residual acid from the manufacturing process existed in the PPI, it would have also increased the titratable acidity of the mixes.

In stage one of the research the titratable acidities within each trial are fairly constant because all the mixes contained one level of

PPI (Table 21). The difference between trials was likely caused by the use of PPI of separate lots in each trial. In the second stage, no significant difference was noted in the titratable acidity between and within trials because all the mixes were made from a common batch of PPI (Table 22). However, the titratable acidity of the mixes in this stage increased with increasing PPI level. This observation is similar to that seen in ice cream mixes where the acidity is raised by increasing MSNF content. As the PPI level in the frozen dessert mixes increased, so did the protein content and hence an increase in the mix acidity. The pH and titratable acidity of the frozen dessert mixes were not adjusted to approximate those of ice cream mix because this study was aimed at utilizing the PPI on an as-is basis so that its performance in this type food system could be studied.

4.3.3 Protein Content of the Mixes

In the first stage of the research, only one level (5%) of PPI was used in the preparation of the mixes because it yielded approximately 4% of protein on a dry weight basis. This protein content was required in the frozen dessert because its formulation was modified from the general composition of an economy grade ice cream (Table 4). This type of ice cream contains 9.0 to 11.0% of MSNF which translates into a protein level of 3.3 to 4.1% since nearly 37.0% of MSNF is made up of milk proteins (Arbuckle, 1986).

The protein content of all the mixes was higher than 4% (Table 23). This is because the PPI powder was used on an as-is basis, no weight adjustment was made in order to give all the mixes exactly 4% protein.

However, there are some fluctuations in the protein content of the mixes. Normal variations in the precision and repeatability of the measurement of the PPI powder and the Kjeldahl test may have also contributed to these observations.

In addition the 5% PPI level used in the first stage, three different levels were introduced into stage two. The purpose of this design was to study the feasibility and the effects of incorporating higher or lower levels of PPI powder into the frozen desserts. A higher PPI level would increase the food value of the frozen desserts because of an increase in the protein content, while a lower PPI level may help to improve the sensory quality of the products. There was a progressive increase in the protein content of the mixes with increasing PPI levels (Table 24). Factors which may have contributed to the variations in the protein content between the two trials were pointed out in the previous paragraph.

TABLE 23

Protein Content of the Non-Dairy Frozen Dessert Mixes made with Five Margarine Oil Blends.

Protein Content (%)[1]			
Sample	Trial 1	Trial 2	mean
HS 37	4.27[1]	4.18	4.23
HS 46	4.22	4.14	4.13
HS 55	4.16	4.24	4.20
HS 64	4.29	4.27	4.28
HS 73	4.18	4.12	4.15

1 % Protein = % N x 6.25 (wet weight basis); average of duplicate measurements.

TABLE 24

Protein Content of the Non-Dairy Frozen Dessert Mixes Prepared at Four Levels of PPI.

Sample	Protein Content (%)[1] Trial 1	Trial 2	mean
P 35	2.88[1]	2.78	2.83
P 50	4.08	4.15	4.12
P 65	5.38	5.45	5.42
P 80	6.55	6.82	6.69

1 % Protein = % N x 6.25 (wet weight basis); average of duplicate measurements.

4.3.4 Fat Content of the Mixes

Since only one level of fat (10.50%) was used in the preparation of all the mixes, the fat test results of the mixes should be fairly consistent, but the fat content was seen to vary between 10.25% and 10.75% in stage one (Table 25) and between 10.25% and 10.50% in stage two (Table 26). This could be the result of variations in the measurement of ingredients during the processing of the mixes, although it should be noted that the fat content of the mixes also included the fat contributed by the PPI (Table 12). Nevertheless, these fluctuations are usually observed in food production lines due to the method and type of equipment used to measure the quantity of ingredients and; due to losses through handling. Such variations are also generally tolerated by the formulation of the product. An example is that an economy grade ice cream may have a fat content of 10±0.5%. Set against this 0.5% tolerance range, the variations seen among the mixes of both stages are acceptable. As a result, it is believed that these fluctuations were not sufficiently large to affect the quality of the frozen desserts.

TABLE 25

Fat Content of the Non-Dairy Frozen Dessert Mixes made with Five Margarine Oil Blends.

Sample	Fat Content (%) Trial 1	Trial 2	mean
HS 37	10.50[1]	10.75	10.63
HS 46	10.25	10.50	10.38
HS 55	10.25	10.50	10.38
HS 64	10.50	10.25	10.38
HS 73	10.50	10.75	10.63

1 Average of duplicate measurements.

TABLE 26

Fat Content of the Non-Dairy Frozen Dessert Mixes Prepared at Four PPI Levels.

Sample	Fat Content (%) Trial 1	Trial 2	mean
P 35	10.50[1]	10.25	10.38
P 50	10.50	10.25	10.38
P 65	10.50	10.50	10.50
P 80	10.25	10.25	10.25

1 Average of duplicate measurements.

4.3.5 Total Solids Content of the Mixes

The total solids content of the mixes in stage one is quite consistent because these mixes were prepared according to a common formulation (Table 27). All the mixes at this stage should contain approximately 37.60% total solids according to the formulation. However, Table 27 shows that the total solids content of the mixes was higher. Two factors may have contributed to these observations. First of which is

the loss of moisture during the pasteurization of the mixes by the batch method in which they were heated at 175^{0}F for 30 min. The second factor may have originated from the variations in the measurement of ingredients. An excess of dry ingredients or insufficient water used during processing could have altered the total solids content of the mixes.

In stage two, the mixes were prepared at four levels of PPI and hence an increase in PPI levels was matched by an increase in the total solids content (Table 28). The PPI level at this stage increased in 1.5% increments. Since the PPI contained 5% moisture, 1.5% of PPI would yield 1.43% dry matter. The total solids content of a mix should therefore differ from the one containing a higher or lower level of PPI by 1.43%. However, this was not observed in Table 28. Factors which could have contributed to these variations were discussed in the previous paragraph.

TABLE 27

Total Solids Content of the Non-Dairy Frozen Dessert Mixes made with Five Different Margarine Oil Blends.

Sample	Total Solids Content (%) Trial 1	Trial 2	mean
HS 37	38.22[1]	38.27	38.25
HS 46	38.13	37.85	37.99
HS 55	38.57	38.65	38.61
HS 64	38.32	38.27	38.30
HS 73	38.50	37.88	38.19

1 Average of duplicate measurements.

TABLE 28

Total solids content of the Non-Dairy Frozen Dessert Mixes Prepared at Four PPI Levels.

Sample	Total Solids Content (%) Trial 1	Trial 2	mean
P 35	36.25[1]	36.26	36.26
P 50	37.56	37.97	37.77
P 65	39.74	40.00	39.87
P 80	40.78	41.12	40.95

1 Average of duplicate measurements.

4.3.6 Viscosity of the Frozen Dessert Mixes

The apparent viscosities of the mixes of stage one and two are shown in Tables 29 and 30, respectively. Both tables show that these mixes were pseudoplastic in nature, as indicated by a decline in viscosity with increasing shear rate (Mohsenin, 1978). The flow of homogenized ice cream mix was also pseudoplastic as observed by Dickinson and Stainsby (1982). It can be speculated that the internal structure of the frozen dessert mixes might have been very similar to that of ice cream mix in order for them to exhibit such a close resemblance in rheological behaviour. However, all the frozen dessert mixes were more viscous than the ice cream mix prepared in this research (Tables 29 and 30). This could be the result of the preparation of the ice cream mix according to a different formulation (Table 25). As seen from Tables 29 and 30, the viscosity readings of the two trials of a sample did not always agree closely at the same shear rate. This is very likely caused by the variations in the fat, protein and total solids content of the mixes from the two trials. It was also shown in the two tables that in

some instances such as HS 64, the apparent viscosity increased shortly after the measurement had begun. This is a usual phenomenon as the mix was undergoing a stabilization process in reaction to the applied stress.

TABLE 29

Apparent Viscosities of the Non-Dairy Frozen Dessert Mixes Made with Five Different Margarine Oil Blends.

	Apparent Viscosity (Pas) at 20°C									
	Sample									
	HS 37		HS 46		HS 55		HS 64		HS 73	
Shear Rate (s^{-1})	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
0.03682	59.52[1]	14.58	29.56	7.334	15.82	8.405	14.61	10.19	15.92	10.58
0.05833	51.04	13.44	26.00	8.206	12.88	8.335	18.91	12.79	16.80	16.18
0.09246	30.94	8.609	14.46	6.381	7.721	6.469	15.04	10.31	10.89	13.94
0.1465	16.58	5.139	7.892	4.485	4.655	4.660	1.037	7.322	6.332	10.50
0.2326	9.821	3.869	5.342	3.731	3.591	3.683	7.559	5.289	4.404	7.117
0.3686	5.050	2.449	3.255	2.492	2.404	2.589	4.95	3.387	2.744	3.699
0.5833	3.164	1.618	2.079	1.778	1.652	1.821	3.315	2.133	1.761	2.155
0.9232	2.041	1.102	1.467	1.255	1.187	1.292	2.237	1.404	1.165	1.373
1.467	1.382	0.7683	1.020	0.9083	0.8510	0.9888	1.599	1.007	0.8135	0.9310
2.322	1.018	0.5591	0.7085	0.6699	0.6588	0.7850	1.204	0.7788	0.6140	0.6736
3.682	0.7590	0.4298	0.5196	0.4790	0.4966	0.6083	0.9249	0.5908	0.4316	0.4954
5.833	0.5900	0.3403	0.3957	0.4158	0.3996	0.5143	0.7425	0.4838	0.3389	0.3895
9.246	0.4795	0.2875	0.3186	0.3473	0.3258	0.4446	0.6254	0.4113	0.2663	0.3150
14.65	0.3915	0.2421	0.2633	0.2860	0.2684	0.3775	0.5188	0.3467	0.2226	0.2769
23.26	0.3251	0.208	0.2191	0.2358	0.2230	0.3218	0.4366	0.2926	0.1861	0.2349
36.86	0.2737	0.1809	0.1866	0.1955	0.1890	0.2749	0.3686	0.2495	0.1591	0.2022
58.33	0.2344	0.1585	0.1619	0.1631	0.1622	0.2339	0.3071	0.2133	0.1393	0.1764
92.32	0.2029	0.1393	0.1417	0.1369	0.1396	0.1990	0.2522	0.1820	0.1233	0.1544
146.7	0.1719	0.1226	0.1235	0.1156	0.1184	0.1705	0.2048	0.1538	0.1086	0.1350
232.2	0.1381	0.1084	0.1077	0.0985	0.09279	0.1458	0.1662	0.1296	0.09638	0.1180
368.2	0.1168	0.09557	0.09394	0.08487	0.07849	0.1247	0.1352	0.1092	0.08634	0.1031
583.3	0.09947	0.08409	0.08198	0.07423	0.07003	0.1068	0.1107	0.09229	0.07756	0.09028
924.6	0.08459	0.07392	0.07238	0.06578	0.06234	0.09163	0.09150	0.07868	0.06992	0.07963
1465	0.06859	0.06539	0.06415	0.05866	0.05381	0.07819	0.07639	0.06831	0.06272	0.07028

1 Average of duplicate measurements.

TABLE 30

Apparent Viscosities of Non-Dairy Frozen Dessert Mixes Prepared at Four PPI Levels and of Ice Cream Mix.

	Apparent Viscosity (Pas) at 20°C								
	Sample								
	P 35		P 50		P 65		P 80		
Shear Rate (s^{-1})	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Ice Cream Mix
0.03682	4.862[1]	3.183	17.41	15.72	16.84	23.28	59.61	59.34	15.40
0.05833	5.191	3.070	14.81	13.41	28.91	18.89	56.32	56.04	8.675
0.09246	4.013	2.593	10.18	9.355	21.36	13.66	39.84	40.65	4.165
0.1465	2.730	1.949	6.787	6.631	13.70	9.781	25.97	27.99	2.149
0.2326	2.328	1.922	4.969	5.073	9.534	7.428	18.57	20.08	1.549
0.3686	1.616	1.323	3.369	3.566	6.214	5.136	12.75	13.65	0.9630
0.5833	1.152	1.062	2.305	2.541	4.283	3.680	8.886	9.464	0.6228
0.9232	0.8187	0.7693	1.640	1.857	2.965	2.673	6.209	6.664	0.4040
1.467	0.6199	0.5697	1.199	1.328	2.132	1.967	4.386	4.796	0.2572
2.322	0.4888	0.4454	0.8952	0.9954	1.589	1.462	3.209	3.458	0.1817
3.682	0.3622	0.3495	0.6401	0.7626	1.140	1.087	2.345	2.523	0.1403
5.833	0.2916	0.2900	0.5001	0.5909	0.8758	0.8034	1.764	1.895	0.1062
9.246	0.2379	0.2396	0.3916	0.4697	0.6752	0.6533	1.339	1.447	0.08521
14.65	0.2008	0.2041	0.3159	0.3776	0.5346	0.5193	1.042	1.121	0.06897
23.26	0.17001	0.1770	0.2577	0.3088	0.4266	0.4197	0.8245	0.8860	0.05929
36.86	0.1443	0.1555	0.2153	0.2594	0.3478	0.3458	0.6683	0.7159	0.05201
58.33	0.1291	0.1378	0.1832	0.2216	0.2899	0.2906	0.5517	0.5909	0.04697
92.32	0.1140	0.1227	0.1591	0.1916	0.2471	0.2493	0.4649	0.4977	0.04239
146.7	0.1007	0.1091	0.1382	0.1669	0.2142	0.2169	0.3963	0.4234	0.03905
232.2	0.08927	0.09706	0.1232	0.1463	0.1878	0.1913	0.3399	0.3631	0.03643
368.2	0.07915	0.08640	0.1088	0.1279	0.1654	0.1691	0.2908	0.3107	0.03436
583.3	0.07014	0.07667	0.09579	0.1112	0.1452	0.1487	0.2485	0.2647	0.03288
924.6	0.06204	0.06779	0.08398	0.09609	0.1267	0.1300	0.2133	0.2255	0.03165
1465	0.05343	0.05881	0.07292	0.08121	0.1091	0.1102	------	------	0.03043

1 Average of duplicate measurements.

Although the fat content of the mixes fluctuated between 10.25% and 10.75% (Table 25), it was not observed to have a direct relationship with the apparent viscosity of the mixes (Table 29). The SFI values of the fat did not have any noticeable effect on the mix viscosity either. But it appears that the type of fat used in frozen dessert mixes may have some influence on the mix viscosity. Youssef et al. (1981) found that the mix viscosity decreased with increasing level of butterfat substitution by cottonseed and corn oils in their ice cream mixes. In a similar study, El-Deeb et al. (1983) observed that the mix viscosity increased with increasing substitution level of butterfat by hydrogenated oils in their mixes. The results of these studies suggested that whether a vegetable oil would differ from butterfat in the ability to affect mix viscosity may be dependent on its source and type.

The protein level of the mixes in this study, however, showed a direct relationship with the apparent viscosity. Table 30 indicates that as the PPI level increased, so did the apparent viscosity of the mixes. Such a trend is expected because proteins dispersed in water exhibit a gelling and/or thickening effect (Igoe, 1982) due to their ability to bind and immobilize large amounts of water (Andreasen, 1985). During the aging period, the milk proteins in ice cream mix become fully hydrated (Mitten and Neirinckx, 1986). The result is an increase in the mix viscosity after aging. It is reasonable to suggest that a similar phenomenon had also occurred in the frozen dessert mixes. The combination of these effects were intensified by the increasing pea protein content of the mixes. The increase in the protein content also corresponded to a steady decline in the overrun of the frozen desserts (Table

31). In other word, the overrun decreased with rising viscosity of the mixes. This agrees with Arbuckle (1986) who stated that the whipping rate of ice cream mix was generally retarded as the mix viscosity increased.

Plant protein preaprations in general seem to be more effective than milk proteins in imparting viscosity to the mix. Lawhon et al. (1980), El-Deeb and Salam (1984) and Gabriel et al. (1986) found that as the level of MSNF replacement with plant protein preparations increased in their frozen dessert mixes, so did the mix viscosity. The viscosities of these mixes were always greater than that of the control. But Simmons et al. (1980) observed that the increase in mix viscosity was not always proportional to increasing replacement level and that the mixes containing plant protein preparations were not, as a rule, more viscous than the control. It appeared that whether plant proteins were more effective than milk proteins in imparting viscosity to the mix was dependent on the replacement level, and the source and type of the protein preparations involved.

4.4 RESULTS OF TESTS PERFORMED ON THE FROZEN DESSERTS

4.4.1 Overrun of the Frozen Desserts

The overrun of the non-dairy frozen desserts from the first stage and the second stage of the research is shown in Tables 31 and 32, respectively. In stage one, all the mixes were prepared with identical formulations. The only variable at this stage was the composition of the fat used in the mixes, although some fluctuations in the fat content were observed (Table 25). These variations may have affected the whippa-

blility of the mixes because foam formation during freezing is depressed as the level of fat rises (Berger et al. 1972a), but they were perhaps too small to influence the overrun of the frozen desserts as the overrun was not seen to have fluctuated with the fat content of the mixes.

However, the overrun of the frozen desserts was affected by the composition of the fat the mixes contained. It was observed to increase with the rising SFI values of the fat in the mixes. This is because excessive fat destabilization which retards the whipping rate of the mix is promoted by fats with large liquid oil fractions (Berger and White, 1971). An increase in SFI values implies a lowering of the liquid oil content of a fat (Waddington, 1986). As the fat in the frozen desserts contained a greater fraction of hard margarine oil i.e. a higher SFI and a lower liquid oil content, the detrimental effect of fat destabilization on mix whippability was lessened. This resulted in an increase in the overrun. Nevertheless, the overrun of the frozen desserts was not as high as that of the ice cream (91.7%) prepared in this research. This is because the frozen dessert mixes and the ice cream mix were not similar in composition (Tables 13 and 14). Also, hydrogenated vegetable oils have been shown to depress the overrun of ice cream. El-Deeb et al. (1983) observed that the overrun of ice cream declined steadily as the level of milkfat substitution by hydrogenated vegetable oils increased. Further, the overrun of these ice cream was lower than that of the control. But the overrun-depressing effect appeared to be related to the type of oils involved. In a similar study using cottonseed and corn oils, Youssef et al. (1981) did not observed any detrimental effect of milkfat substitution by cottonseed and corn oils on overrun.

In the second stage, the overrun of the frozen desserts decreased with rising PPI levels in the mixes (Table 32). A study by Simmons et al. (1980) using plant protein isolates to partially replace MSNF in frozen desserts showed that the overrun declined with increasing level of replacement. Another study by El-Deeb and Salam (1984) using seed flours also resulted in similar findings. Both investigations found that the overrun of the controls was higher. It is possible that the ability to impair overrun was an inherent property of plant protein preparations. But this property may be dependent on the type and source of the protein involved because Gabriel et al. (1986) found that increasing level of MSNF substitution with groundnut protein isolate did not result in a corresponding decrease in overrun.

As was mentioned earlier that the apparent viscosity of the mixes increased with increasing level of PPI (Table 30). Arbuckle (1986) pointed out that as the viscosity of ice cream mix increases, the whipping rate becomes retarded. But the studies by Simmons et al. (1980) and Gabriel et al. (1986) showed that an increase in the viscosity of their frozen dessert mixes containing plant protein preparations did not necessarily result in a decline in the overrun. Perhaps whether the overrun would drop with rising mix viscosity was again a function of the type and source of protein preparations used in the mixes.

TABLE 31

Overrun of Non-Dairy Frozen Dessert Mixes made with Five Different Margarine Oil Blends.

	Overrun (%)		
Sample	Trial 1	Trial 2	mean
HS 37	50.0[1]	51.7	50.9
HS 46	52.4	54.2	53.3
HS 55	54.9	59.7	57.3
HS 64	60.1	62.0	61.1
HS 73	63.2	65.4	64.3

1 Average of six measurements.

TABLE 32

Overrun of Non-Dairy Dessert Mixes Prepared at Four Different PPI Levels.

	Overrun (%)		
Sample	Trial 1	Trial 2	mean
P 35	63.4[1]	67.2	65.3
P 50	57.1	55.6	56.4
P 65	45.8	44.2	45.0
P 80	35.4	39.4	37.4

1 Average of six measurements.

4.4.2 Sensory Analysis of the Non-Dairy Frozen Desserts

Regular ice cream was not used as a control in the sensory evaluation of the frozen desserts because the objective of the sensory testing in this research was to judge the frozen desserts based on their own qualities per se, rather than in comparison to those of ice cream. Simple preference test alone was used because of the exploratory nature of this

investigation due to the lack of information on the properties of this type of products which contain PPI. Only the frozen desserts from the second trial of each stage of the research were subjected to sensory evaluation and each panel was not repeated. This is because replication in preference testing is not a typical practice since the objective of the test is to provide generalized results on sample differences (Stone and Sidel, 1985). Furthermore, replication in hedonic testing is not effective as a consistency check on the panel results (O'Mahony, 1986).

The analysis of variance of the sensory evaluation data of the frozen desserts of the first stage is shown in Appendix B. The analysis showed that there were significant variations among the samples and among panelists at the 5% level of significance. Despite the significant variations among the panelists, analysis of the sensory evaluation data by the coefficient of concordance ($\alpha = 0.05$) showed that the ranking of the samples was not a random event (Appendix C). This implied that there was a general consensus among the panelists regarding the order of preference for the samples.

The order of preference for the frozen desserts was obtained by ranking the mean scores (Table 33). On the other hand, the order of preference established by the sums of ranks is slightly different, but it is considered to be an accurate estimate of the preferential order of the samples (Kendall, 1970). The degree of acceptability or preference increases with the magnitude of the mean score or the sum of ranks. Despite the slight discrepancy in the ranking of the samples by the two orders of preference, they both ranked HS 64 as the most acceptable product. The Tukey test results (Table 33) revealed that HS 64 was

significantly more acceptable than HS 37 and HS 46, but did not differ from HS 55 and HS 73 in acceptability at the 5% level of significance. HS 55 and HS 73 did not in turn differ significantly from HS 37 and HS 46. The differences among the samples may therefore be marginal and were not very distinctive to the panelists. This may help to explain the slight variation seen in the ranking of the frozen desserts based on the mean scores and on the sums of ranks.

TABLE 33

Sums of Ranks and Tukey Test Results on the Mean Scores of the Non-Dairy Frozen Desserts made with Five Different Margarine Oil Blends.

Sample	HS 64	HS 55	HS 73	HS 37	HS 46
Sum of Ranks[1]	191.5	158.5	163.5	151.0	130.5
Mean Score[2]	6.51 a	5.94 ab	5.87 ab	5.77 b	5.40 b

Honestly significant difference for the Tukey test = 0.69 (α = 0.05). Mean scores with the same letter(s) are not significantly different at the 5% level of significance.
1 from Appendix C.
2 from Appendix B.

Although the fat content of the frozen dessert mixes varied (Table 25), there was no direct relationship between these variations and the sensory scores of the end products. On the contrary, the composition of the fat may be the dominant factor which had influenced the quality of the frozen desserts at this stage. This can be seen in Table 25 that although HS 73 contained more fat than HS 55, the mean scores of the two samples did not differ significantly (Table 33). However, both HS 73 and HS 37 had identical levels of fat (Table 25) and yet the latter was

significantly less preferred by the panelists to HS 64 based on the mean scores (Table 33). These observations suggest that the composition rather than the content of fat which may have affected the quality of the frozen desserts. This point is reflected in two studies. Youssef et al. (1981) did not find any direct relationship between the overall sensory score and the level of substitution of butterfat with corn and cottonseed oils in ice cream. The controls scored higher. On the contrary, El-Deeb et al. (1983) found that as the level of milkfat substitution with hydrogenated oils increased in their mixes, the overall score of the resultant ice cream declined accordingly. The findings of these studies suggested that vegetable oils may affect the sensory qualities of ice cream to which they were added, but the effect appeared to be influenced by the type as well as the amount of oil used. Since the frozen desserts in this research contained only vegetable oils, it is safe to infer that they are inferior to ice cream with respect to their sensory quality.

As for the first stage of this study, the oil blend HS 64 was found to be the optimum fat composition which could be used to manufacture an acceptable frozen dessert. The mean scores of the frozen desserts decreased as the oil blend composition move toward HS 55 or HS 73 (Table 33). This in essence provides a fat composition/SFI range for formulating a fat, in conjunction with the PPI, which is able to produce a satisfactory frozen dessert. According to the findings of this stage of the study, the optimum SFI for a fat to be use in the frozen dessert mix would be 24.29 at 10°C (HS 64), within a range of 22.07 (HS 55) and 25.05 (HS 73) (Table 18).

The analysis of variance of the sensory evaluation results of stage two is shown in Appendix D. Significant variations (α = 0.05) among the panelists and among the samples tested were revealed. Despite the variations among the panelists, the analysis by the coefficient of concordance (α = 0.05) indicated that the panelists generally rank the samples in the same order according to some characteristics of the samples (Appendix E). The mean scores and the sums of ranks of the frozen desserts are shown in Table 34. Both the mean scores and the sums of ranks dropped steadily as the PPI levels increased. The Tukey test results (Table 34) showed that P 35 was significantly higher than P 65 and P 80, but not P 50 in the mean score. Both P 50 and P 65 did not differ from each other but scored significantly higher than P 80. The order of preference for the samples according to both the mean scores and the sums of ranks was P 35 first, P 50 second, P 65 third, and P 80 last. The panelists' order of preference for the samples at this stage clearly indicated that high levels of PPI in the mixes negatively affect the sensory qualities of the frozen desserts.

TABLE 34

Sums of Ranks and Tukey Test Results on the Mean Scores of the Non-Dairy Frozen Desserts Prepared at Four Different PPI Levels.

Sample	P 35	P 50	P 65	P 80
Sum of Ranks[1]	152.0	131.5	115.5	81.0
Mean Score[2]	6.65 a	6.19 ab	5.73 b	4.60 c

Honestly significant difference for the Tukey test = 0.69 (α = 0.05).
Mean scores with the same letter are not significantly different at the 5% level of significance.
1 from Appendix E.
2 from Appendix D.

The suggestion that the incorporation of plant protein preparations into ice cream would affect the finished product quality have been reflected in two studies. El-Deeb and Salam (1984) and Gabriel et al. (1986) found that increasing levels of MSNF substitution with plant protein preparations in ice cream mix was matched by a steady decline in the sensory/overall score of the resultant ice cream. However, two earlier studies produced slightly different results. Simmons et al. (1980) found that increasing levels of MSNF substitution with plant proteins did decrease the overall acceptability of ice cream. Lawhon et al. (1980) also obtained similar results with some exceptions that the substitution level did not show any direct relationship with overall acceptability. But in both studies it appeared that whether the lower scores of the experimental products were significantly different from that of the control was influenced by the substitution level and the type and source of protein preparations used. As the present investigation is concerned, the PPI level of 3.5% yielded the most acceptable frozen dessert as compared to those containing higher levels of PPI. Significantly less acceptable products resulted from the use of PPI levels higher than 5%. This indicated that the 5% level was the upper limit to which PPI could be used in the mix without negatively affecting the quality of the frozen dessert.

4.4.3 Melting Quality of the Frozen Desserts

The melting quality of the frozen desserts was studied because it is an objective method of assessing the influence of the formulation and processing conditions on their quality. Figures 4 and 5 show the

melting behaviour of the frozen desserts from trial one and two of the first stage of the research, respectively. It was shown that the frozen desserts in the two trials melted in a uniform manner at room temperature within a period of one hour. No melting quality defects were noted. This suggested that the frozen desserts had been properly formulated and processed.

The melting quality of the frozen desserts of the first and second trial of stage two of the study is depicted in Figures 6 and 7, respectively. While P 35 and P 50 in both trials melted completely at the end of the one-hour period, P 65 and P 80 behaved differently as both showed a slow rate of melting. It can be seen that P 65 still contained some materials which had failed to melt after being exposed to room temperature for an hour. On the other hand, P 80 obviously suffered from the does-not-melt defect as frozen materials were clearly visible at the end of the observation period. One of the causes of this melting defect is overstabilization of the mix. The mixes were overstabilized as a result of the high levels of PPI used in P 65 and P 80. Pea protein isolates contain fiber and oligosaccharides (Table 12). These materials, as well as the pea proteins, are able to bind water and therefore act like stabilizers. Consequently, high levels of PPI, combined with the amount of stabilizer in the formulation, resulted in an excessive stabilization effect in the mixes.

The melting behaviour of the frozen desserts at this stage was also seen to be related to the sensory scores. As the PPI level in the frozen desserts increased, so did their resistance to melting which was in turn matched by a decline in the mean scores and sums of ranks (Table

34). The does not melt defect is usually accompanied by a soggy, gummy or sticky body. Figures 6 and 7 show that both P 65 and P 80 appeared to be soggy. Although the panelists were asked to judge the frozen desserts on the basis of general preference, the negative qualities of the samples must have been sufficiently noticeable to be reflected by the low scores.

Figure 4: Melting Behaviour of the Frozen Desserts Prepared with Five Margarine Oil Blends - Trial 1.

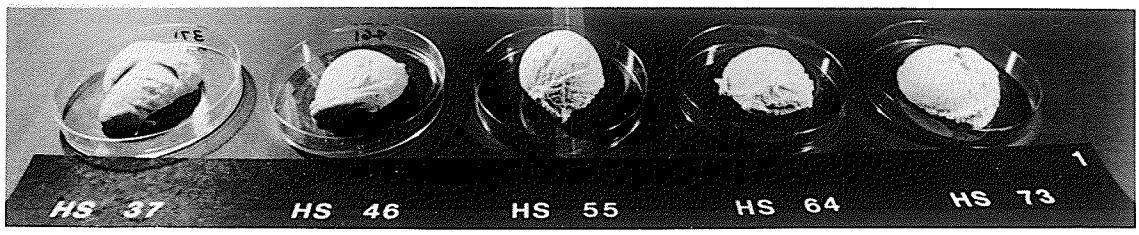
From top to bottom:

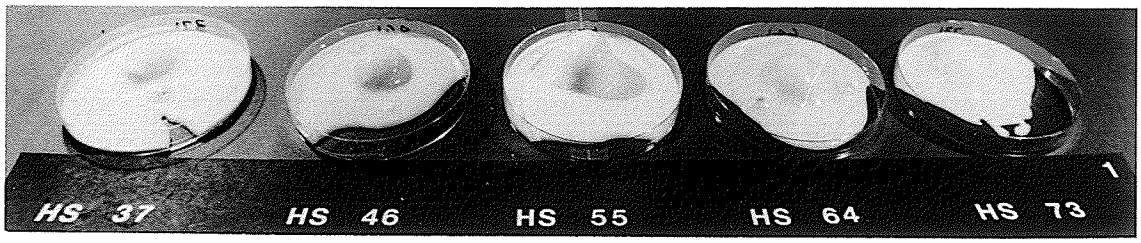
0 minute

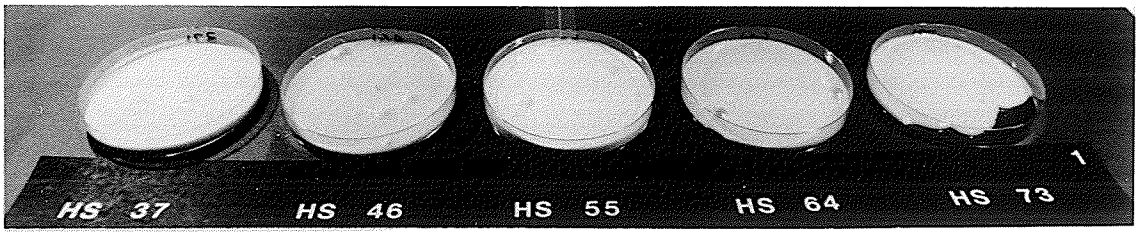
20 minutes

40 minutes

60 minutes


HS 37
HS 46
HS 55
HS 64
HS 73
1


HS 37
HS 46
HS 55
HS 64
HS 73
1


HS 37
HS 46
HS 55
HS 64
HS 73
1

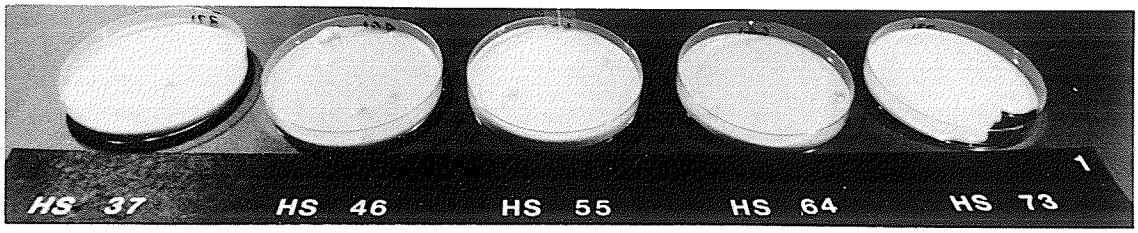

HS 37
HS 46
HS 55
HS 64
HS 73
1

Figure 5: Melting Behaviour of the Frozen Desserts Prepared with Five Margarine Oil Blends - Trial 2.

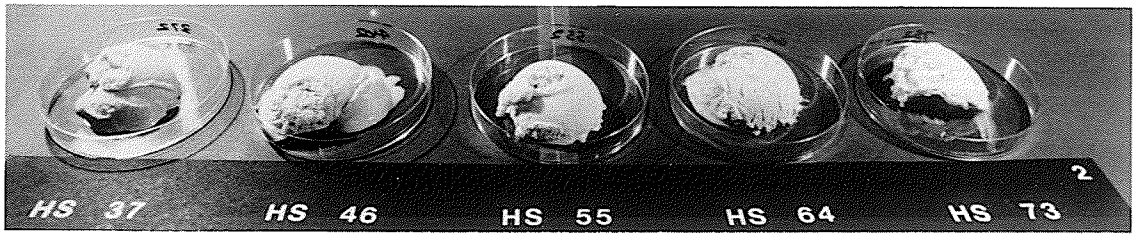
From top to bottom:

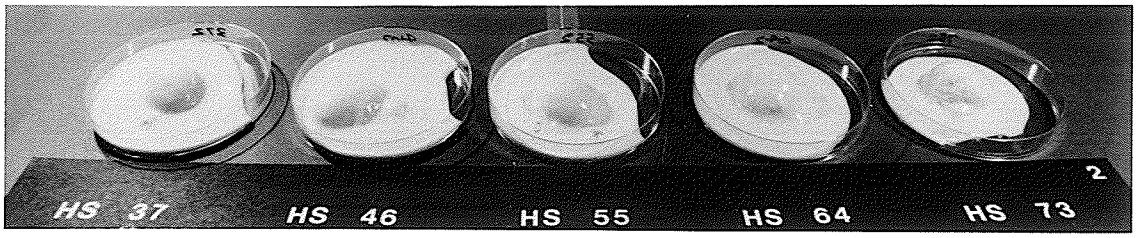
0 minute

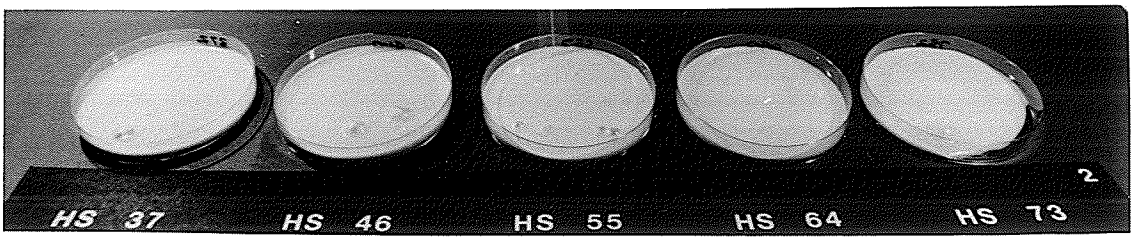
20 minutes

40 minutes

60 minutes


HS 37
HS 46
HS 55
HS 64
HS 73
2


HS 37
HS 46
HS 55
HS 64
HS 73
2


HS 37
HS 46
HS 55
HS 64
HS 73
2

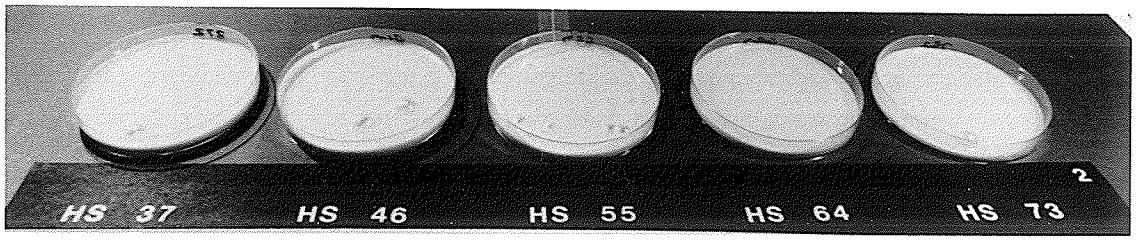

HS 37
HS 46
HS 55
HS 64
HS 73
2

Figure 6: Melting Behaviour of Ice Cream and the Frozen Desserts Made with Four Levels of PPI - Trial 1.

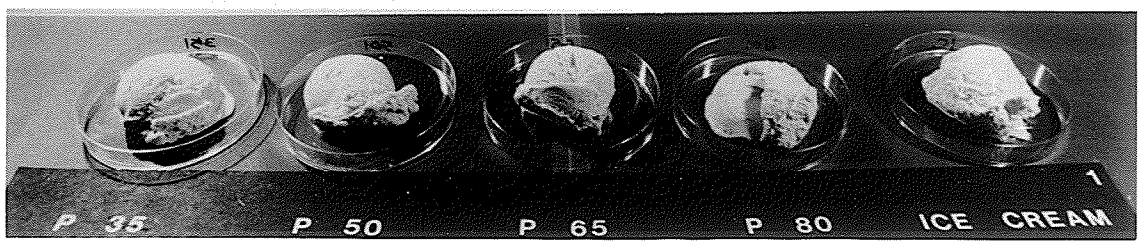
From top to bottom:

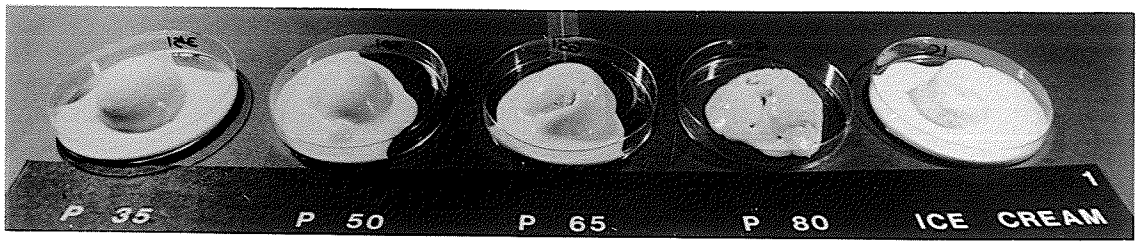
0 minute

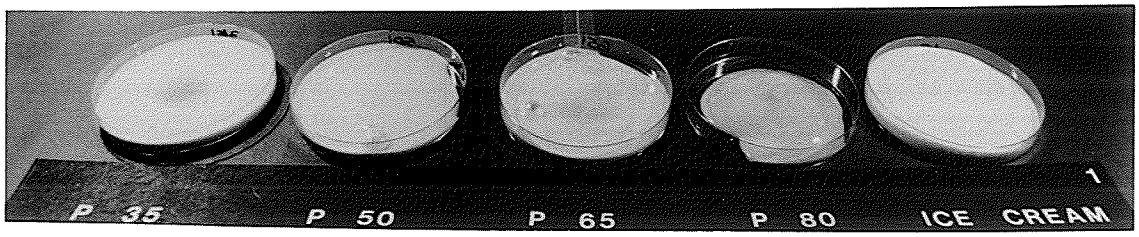
20 minutes

40 minutes

60 minutes


P 35
P 50
P 65
P 80
ICE CREAM
1


P 35
P 50
P 65
P 80
ICE CREAM
1


P 35
P 50
P 65
P 80
ICE CREAM
1


P 35
P 50
P 65
P 80
ICE CREAM
1

Figure 7: Melting Behaviour of the Frozen Desserts Made with Four Levels of PPI - Trial 2.

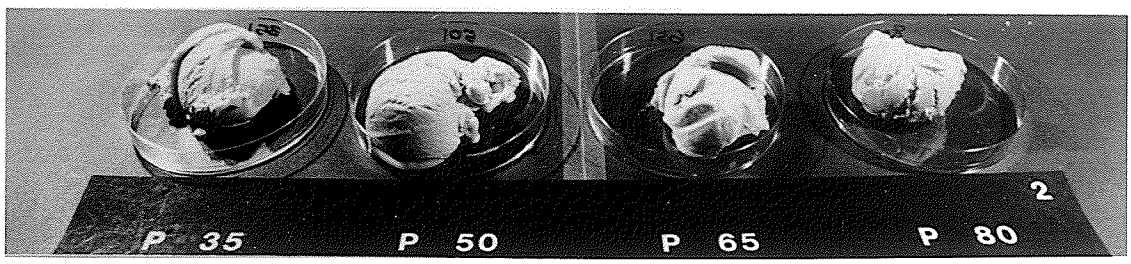
From top to bottom:

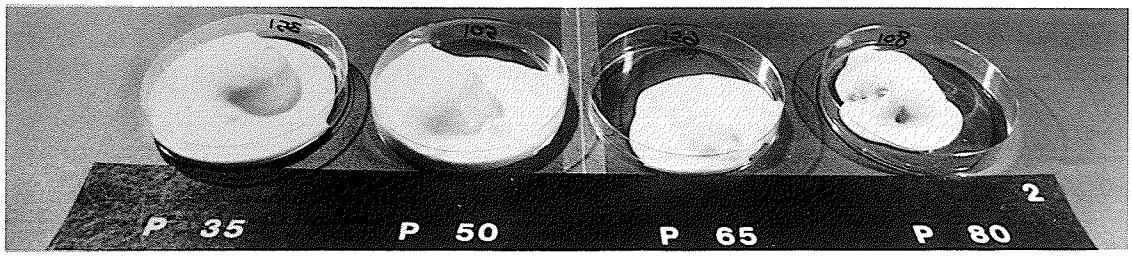
0 minute

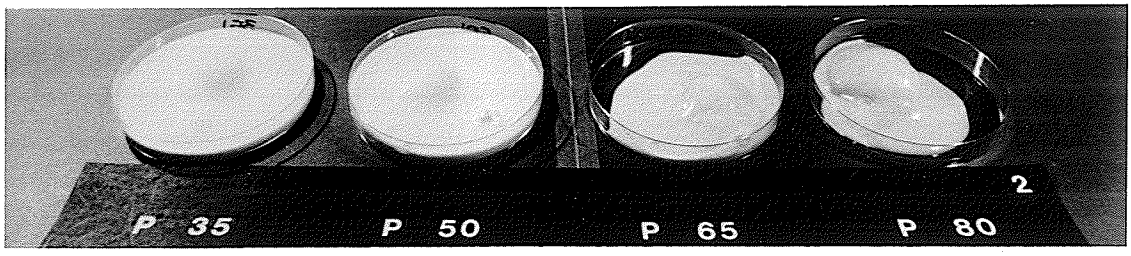
20 minutes

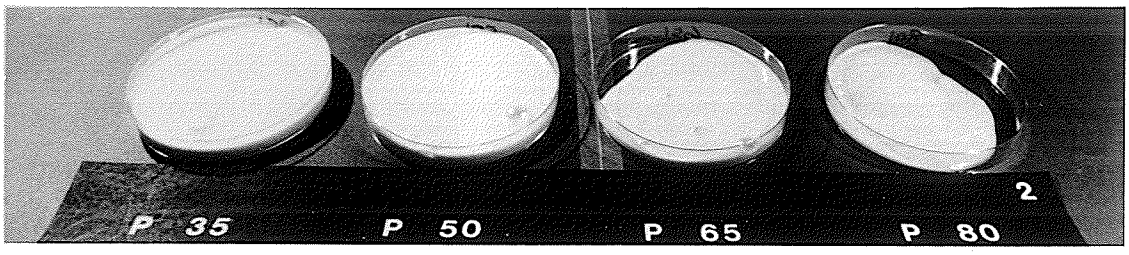
40 minutes

60 minutes


P 35
P 50
P 65
P 80
2


P 35
P 50
P 65
P 80
2


P 35
P 50
P 65
P 80
2


P 35
P 50
P 65
P 80
2

4.4.4 Microstructure of the Frozen Desserts

This part of the research was primarily carried out to provide a general comparison of the internal structure of the frozen desserts. It was not intended to be a detail and in-depth study due to the many technical difficulties involved. Only representative illustrations are presented in this section. Photographs of the most and the least preferred samples from each stage of the study were selected. Figures 8, 9, 10 and 11 show the internal structure of HS 64, HS 46, P 35 and P 80, respectively. Each figure also includes a photograph of the structure of ice cream for comparison purposes. The photographs did not have high resolution since the image of the frozen desserts were magnified 63 times. Higher magnification factor could not be achieved because the cooling stage employed to prevent rapid melting of specimen made the use of the more powerful objectives of the microscope impossible.

Figures 8, 9, 10 and 11 shows that the ice cream specimen had a comparatively more defined structure than the frozen desserts. There was no attempt made to identify the various features of the microstructure of the frozen desserts because such an undertaking is beyond the objective of this study. Further, due to the low magnification and the rudimentary technique used to prepare these photographs, it was not possible to obtain accurate identification of the various structural components. The specimens were not dyed as the colours of the photographs may have suggested. The various colours in the photographs are the combined result of the age of the slides from which the photographs were printed and the printing process. Nevertheless, the structure of the frozen desserts was very obscured and ill-defined with the exception

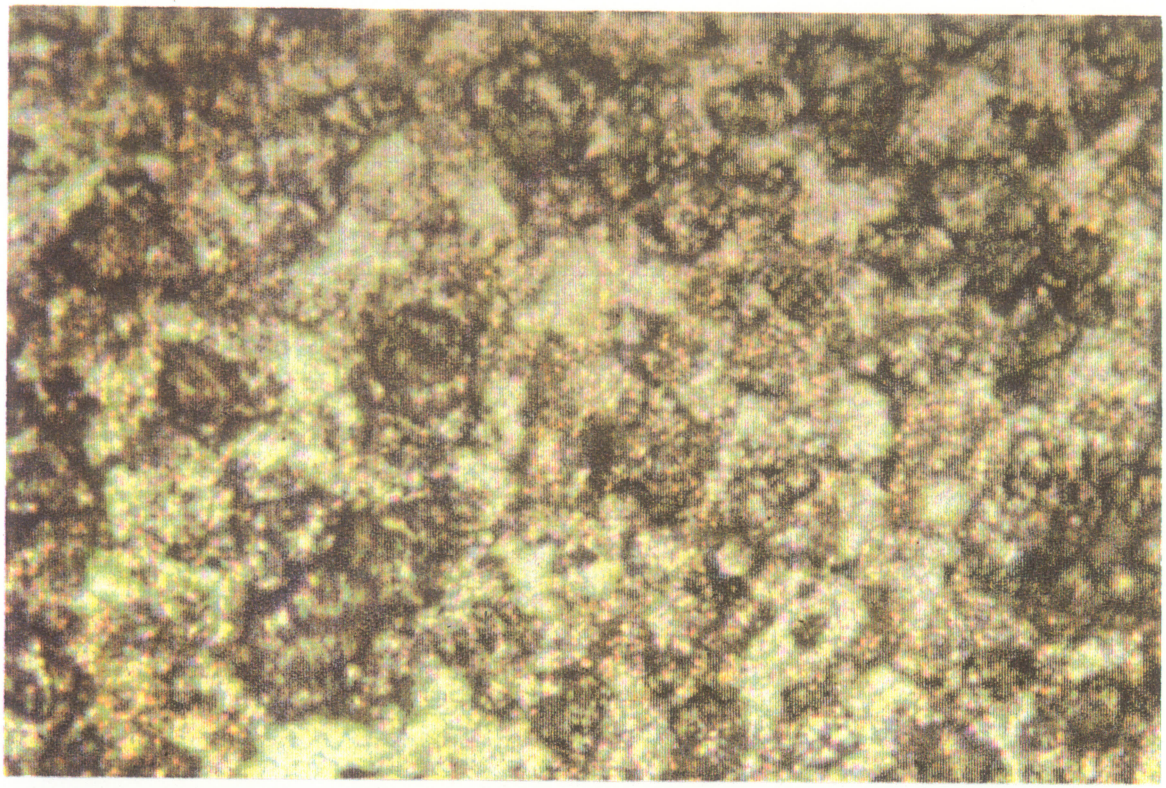
of P 35 which appeared similar to ice cream but its structural integrity may be inferior to ice cream as indicated by the fractures observed. These photographs suggest that both the vegetable fat and pea proteins were not able to give a structure that is similar to ice cream to the frozen desserts. This may in turn negatively affect the product quality/acceptability.

Figure 8: The Internal Structure of the Frozen Dessert Made with the HS 64 Oil Blend and of Ice Cream.

Magnification: 63X

Top: HS 64

Bottom: Ice Cream



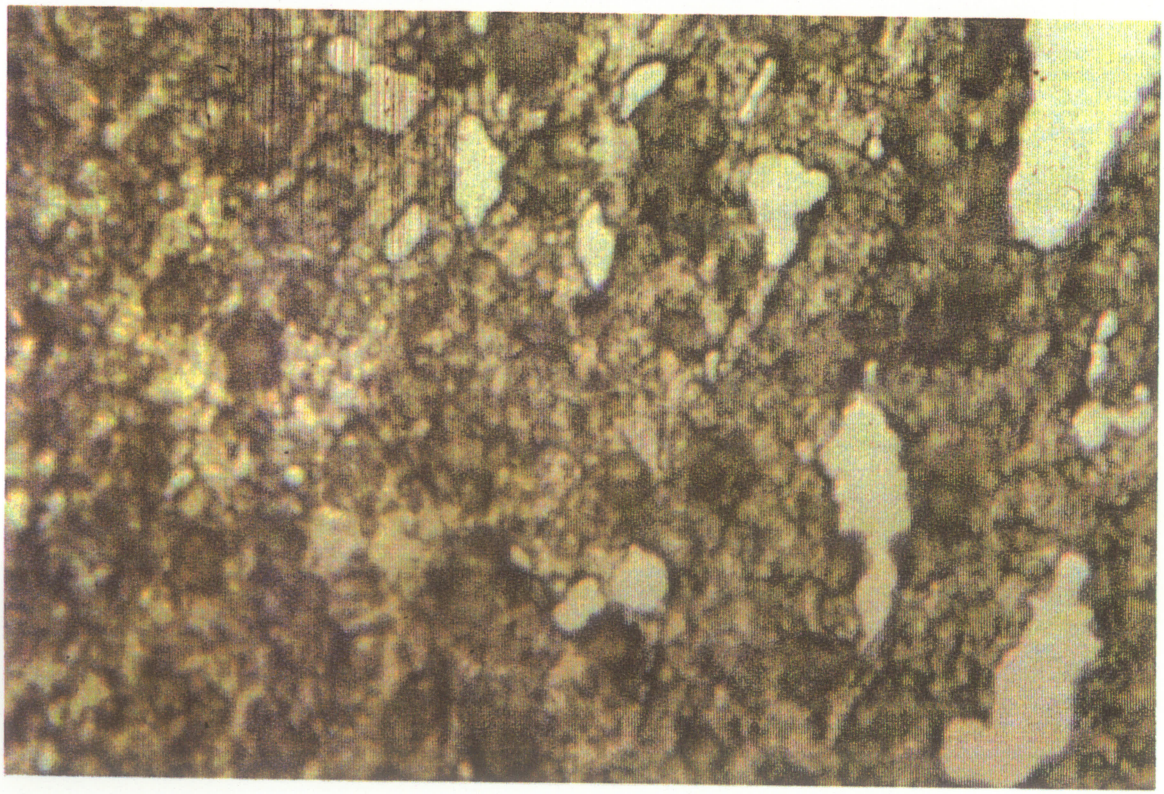
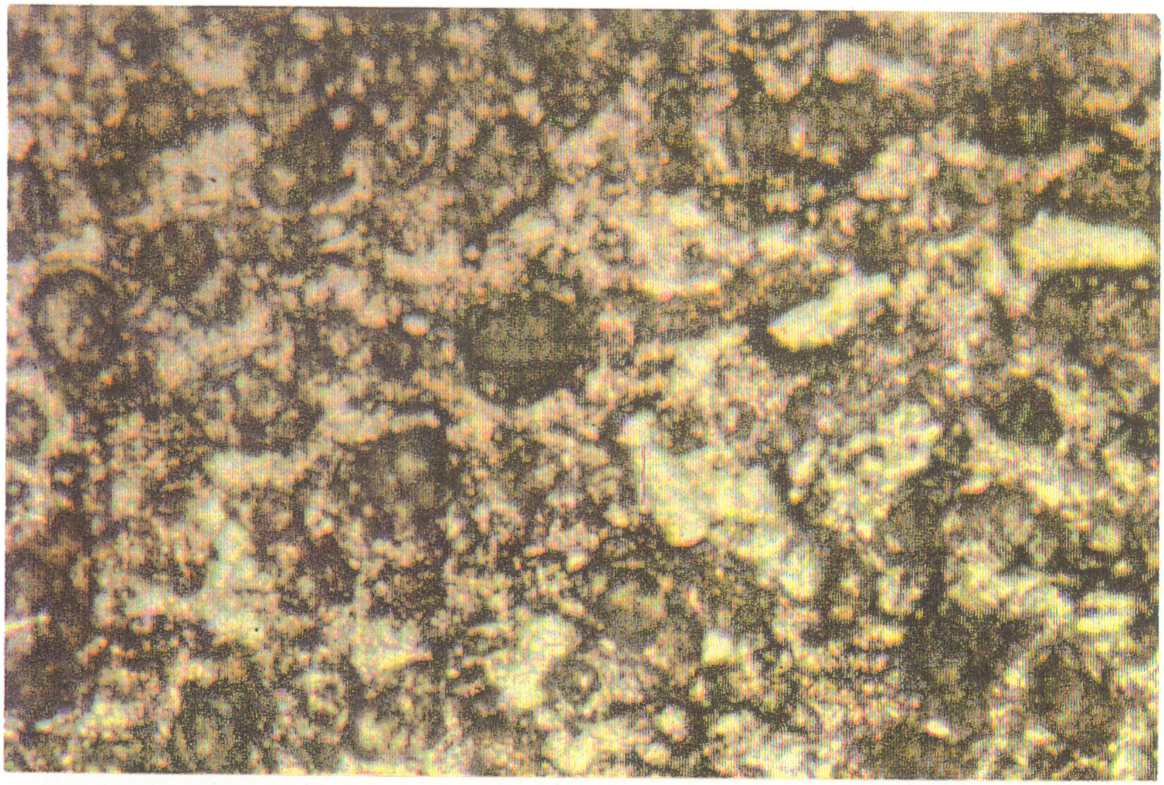


Figure 9: The Internal Structure of the Frozen Dessert Made with the HS 46 Oil Blend and of Ice Cream.

Magnification: 63X

Top: HS 46

Bottom: Ice Cream



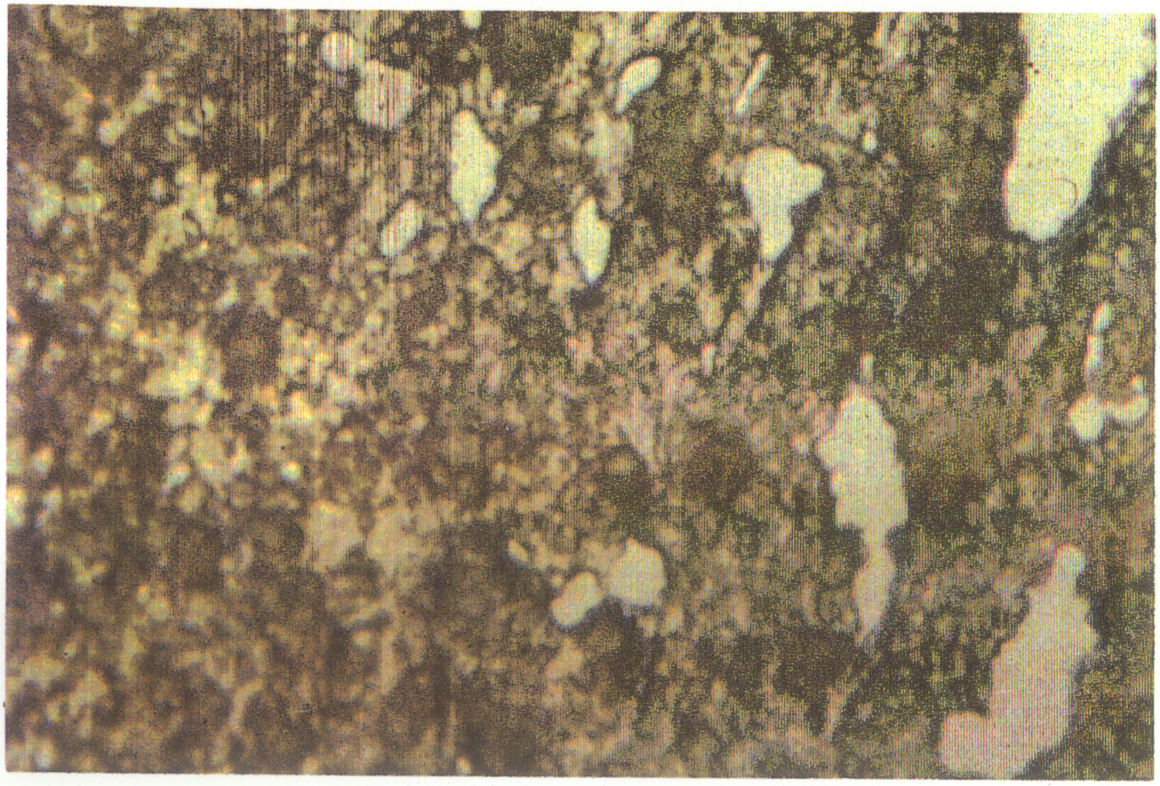
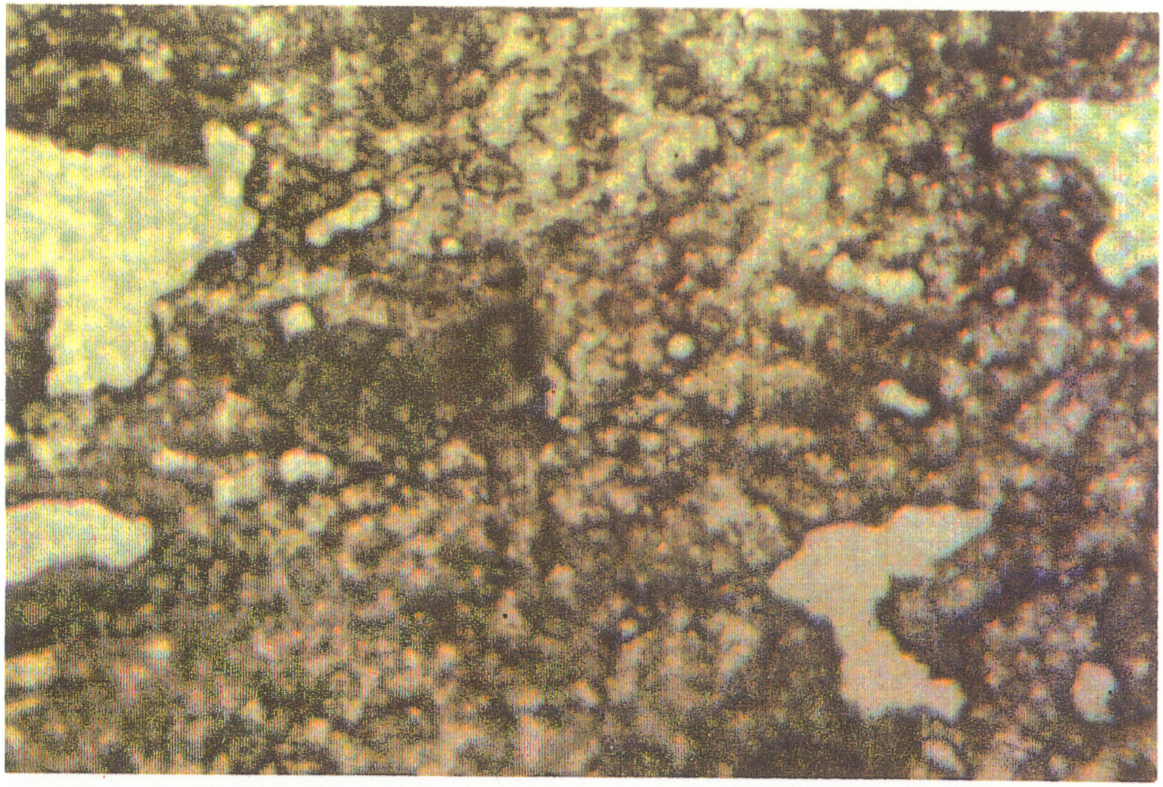


Figure 10: The Internal Structure of the Frozen Dessert Containing 3.5% PPI (P 35) and of Ice Cream.

Magnification: 63X

Top: P 35

Bottom: Ice Cream



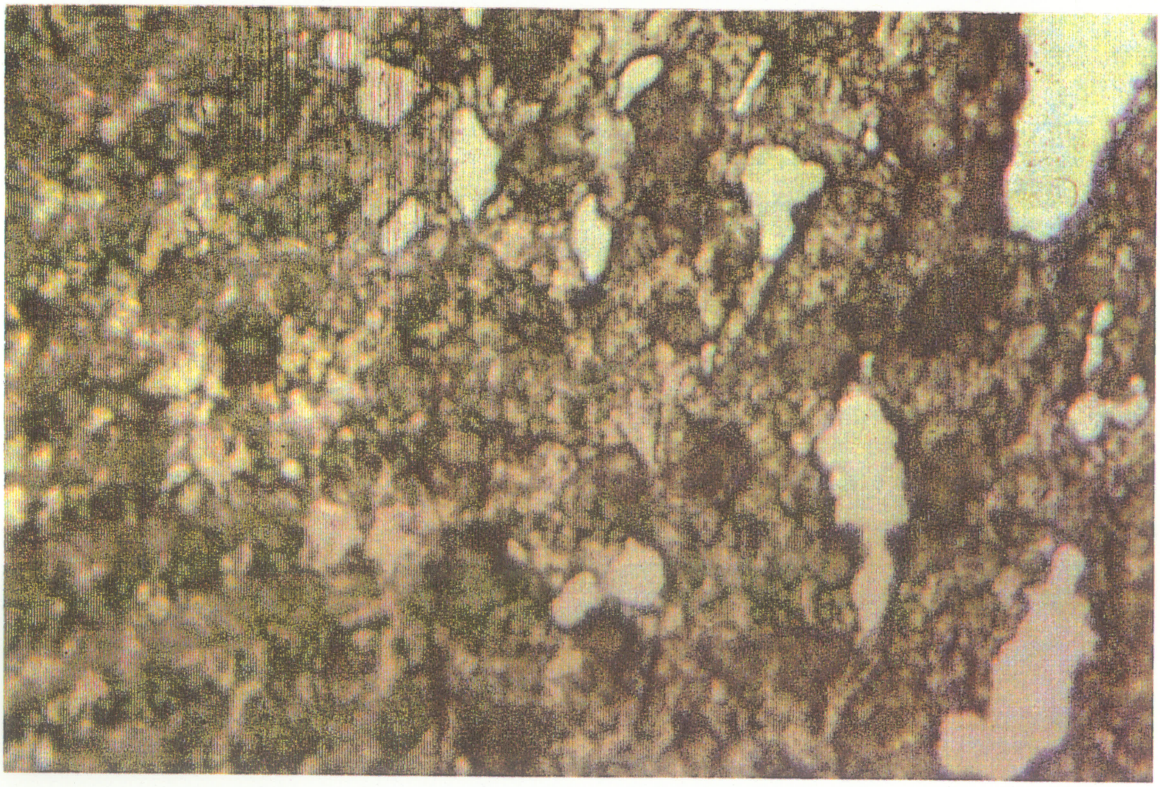
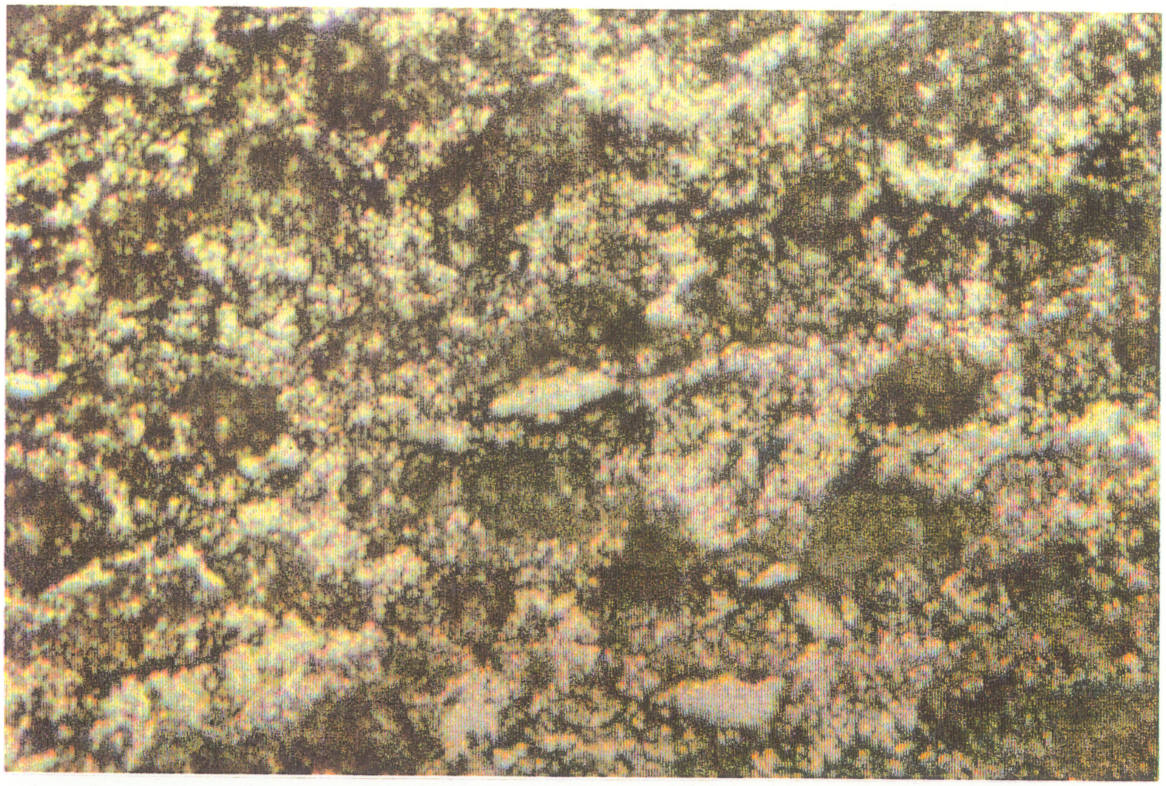


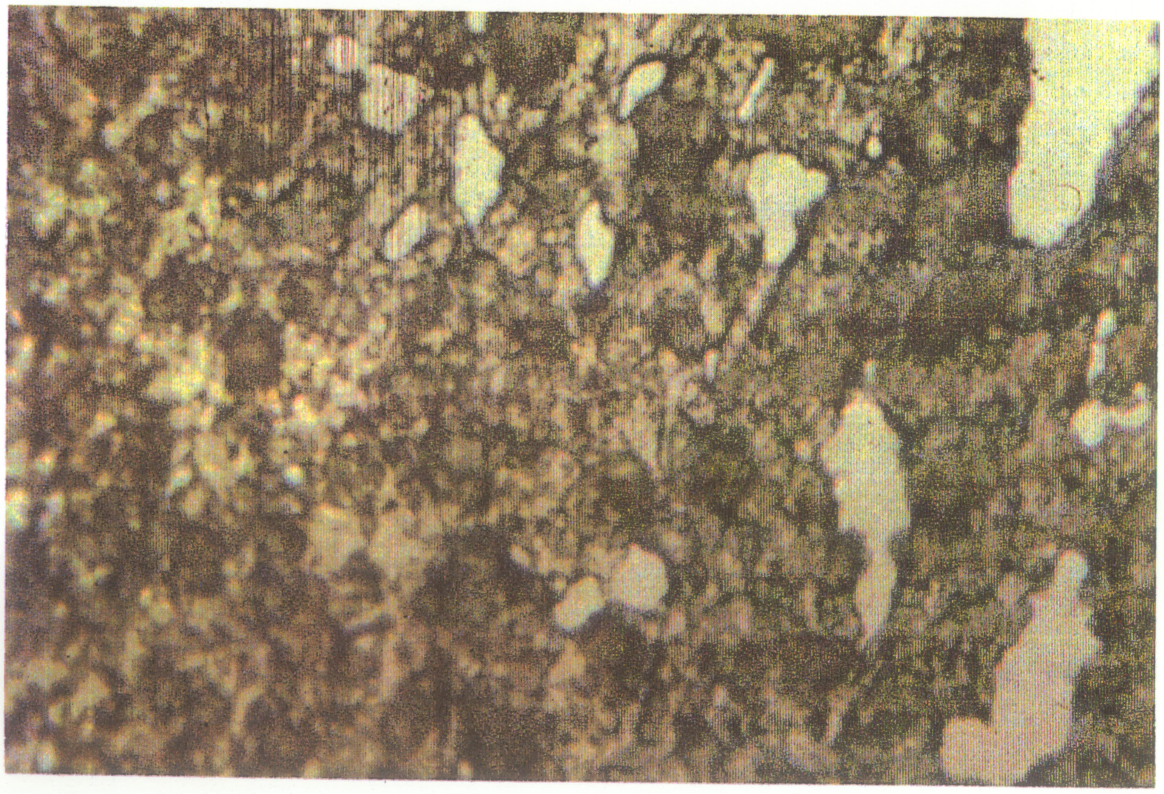
Figure 11: The Internal Structure of the Frozen Dessert Containing 8.0% PPI (P 80) and of Ice Cream.

Magnification: 63X

Top: P 80

Bottom: Ice Cream





Chapter V

SUMMARY AND CONCLUSIONS

The objective of this study was to combine commercial pea protein isolate (PPI) and oil blends prepared from hard (H) and soft (S) margarine oils to produce a non-dairy frozen dessert of acceptable quality. To achieve this goal, the study was divided into two stages. In the first, oil blends of five weight proportions (%H/%S: 30/70, 40/60, /50/50, 60/40 and 70/30) and a common level (5%) of PPI were used in order to identify the oil blend which would produce the most acceptable frozen dessert. This oil blend was subsequently used in the second stage of the study in conjunction with four PPI levels (3.5%, 5.0%, 6.5% and 8.0%) in order to determine the optimum oil blend/PPI level combination that would result in a frozen dessert with satisfactory acceptability. The major findings of this study are summarized in the following paragraphs.

The flavour of the 10% PPI slurries was found to be unacceptable, contrary to the manufacturer's claim. DSC analysis indicated that the PPI was severely denatured, most likely the result of harsh processing conditions. Although the functionality of the PPI may have diminished due to the denaturation, the results of the alcohol coagulation test showed that the pea proteins were able to remain stable in the frozen mixes. Increases in PPI levels in the mixes were matched by rising total solids content and mix viscosity, and by increasing resistance to

melting in the frozen desserts. The frozen desserts containing 6.5% and 8.0% PPI showed a melting defect (does-not-melt).

The margarine oil blends all showed lower SFI values than butterfat. Mix viscosity was not affected by the composition of the oil blends. Overrun, on the contrary, increased with increasing proportions of hard margarine oil in the oil blends. No difference in the melting behaviour among the frozen desserts containing various oil blends was observed.

In the first stage of this study, it was found that at a common level of PPI (5.0%), the oil blend HS 64 was able to produce a frozen dessert with the highest sensory score in comparison to the others. The oil blends HS 55 and HS 73 did not differ significantly from HS 64, HS 73 and HS 46 in influencing the acceptability of the frozen desserts. However, frozen desserts containing the oil blends HS 37 and HS 46 were significantly less preferred to the one prepared with HS 64. The SFI values of the oil blends which were able to produce a satisfactory frozen dessert ranged from 22.07 to 25.50 at 10°C.

Results from the second stage showed that the PPI level of 3.5% produced a frozen dessert with the highest score as compared to the others. The use of PPI levles of 6.5% and 8.0% resulted in significantly less acceptable products. The maximum level of PPI which could be used to manufacture a satisfactory frozen dessert was found to be 5.0%.

In conclusion, an oil blend composed of 60% (w/w) of hard margarine oil and 40% (w/w) of soft margarine oil, used at a level of 10.50% in conjunction with 3.5% PPI, was found to be the optimum combination in producing a non-dairy frozen dessert with an acceptable quality. It was

not feasible to incorporate high levels of PPI into the frozen dessert mix in order to raise the nutritional value of the finished product while maintaining its acceptability.

Due to the exploratory nature of this research, its scope has been restricted to identifying the oil blend/PPI level combination at which a generally satisfactory non-dairy frozen dessert could be produced. Recommendations for future research include:

1. investigation of the possibility of improving the acceptability and functionality of PPI.
2. detail study of the characteristics of the frozen desserts.
3. feasibility studies of the development of other dairy-like products utilizing PPI and margarine oil blends.
4. feasibility studies of utilizing PPI and margarine oil blends in other types of food system.

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Appendix A

FLAVOUR EVALUATION DATA OF THE PPI SLURRIES.

	Score			
	Samples (Grade)			
Judges	Baking	Gold	Replacement	Total
1	5	6	3	14
2	3	2	4	9
3	6	6	4	16
4	4	5	2	11
5	2	3	3	8
6	5	2	3	10
7	2	2	3	7
8	2	2	3	7
9	5	6	4	15
10	1	3	4	8
11	4	3	3	10
12	7	6	4	17
13	6	4	5	15
14	3	4	5	12
15	2	4	3	9
16	2	1	1	4
Total	59	59	54	172
Mean Score	3.69	3.69	3.38	

Table of Analysis of Variance

Source of Variation	df	SS	MS	F
Samples	2	1.05	0.53	0.14 ns[1]
Judges	15	70.34	4.69	1.28 ns
Error	30	109.67	3.66	---
Total	47	181.09		

$F(0.05, 2, 30) = 3.32$
$F(0.05, 15, 30) = 2.01$
1 non-significant at $\alpha = 0.05$

Appendix B

SENSORY EVALUATION DATA OF THE NON-DAIRY FROZEN DESSERTS MADE WITH FIVE MARGARINE OIL BLENDS.

	Score					
	Samples					
Judges	HS 37	HS 46	HS 55	HS 64	HS 73	Total
1	7	5	7	8	6	33
2	8	8	8	8	8	40
3	3	3	3	6	5	20
4	5	4	6	7	6	28
5	4	6	4	7	6	27
6	6	4	7	6	7	30
7	6	5	5	6	6	28
8	6	6	4	8	7	31
9	6	6	5	7	8	32
10	4	7	7	8	6	32
11	8	8	8	8	8	40
12	8	8	8	8	8	40
13	7	6	7	8	7	35
14	9	9	8	8	8	42
15	6	5	6	4	7	28
16	4	7	6	7	8	32
17	6	3	6	6	3	24
18	7	8	8	8	7	38
19	4	3	4	4	6	21
20	6	4	4	4	6	24
21	6	4	6	3	5	24
22	4	3	7	6	6	26
23	8	7	6	7	7	35
24	8	6	9	8	9	40
25	3	4	7	8	6	28
26	6	4	7	7	4	28
27	7	3	7	6	3	26
28	3	4	3	6	3	19
29	4	6	5	8	4	27
30	7	3	7	6	4	27
31	5	6	3	4	3	21
32	4	6	7	6	4	27
33	2	6	3	4	4	19
34	7	6	6	6	7	32
35	7	7	8	8	8	38
36	6	3	2	7	7	25
37	7	5	3	7	3	25

38	7	4	6	8	8	33
39	6	6	4	7	7	30
40	8	7	8	8	8	39
41	4	6	6	6	6	28
42	5	7	7	7	8	34
43	4	4	6	7	7	28
44	5	7	8	6	4	30
45	6	7	4	7	3	27
46	7	2	6	6	3	24
47	5	7	6	4	3	25
48	6	5	5	7	6	29
49	4	4	4	7	6	25
50	7	7	7	6	6	33
51	6	5	5	7	6	29
52	8	6	9	7	4	34
53	4	4	7	2	6	23
Total	306	286	315	345	311	1563
Mean Score	5.77	5.40	5.94	6.51	5.87	

Table of Analysis of Variance.

Source of Variation	df	SS	MS	F
Samples	4	34.14	8.53	4.99*[1]
Judges	52	353.85	6.80	3.98*
Error	208	356.26	1.71	---
Total	264	744.25		

F(0.05, 4, 208) = 2.41
F(0.05, 52, 208) = 1.42
1 * significant at $\alpha = 0.05$

Appendix C

RANKED SENSORY EVALUATION DATA OF NON-DAIRY FROZEN DESSERTS MADE WITH FIVE MARGARINE OIL BLENDS AND THE CALCULATION OF THE COEFFICIENT OF CONCORDANCE.

	Rank						
	Samples						
Judges	HS 37	HS 46	HS 55	HS 64	HS 73	NT[1]	t[2]
1	3.5	1.0	3.5	5.0	2.0	1	2
2	3.0	3.0	3.0	3.0	3.0	1	5
3	2.0	2.0	2.0	5.0	4.0	1	3
4	2.0	1.0	3.5	5.0	3.5	1	2
5	1.5	3.5	1.5	5.0	3.5	2	2,2
6	2.5	1.0	4.5	2.5	4.5	2	2,2
7	4.0	1.5	1.5	4.0	4.0	2	2,3
8	2.5	2.5	1.0	5.0	4.0	1	2
9	2.5	2.5	1.0	4.0	5.0	1	2
10	1.0	3.5	3.5	5.0	2.0	1	2
11	3.0	3.0	3.0	3.0	3.0	1	5
12	3.0	3.0	3.0	3.0	3.0	1	5
13	3.0	1.0	3.0	5.0	3.0	1	3
14	4.5	4.5	2.0	2.0	2.0	2	2,3
15	3.5	2.0	3.5	1.0	5.0	1	2
16	1.0	3.5	2.0	3.5	5.0	1	2
17	4.0	1.5	4.0	4.0	1.5	2	2,3
18	1.5	4.0	4.0	4.0	1.5	2	2,3
19	3.0	1.0	3.0	3.0	5.0	1	3
20	4.5	2.0	2.0	2.0	4.5	2	2,3
21	4.5	2.0	4.5	1.0	3.0	1	2
22	2.0	1.0	5.0	3.5	3.5	1	2
23	5.0	3.0	1.0	3.0	3.0	1	3
24	2.5	1.0	4.5	2.5	4.5	2	2,2
25	1.0	2.0	4.0	5.0	3.0	0	0
26	3.0	1.5	4.5	4.5	1.5	2	2,2
27	4.5	1.5	4.5	3.0	1.5	2	2,2
28	2.0	4.0	2.0	5.0	2.0	1	3
29	1.5	4.0	3.0	5.0	1.5	1	2
30	4.5	1.0	4.5	3.0	2.0	1	2
31	4.0	5.0	1.5	3.0	1.5	1	2
32	1.5	3.5	5.0	3.5	1.5	2	2,2
33	1.0	5.0	2.0	3.5	3.5	1	2
34	4.5	2.0	2.0	2.0	4.5	2	2,3
35	1.5	1.5	4.0	4.0	4.0	2	2,3
36	3.0	2.0	1.0	4.5	4.5	1	2

37	4.5	3.0	1.5	4.5	1.5	2	2,2
38	3.0	1.0	2.0	4.5	4.5	1	2
39	2.5	2.5	1.0	4.5	4.5	2	2,2
40	3.5	1.0	3.5	3.5	3.5	1	4
41	1.0	3.5	3.5	3.5	3.5	1	4
42	1.0	3.0	3.0	3.0	5.0	1	3
43	1.5	1.5	3.0	4.5	4.5	2	2,2
44	2.0	4.0	5.0	3.0	1.0	0	0
45	3.0	4.5	2.0	4.5	1.0	1	2
46	5.0	1.0	3.5	3.5	2.0	1	2
47	3.0	5.0	4.0	2.0	1.0	0	0
48	3.5	1.5	1.5	5.0	3.5	2	2,2
49	2.0	2.0	2.0	5.0	4.0	1	3
50	4.0	4.0	4.0	1.5	1.5	2	2,3
51	3.5	1.5	1.5	5.0	3.5	2	2,2
52	4.0	2.0	5.0	3.0	1.0	0	0
53	2.5	2.5	5.0	1.0	4.0	1	2
Sum of Ranks[3]	151.0	130.5	158.5	191.5	163.5		

1 number of tied observations
2 number of ranks in each tie
3 the degree of preference increases with increasing sum of ranks.

Formula for calculating the coefficient of concordance:

$$W' = \frac{1}{k} \cdot \frac{\sum_{j=1}^{n} \left[Ri - \frac{k(n+1)}{2} \right]^2}{\frac{kn(n^2-1) - \sum\sum t(t^2-1)}{12}}$$

where W' = corrected coefficient of concordance
k = number of observers
n = number of treatments
Ri = sum of ranks of each treatment
t = number of ranks in each tie

Interpretation:

If $W' \cdot k(n-1)$ is greater than the chi-square value at $(n-1, \alpha)$, reject the null hypothesis that there was no consensus among the judges regarding the order of preference for the samples.

In stage one, $W' \cdot k(n-1) = 17.91$ and the chi-square value at $(4, 0.05) = 9.49$, the null hypothesis is therefore rejected.

Appendix D

SENSORY EVALUATION DATA OF NON-DAIRY FROZEN DESSERTS PREPARED AT FOUR LEVELS OF PPI.

	Score				
	Samples				
Judges	P 35	P 50	P 65	P 80	Total
1	4	4	5	3	16
2	7	6	3	3	19
3	9	6	7	6	28
4	8	7	6	5	26
5	8	6	4	3	21
6	6	7	7	5	25
7	5	8	7	4	24
8	8	7	7	8	30
9	5	6	3	3	17
10	4	8	8	2	22
11	7	6	7	4	24
12	8	6	6	6	26
13	8	6	6	8	28
14	9	8	7	7	31
15	6	8	4	2	20
16	7	4	6	4	21
17	8	7	7	2	24
18	7	6	5	4	22
19	8	6	7	7	28
20	7	8	8	7	30
21	7	4	5	3	19
22	8	8	8	9	33
23	8	7	7	3	25
24	7	8	6	4	25
25	7	6	4	3	20
26	4	8	7	4	23
27	4	3	6	5	18
28	7	8	7	6	28
29	3	7	5	4	19
30	6	4	8	3	21
31	7	7	7	6	27
32	7	7	6	6	26
33	7	6	6	6	25
34	7	4	4	3	18
35	8	7	6	2	23
36	4	1	1	1	7
37	4	4	2	3	13

38	7	7	4	3	21
39	7	4	3	6	20
40	7	6	4	3	20
41	8	7	6	5	26
42	6	6	8	8	28
43	7	8	7	9	31
44	7	7	8	8	30
45	7	4	4	4	19
46	6	7	7	3	23
47	6	7	5	6	24
48	7	5	4	2	18
Total	319	297	275	221	1112
Mean Score	6.65	6.19	5.73	4.60	

Table of Analysis of Variance.

Source of Variation	df	SS	MS	F
Samples	3	110.42	36.81	20.22*[1]
Judges	47	301.27	6.41	3.52*
Error	141	256.08	1.82	---
Total	191	667.77		

F(0.05, 3, 141) = 2.67
F(0.05, 47, 141) = 1.44
1 * significant at α = 0.05

Appendix E

RANKED SENSORY EVALUATION DATA OF NON-DAIRY FROZEN DESSERTS PREPARED AT FOUR PPI LEVELS AND THE CALCULATION OF THE COEFFICIENT OF CONCORDANCE.

	Rank					
	Samples					
Judges	P 35	P 50	P 65	P 80	NT[1]	t[2]
1	2.5	2.5	4.0	1.0	1	2
2	4.0	3.0	1.5	1.5	1	2
3	4.0	1.5	3.0	1.5	1	2
4	4.0	3.0	2.0	1.0	0	0
5	4.0	3.0	2.0	1.0	0	0
6	2.0	3.5	3.5	1.0	1	2
7	2.0	4.0	3.0	1.0	0	0
8	3.5	1.5	1.5	3.5	2	2,2
9	3.0	4.0	1.5	1.5	1	2
10	2.0	3.5	3.5	1.0	1	2
11	3.5	2.0	3.5	1.0	1	2
12	4.0	2.0	2.0	2.0	1	3
13	3.5	1.5	1.5	3.5	2	2,2
14	4.0	3.0	1.5	1.5	1	2
15	3.0	4.0	2.0	1.0	0	0
16	4.0	1.5	3.0	1.5	1	2
17	4.0	2.5	2.5	1.0	1	2
18	4.0	3.0	2.0	1.0	0	0
19	4.0	1.0	2.5	2.5	1	2
20	1.5	3.5	3.5	1.5	2	2,2
21	4.0	2.0	3.0	1.0	0	0
22	2.0	2.0	2.0	4.0	1	3
23	4.0	2.5	2.5	1.0	1	2
24	3.0	4.0	2.0	1.0	0	0
25	4.0	3.0	2.0	1.0	0	0
26	1.5	4.0	3.0	1.5	1	2
27	2.0	1.0	4.0	3.0	0	0
28	2.5	4.0	2.5	1.0	1	2
29	1.0	4.0	3.0	2.0	0	0
30	3.0	2.0	4.0	1.0	0	0
31	3.0	3.0	3.0	1.0	1	3
32	3.5	3.5	1.5	1.5	2	2,2
33	4.0	2.0	2.0	2.0	1	3
34	4.0	2.5	2.5	1.0	1	2
35	4.0	3.0	2.0	1.0	0	0
36	4.0	2.0	2.0	2.0	1	3

37	3.5	3.5	1.0	2.0	1	2
38	3.5	3.5	2.0	1.0	1	2
39	4.0	2.0	1.0	3.0	0	0
40	4.0	3.0	2.0	1.0	0	0
41	4.0	3.0	2.0	1.0	0	0
42	1.5	1.5	3.5	3.5	2	2,2
43	1.5	3.0	1.5	4.0	1	2
44	1.5	1.5	3.5	3.5	2	2,2
45	4.0	2.0	2.0	2.0	1	3
46	2.0	3.5	3.5	1.0	1	2
47	2.5	4.0	1.0	2.5	1	2
48	4.0	3.0	2.0	1.0	0	0
Sum of Ranks[3]	152.0	131.5	115.5	81.0		

1 number of tied observations
2 number of ranks in each tie
3 the degree of preference increases with increasing sum of ranks.

Formula for calculating the coefficient of concordance:

$$W' = \frac{1}{k} \cdot \frac{\sum_{j=1}^{n} \left[Ri - \frac{k(n+1)}{2} \right]^2}{\frac{kn(n^2-1) - \sum\sum t(t^2-1)}{12}}$$

where W' = corrected coefficient of concordance
k = number of observers
n = number of treatments
Ri = sum of ranks of each treatment
t = number of ranks in each tie

Interpretation:

If $W' \cdot k(n-1)$ is greater than the chi-square value at $(n-1, \alpha)$, reject the null hypothesis that there was no consensus among the judges regarding the order of preference for the samples.

In stage two, $W' \cdot k(n-1) = 38.17$ and the chi-square value at $(3, 0.05) = 7.81$, the null hypothesis is therefore rejected.