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Effect of directly acidified Cottage cheese whey ultrafiltration retentates on the physical and sensory properties of orange sherbet.

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EFFECT OF DIRECTLY ACIDIFIED COTTAGE CHEESE WHEY ULTRAFILTRATION RETENTATES ON THE PHYSICAL AND SENSORY PROPERTIES OF ORANGE SHERBET

by

FLORA GEORGIOS MANGANARI

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ABSTRACT

EFFECT OF DIRECTLY ACIDIFIED COTTAGE CHEESE WHEY ULTRAFILTRATION RETENTATES ON THE PHYSICAL AND SENSORY PROPERTIES OF ORANGE SHERBET

by

FLORA GEORGIOS MANGANARI

Directly acidified Cottage cheese whey concentrated by ultrafiltration and diafiltration was used as an ingredient in orange sherbet. Four sherbet mixes containing 0% (sherbet A), 25% (sherbet B), 50% (sherbet C) and 75% (sherbet D) whey solids as a replacement of milk solids non-fat were prepared. All sherbets otherwise contained 1.5% milkfat, 3.4% solids non-fat, 20% sucrose, 9% corn syrup solids and 0.3% emulsifier-stabilizer. Sherbet A had lower ($p<0.05$) melting resistance than sherbets containing whey solids. In a consumer panel, sherbet B received a score of 7.02 and 7.42 for the flavor and texture acceptability, respectively, on a 9-point hedonic scale, and was found similar to control sherbet A, but more acceptable in flavor ($p<0.05$) and texture ($p<0.001$) than sherbets C and D. Sherbets A and B were found less icy and creamier than sherbets C and D ($p<0.01$). Sherbet A was found sweeter than sherbets C and D ($p<0.05$), whereas sherbet B was sweeter than sherbet D ($p<0.05$). Overall, sherbet B was found not different from control.

I dedicate this work to my parents for their love and support.

ACKNOWLEDGEMENTS

The author would like to thank her major advisor, Dr. J. Partridge, for his support and guidance during the time spent at Michigan State University. Special gratitude is also expressed to Dr. D. Ott for her very useful suggestions and help in the sensory evaluation part of this research. Sincere thanks to the State Scholarship Foundation of Greece, which supported me financially. Without their help I would not be able to pursue graduate studies outside Greece.

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I would also like to thank Country Fresh Inc., for supplying the acid whey and for sending me any information I requested. Finally, I thank my friends D. Argyropoulo and A. Drakopoulo, who helped me without hesitation whenever I needed any help.

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ABBREVIATIONS

ANOVA:	Analysis of Variance
BOD:	Biological Oxygen Demand
CAS:	Sodium Caseinate
CF:	Concentration Factor
CMC:	Carboxy-Methyl-Cellulose
COD:	Chemical Oxygen Demand
CSS:	Corn Syrup Solids
DE:	Dextrose Equivalent
DSW:	Dry Sweet Whey
ED:	Electrodialysis
GF:	Gel Filtration
GLC:	Gas Liquid Chromatography
IE:	Ion Exchange
max:	Maximum
min:	Minimum
MS:	Mass Spectroscopy
MSNF:	Milk Solids Non Fat
MSU:	Michigan State university
NFDM:	Non Fat Dry Milk
NPN:	Non Protein Nitrogen
PER:	Protein Efficiency Ratio
PN:	Protein Nitrogen
RO:	Reverse Osmosis
RPM:	Revolutions Per Minute
SNF:	Solids Non Fat
STEM:	Stabilizer/Emulsifier system
TA:	Titratable Acidity
TCA:	Trichloroacetic Acid
TN:	Total Nitrogen
UF:	Ultrafiltration
WPC:	Whey Protein Concentrate

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INTRODUCTION

Several studies that have been done on the utilization of whey indicated that whey is a good source of solids for frozen desserts. In most of the studies, however, dry whey or whey protein concentrates from sweet whey were examined. Few researchers have worked with acid whey, so the information for the utilization of this by-product as a frozen dessert ingredient is limited.

In this study, acid whey from direct-set Cottage cheese was used to supply part of the solids in an orange sherbet formulation. Casein precipitation in the cheese was achieved by acidifying with hydrochloric acid (HCl). Direct-set Cottage cheese was chosen, because it does not contain any added cultures that could impart fermented flavors to the whey and, possibly, to the final product. There appeared to be a greater potential for use of direct-set acid whey in foods than for culture-set acid whey. Sherbet was chosen as the frozen dessert for this research for two reasons. The acidity of such a whey would be compatible with the fruit flavor sherbets have. Also, about forty six million gal of sherbet are produced every year in U.S.A. [IAICM (1984)] and a 25% replacement of the milk solids non-fat of these sherbets by acid whey solids would consume about 60 million lbs of acid whey (from an average of 5,700 million lbs produced each year - Table B.1.). The sherbet was chosen to have orange flavor, because orange sherbet is traditionally the most popular sherbet in U.S.A. [IAICM (1965)].

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The acid whey was fractionated by ultrafiltration and diafiltration. These processes concentrated the whey protein while removing most of the lactose and minerals from the acid whey.

The objective of this study was to determine the feasibility of the utilization of acid whey from direct-set Cottage cheese concentrated by ultrafiltration and diafiltration as an ingredient in orange sherbet. The effect of the replacement of milk solids non-fat at the level of 25, 50 and 75% with fractionated acid whey on the rheological properties of the sherbet mixes, the melting resistance, the organoleptic quality and the storage and heat-shock stability of the final products were determined.

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LITERATURE REVIEW

DEFINITION AND COMPOSITION OF WHEY

Whey is the greenish-yellow liquid remaining after the precipitation of casein and removal of fat from milk. It is a by-product in the manufacture of cheese and may be classified as sweet whey, known also as rennet whey, or acid whey, depending on the kind of coagulation used in the cheesemaking process. Sweet whey is from the manufacture of cheese or casein from milk by the action of rennet-type enzymes with relatively little or no acid development. Acid whey is produced when milk is coagulated primarily by acid. Acids that are normally used for the cheese coagulation are food grade lactic acid, sulfuric acid, hydrochloric acid, phosphoric acid, D-glucono-delta-lactone and citric acid. Manufacture of Cottage cheese results in acid whey production. Sweet whey has a minimum pH of 5.6 and acid whey a maximum pH of 5.1 [Arbuckle (1979), Hansen (1979), Marshall (1982), Sienkiewicz and Riedel (1990)].

The composition of whey varies with the composition of milk, the cheese or casein type and the processing methods. The approximate composition of whey produced by different methods of casein precipitation is given in Table 1. In addition to the constituents mentioned in Table 1, another study [ADPI (1991)] includes mineral, vitamin and amino acid composition of sweet and acid dry wheys. The results of this analysis are presented in Appendix A

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(Table A.1, A.2). Comparison of these results with those found by Glass and Hedrick (1977a,b) shows very good agreement.

Table 1. Composition (%) of whey produced by different methods of casein precipitation [Hansen and Jensen (1977)].

	Rennet precipitation		Acid Precipitation			
	Lactic acid fermentation		Biological Lactic acid bacteria	Chemical HCl	H_2SO_4	Lactic acid
pH of precipitation	6.4	5.4	4.6	4.5	4.5	4.5
Total solids	6.27	6.43	6.00	6.40	6.44	6.70
Lactose	4.79	4.56	3.93	4.81	4.78	4.80
Fat	0.04	0.04	0.04	0.04	0.04	0.04
Total protein	0.82	0.87	0.80	0.70	0.70	0.70
Casein	0.19	0.15	0.17	0.16	0.17	0.16
Whey proteins	0.41	0.46	0.35	0.36	0.35	0.37
Ash	0.48	0.63	0.65	0.78	0.79	0.68
Low-molecular wt. N-compounds	0.22	0.26	0.28	0.18	0.18	0.18
Lactic acid	0.14	0.33	0.62	0.13	0.13	0.53

The major protein constituents of whey are β-lactoglobulin, α-lactalbumin, bovine serum albumin, immunoglobulins and proteose-peptones. There are several minor whey proteins including lactoferrin, lactollin, glycoprotein and blood transferrin. Whey from bovine milk contains 4-7g protein/L, the concentration depending on the type of whey, the stage of lactation and the processing conditions used in the manufacture of cheese or casein [Marshall (1982)].

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USES OF WHEY

Manufacture of cheese, Cottage cheese or industrial casein results in production of up to 9 kg of liquid whey for every kg of final product. Because of its perishable nature, whey cannot be easily stored for any length of time, and in today's environment its potential as a major pollutant prohibits dumping. In 1988, 55,776 million lbs of fluid sweet and acid whey and 3,625 million lbs of whey solids were produced in U.S. Estimated U.S. fluid whey and whey solids production (by type) and resulting quantity of whey solids further processed are summarized in Table B.1 in Appendix B [ADPI (1991)].

Whey and whey products are being used in animal feeds, as fertilizer on the land and in human foods. One of the first uses of fluid whey was to supplement the vitamin and mineral diets of poultry and pigs. Some research reports also indicated that liquid whey was an acceptable feed for dairy and beef cattle. Today, whey is used as part of the feed of many different animals [Sienkiewicz and Riedel (1990)]. Table B.2 in Appendix B summarizes the utilization of whey and products derived from it in animal feeds for 1988 and 1989 [ADPI (1991)]. As a fertilizer, whey was found to increase corn yields by 110 bushels to the acre, when it was sprayed at a rate of 8 in/acre (one inch to the acre represents 22,000 gallons) [Ryder (1980)].

An enhancement in "mouthfeel" has also been reported, when whey powder or dried whey are used as ingredients in foods. Whey products have been used to replace part of the non-fat dry milk normally used in preparing commercial foods [Saal (1976)]. In infant food formulations, modified whey solids may be added to bovine milk to give it characteristics of human milk [Mathur and Shahani (1979)]. Liquid, concentrated or spray dried whey are also used in frozen desserts. Whey used for frozen desserts should be preferably m

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bly made from single culture Streptococcus lactis. Organisms which convert the citrates to diacetyl or other flavor compounds are undesirable in ice creams [Arbuckle (1979)] . Limited information concerning liquid whey use is available. Its use as an ingredient for flavored beverages has been investigated, and it was found that a 100% substitution of Cottage cheese whey for water as a liquid component resulted in equal acceptability. Acid whey has also been used as a base for salad dressings and was well accepted by a sensory panel. The acid whey enhanced the tartness of the salad dressings. In acid products, acid whey imparts desirable flavor characteristics [Holmes (1979), Stull *et al.* (1977)]. Liquid cheese whey has been used directly from the Cottage cheese operation in the manufacture of ice cream. This acid whey is usually standardized to titratable acidity 0.13-0.14 or to pH 6.6-6.7 before use in ice cream mix [Arbuckle (1979), Hansen (1979)].

Whey may be used as a tenderizer and helps retain moisture and freshness. It helps to produce a better crust for pie dough and softer textured baked goods with longer shelf life in grocery stores and bakeries. Whey gives a more pleasing color to almost any bakery product than when non-fat dry milk (NFDM) is used alone. Bread with whey as an ingredient was said to have been better-colored and smoother-textured. Sweet rolls and coffee cakes with whey in the dough had more even browning and more acceptable flavor [Holmes (1979), Mathur and Shahani (1979)]. Ice creams, fudges, toppings, caramels, syrups, coatings, frozen pies and fillings were said to have been better products as a result of the use of whey. The blending of candies and their appearance are said to be improved when whey is used in their formulation [Saal (1976)].

Some of the large flour companies experimented with whey in their mixed products and had good results. Kraft entered the bake-mix business with products in which a principal ingredient has been dried whey since 1974.

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After years of research, the company came up with special mixes for breads, hot rolls and various kinds of cakes. Whey solids in combination with small quantities of gelatin have been advocated as a new kind of flow agent, that has the capacity to hold twice its own weight in oils, fats and flavors. This property proved very useful for the production of non-aqueous products. Whey-based coatings have been suitable for food applications and used by ice cream novelty makers, candy makers and bakers [Mathur and Shahani (1979), Saal (1976)].

The ultimate result of research sponsored by Kraft was Velvetta cheese, with whey as a major ingredient [Saal (1976)]. Some of the commercial products manufactured utilizing whey as an ingredient include breakfast drinks, Ricotta cheese, chip dips, spreads, sour cream, buttermilk, yogurt and the Norwegian cheese Mysost [Holmes (1979), Jelen (1979), Mathur and Shahani (1979)].

Whey protein concentrate (WPC) is the substance obtained by the removal of sufficient non-protein constituents from whey, so that the finished dry product contains not less than 25% protein [CFR (1990a)]. Whey protein concentrates have nutritive values and functional properties which determine their utilization. The good solubility of these concentrates over a wide pH range make them good ingredients for beverages containing up to 3% protein that have been prepared over a pH range of 2.5-7.0. Other products made with WPC are marshmallows and similar confectionery items, desserts of the souffle type, meringues and frozen desserts [Anon (1979), Marshall (1982), Mathur (1979), Muller (1976)].

Brothiness, bitterness and volatile acidity flavor characteristics of acid whey from direct-set and cultured products may limit use in bland products. Both the volatile and the non-volatile fractions contribute to these flavors. The amino acids, peptides and calcium salts probably contribute to the brothy and ıitter f

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bitter flavors, however there may be additional components that contribute a "whey-like" flavor to bland products [McGugan *et al.* (1979)].

THE NECESSITY OF WHEY UTILIZATION

Until the 20th century, nobody cared what happened to whey. Until recently, the methods of disposal involved dumping the whey into a sewer or stream, giving it back to the farmer for feeding to hogs, or spreading it on fields for use as a fertilizer. People have realized that whey, discharged in large amounts into rivers and streams, was a fatal pollutant for fish. When improperly dumped in the fields, it gave off a rank, fetid, skunk-like odor. People persuaded their politicians to enact legislation prohibiting these kinds of pollution. Stringent limits were placed on the volume of biological oxygen demand (BOD) that a particular plant could discharge into municipal or county sewer systems, and whey had to be properly diluted, before it could be sprayed on fields [Christensen (1976), Saal (1976)]. It is worth mentioning that 100 Kg of liquid whey, containing approximately 3.5 Kg of BOD and 6.8 Kg of chemical oxygen demand (COD), has the polluting strength equivalent to sewage produced by 45 people [Jelen (1979)]. Whey is the most potent of all dairy wastes and one of the strongest wastes of any kind. Table 2 shows the BOD of several food processing wastes, including whey.

Dairy plants had to build treatment facilities at great cost. This added to the cost of manufacture per pound of cheese. There were not enough pigs or other animals to economically absorb the available whey supply as slops, so cheesemakers have redoubled their efforts to find new uses for whey.

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Table 2. Characteristics of food processing wastes [Jelen (1979)].

Food processing wastes	BOD (mg/lt)
Dairy processing waste waters	
fluid milk plant	1000
ice cream plant	2500
Cottage cheese plant	6000
whey powder plant	40
Other food processing waste waters	
sweet goods bakery	2500
meat canning	1500
candy plant	4000
poultry processing	5000
Raw wastes	
sweet whey	35000
acid whey	45000
fish processing stickwater	50000
domestic sewage	300

THE BENEFITS OF WHEY UTILIZATION

Although whey is considered a waste product, it contains about 20% of the milk protein, almost all of the milk sugar, and altogether about 50% of all nutrients consumed normally in milk [Jelen (1979)]. Cheese whey has the ability to supply high amounts of whey protein. The quality of any protein is determined by the lowest quantity of any one of the essential amino acids. A high quality whey protein consists of at least 18 amino acids. It has an oversupply of five of the seven essential amino acids that are usually lacking in other proteins. Whey protein provides a good fortifying effect for most foods as the excess of these five amino acids complement deficiencies, such as those found in cereal grains. The average Protein Efficiency Ratio (PER) of whey protein is 3.2, whereas soy protein has PER 1.8 and casein 2.5. Ten pounds of whey blende

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blended with ninety pounds of soy protein will increase the PER of the blend to 2.23. Whey protein concentrates were found to be very good supplementary proteins for soy protein and flour [Loewenstein (1975), Muller (1976), Weiner (1977)].

Whey is very cheap, and manufacturers can realize considerable savings in replacement of milk solids by whey solids. The price of milk solids keeps increasing and, consequently, so does the price of the products that are formulated with this ingredient. This is the reason why there is a lot of research in the area of substitution of whey solids in frozen dairy products for milk solids non-fat (MSNF) [Frazeur(1977), Hekmati and Bradley (1979)].

MODIFIED WHEY PRODUCTS

One of the major problems hindering the development of new consumer products containing whey is its high moisture combined with the high salt, lactose and, for the case of acid whey, high acid content. The need for water removal for most product uses accentuates the saltiness, lactose content and acidity even more. There is, however an effort towards the manufacture of modified wheys, which have composition similar to the MSNF composition or appropriate for their incorporation into a certain food item. The term modified whey products is used to designate a group of whey products obtained through processing whey by special techniques. Examples of modified wheys are partially delactosed whey, partially demineralized whey, demineralized whey and whey protein concentrates [Frazeur (1977), Weiner (1977)].

Ingredient suppliers to the ice cream manufacturers have been restructuring their ingredients, to provide the industry with functional products

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or ingredients at lower cost. After extensive testing, a series of products has been designed to replace MSNF in frozen desserts. These ingredients provide the same functional characteristics as MSNF, while at the same time offering significant savings potentials. With some of the replacement products, the protein quality, as measured by the PER, is actually increased. Ingredients found in the market include specially processed WPCs with enhanced dairy flavor and sweetness and reduced undesirable after-tastes, formulations of WPC, milk protein and whey solids that provide a balance of product functionality with excellent economics and spray-dried products consisting of milk proteins and whey solids [Anon (1976), Carter *et al.*(1982)]. Computer simulation programs are available that make cost predictions on any combination of processes applied to whey [Olson (1979)].

METHODS OF WHEY PROCESSING

The traditional processes used for the production of dried whole whey include spray drying, roller drying, concentration to semisolid feed blocks or production of sweetened condensed whey [Jelen (1979)]. Use of dried whole whey in human foods is limited due to varying functional properties of the individual components. The objection to the whey powder is that the protein level is only about 12% in relation to the high lactose and ash content, and this fact limits the amount that can be used in food formulations. Roller and spray dried whole whey powder products were gritty, insoluble and difficult to incorporate in food products [Christensen (1976)]. Fractionation techniques can be used to remove some of the undesirable components (salts, lactose, acids) and recover the most valuable whey components. The relatively recently developed and co

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and commercialized separation techniques such as electrodialysis (ED), ion exchange (IE), reverse osmosis (RO) and ultrafiltration (UF) have substantially widened the range for manufacture of various fractionated, modified or reconstructed whey products [Jelen (1979), Morr *et al.* (1973)].

The electrodialysis process reduces the mineral and nitrate contents of whey without any significant effect on lactose and protein contents. The whey flows through the electrodialysis module with ion-selective membranes under the influence of a small electrical potential. Cation selective membranes contain negatively charged, covalent-bonded groups, such as sulfonic acid that permit the passage of cations and exclude anions. On the anion selective membranes the positively charged groups, quarternary amines, produce the opposite result [Christensen (1976), Sienkiewicz and Riedel (1990), Smith (1976)].

Ion-exchange also is used to remove minerals from whey. The basic principle of this technique is the exchange of "mobile" ions of the stationary phase for the equivalently charged ions from the surrounding solution. The whey is first conducted through a cation and then an anion exchanger. The cation exchanger binds the cation of the minerals with the release of corresponding acids, whose anions are bound to the anion exchanger. After its passage through both exchanger columns the whey is demineralized, depending on its type, from 90 to 99%. Whey which has been demineralized up to 90% can be directly concentrated and dried [Sienkiewicz and Riedel (1990)].

Reverse osmosis (RO) is a membrane separation technique (also known as hyperfiltration), in which only water and small amounts of solutes from whey are removed, resulting in concentration of the total solids. RO involves the use of semi-permeable membranes (polyamide, polysulfone and cellulose triacetate membranes) with pore size 0.4 nm and hydraulic pressure usuall

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usually between 50-100 bar (5,000-10,000 kPa) [Marshall (1982), Sienkiewicz and Riedel (1990)].

In ultrafiltration (UF), a membrane permeable to water and small molecules, but not to large molecules, separates the protein from the smaller lactose and salt molecules. Ultrafiltration involves the use of semi-permeable membrane with pore size of about 2 nm and pressure between 1-10 bar (100-1,000 kPa) [Anon (1979), Sienkiewicz and Riedel (1990)].

Ultrafiltration

The ultrafiltration process consists essentially of the following steps:

- Separation and cooling of whey (whey is very unstable and cooling reduces chemical and microbiological changes).
- Clarification/filtration of whey and passing through the ultrafiltration module.
- Forcing of the feed liquor in the ultrafiltration module across the membrane surfaces under pressure until the desired or maximum possible concentration is reached. Ultrafiltration can increase the concentration of milk proteins to 10-15% solids.
- Pasteurization of the protein concentrate and further concentration by standard evaporation systems to about 45% total solids.
- Spray drying by conventional methods [Christensen (1976), Crocco (1975)].

During ultrafiltration the components of whey are fractionated as a function of their size and structure, by means of a pressure gradient and a semi-permeable membrane. By this process two fractions are obtained. The

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concentrate or retentate consists of whey components that cannot pass the membrane pores, predominantly proteins, fat globules, suspended solids, minerals and vitamins bound to proteins, lecithin and enzymes. Since separation is not complete, the product is a WPC which still contains some lactose and minerals dissolved in water. The other fraction is the filtrate or permeate, which consists of whey components smaller than the pore size of the membrane such as lactose, unbound minerals, organic acids, non-protein nitrogen, water soluble vitamins and water. A schematic representation of ultrafiltration of whey is demonstrated in Figure 1 [Marshall (1982)]. The ultrafiltration membranes commonly used in dairy processing retain the components with molecular weight of 10,000 or above. Ultrafiltration usually takes place in the temperature range of 50°F-122°F (10°C-50°C) using 1-10 bar (100-1,000 kPa) pressure [Horton *et al.* (1972), Roualeyn *et al.* (1971), Siekiewicz and Riedel (1990)]. The composition changes occurring during the ultrafiltration process are demonstrated in function of volume reduction and concentration ratio in Table 3.

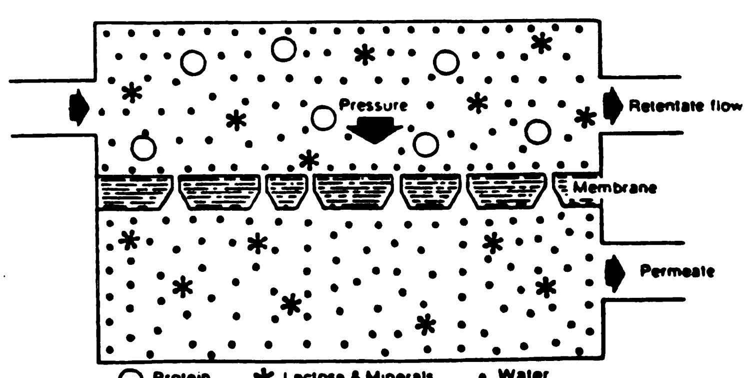

Figure 1. Schematic representation of the ultrafiltration of whey [Marshall (1982)].

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Table 3. Composition changes of whey occurring during ultrafiltration [Babella (1984)].

Volume reduction (%)	0	50	60	80	90	95
Composition (%) in dry basis	**Whey concentrates**					
Protein	12	22	24	37	52	66
Lactose	79	69	68	56	41	28
Mineral salts	9	9	8	7	7	6

Whey proteins with high purity can be produced in a multi-phase process called diafiltration. In diafiltration, water is added to the feed in the final stages of the ultrafiltration. The water dilutes the retentate, decreases the viscosity and, as it permeates, washes out lactose, non-protein nitrogen (NPN) and minerals. The end result is to increase the purity of the whey protein in the concentrate by the reduction in NPN, lactose and ash, while maintaining the true protein concentration essentially constant [Goldsmith (1981), Jelen (1983), Marshall (1982), Muller (1976), Sienkiewicz and Riedel (1990)].

The ultrafiltration membranes do have physical limitations which have contributed to their early lack of acceptance. Extremes of pH, heat or corrosive chemicals, for example, will corrode first generation membranes, such as those constructed of cellulose acetate. Moreover, cellulose acetate was sensitive to microorganisms and some commonly used disinfectants. To a great extent, however, these limitations have been overcome. Second generation membranes, such as polysulphones or polyamides, offer improved corrosion resistance resulting in greater acceptance [Anon (1981), Marshall (1982)]. Table 4 shows the properties of some ultrafiltration membrane materials.

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Table 4. UF membrane materials and their properties [Anon.(1981)].

Material type	pH range at pH 7	Max temp. resistance	Chlorine resistance	Solvent
Cellulose acetate	4.5- 9	55°C	Good	Poor
Polyamide	3.0-12	80°C	Poor	Good
Polysulphone	0 - 14	80°C	Good	Good
Polyacrylonitrile	2.0-12	60°C	Good	Poor
Polyfuran	2.0-12	90°C	Poor	Good

The major problem in the ultrafiltration of whey is membrane fouling by proteins and salts which become concentrated on the membrane surface. Other limitations include prolonged exposure to elevated temperatures with associated problems due to microbial contamination, protein denaturation and incomplete removal of low molecular weight components. Membrane compaction causes a serious permeate flux reduction at higher operating pressures.

Fouling may result in a short-term decline of flux or in a permanent impairment of the membrane permeability. Pretreatments of liquids to be ultrafiltered may be employed to increase the rate and/or to change the nature of the deposit formation. Some pretreatments that have been suggested in the literature include clarification by centrifugation or filtration followed by separation for removal of cheese fines and fat that will contribute to fouling and may also affect the quality of the WPC, heating for reduction of the viscosity and microbial loads of whey, microfiltration for separation of fat and bacteria by passing through a membrane with pore size of 1.2 μm, pH adjustment, demineralization and preconcentration [Marshall (1982), Matthews *et al.* (1978), Morr (1982), Richter (1983), Sienkiewicz and Riedel (1990), Tarnawski and Jelen (1986)]. The ultrafiltration of acid whey results in lower flux rates than sweet whey. Calcium apatite, whey protein structure and their interactions have been implicated. For acid whey pH adjustment from 4.6 to 7.0 is usually accomplished with NaOH or $Ca(OH)_2$, that yields calcium phosphate, which absorbs fat and protein and is separated by gravity [Sienkiewicz and Riedel (1990)].

Sanitation can be another problem, because membrane systems must be scrupulously cleaned and microbiologically monitored, to avoid blockages, poor flux and membrane fouling may occur. Membranes should not be physically handled, so clean-in-place schemes with high velocity liquid streams are used. Two to four hours of cleaning includes cleaning cycles followed by a sanitation cycle [Kock Membranes, Inc.].

Another disadvantage of membrane systems has been the high capital and membrane replacement costs. Higher capital costs, however, are offset by other advantages. Because they operate at lower temperatures, and no phase change (from liquid to vapor) is involved, membrane systems use less energy than other systems. Thus, the feasibility of membrane filtration is tied to low operational costs [Anon (1981), Sienkiewicz and Riedel (1990)].

Functional properties of whey protein concentrates

Whey protein concentrates obtained by ultrafiltration and other membrane separation processes are generally up to 90% water soluble in the pH range 3-8. Application of heat during spray drying has little effect on solubility. Pasteurization of the WPC solution can, however, result in a denaturation of up to 20% and a solubility loss in the isoelectric range [Sienkiewicz and Riedel (1990)].

Fat emulsifying capacity is defined as the oil quantity, in grams, which is retained by one gram of protein of the WPC under prescribed conditions. Whey protein concentrates have emulsion capacity values which are worse than those of sodium caseinate. This is due to their comparatively more regular sequence of hydrophobic and hydrophilic groups and their more compact, globular conformation [Muller (1976), Sienkiewicz and Riedel (1990), Smith (1976)].

The whipping properties of WPCs are variable, and values ranging from 0 to 680% were found for metaphosphate complex and gel filtration protein concentrates. Whipping ability is the amount of air which is incorporated into a given amount of sample during its churning for a given period of time and is usually expressed as a percentage of the sample volume. Whey protein concentrate solutions with 10% protein can give good whips, but the presence of more than 2% fat can adversely affect whipping, and there is some evidence that whippability is affected by the temperature history of the sample, pH, clarification, calcium level and the addition of such materials as sucrose and hydrolyzed starch [Smith (1976)].

Similarly, the patterns of buffering capacity versus pH for the WPCs are varied. Only those prepared by electrodialysis, ultrafiltration and gel filtration were somewhat similar in format with low buffering capacity at pH 7.0, which gradually increased in the lower pH regions [Smith (1976)].

Water-holding capacity of a substance is the grams of water bound to 1 gram of dry matter of this substance. The water-holding capacity of WPCs is dependent on the protein concentration, the mineral content and the degree of the denaturation of the proteins. For native and denatured whey proteins the water-holding capacity ranges from 0.5 to 1.2 g H_2O per 1 g dry matter and is very low in comparison to both soya protein concentrates and sodium caseinate solutions [Sienkiewicz and Riedel (1990)].

The protein content of the WPC which can be reached by using ultrafiltration is practically limited to about 80%. At these high protein contents, the functional properties are marred by the retention of fat by the UF membrane, thus causing loss of whipping properties. For this reason, removal of residue lipids before the ultrafiltration is very important for improving whipping and, perhaps, other functional properties of the WPCs [Marshall (1982), Ryder (1980), Sienkiewicz and Riedel (1990)].

USES OF WHEY IN FROZEN DESSERTS

The standards of identity for ice creams do not allow replacement of MSNF by whey solids at a level higher than 25%. Ice cream must have, at least, 2.7% milk-derived protein by weight [CFR (1990b),Weiner (1977)]. A major reason for use of whey solids in ice creams and other frozen desserts is that it is the least expensive dairy product that can be used in such formulations.

Modified whey products have been successfully used to contribute to the milk solids non-fat content of ice cream and other frozen desserts. Use of modified whey in ice cream is said to eliminate or reduce the effect of some objectionable changes that we encounter in ice cream, such as shrinkage and sandiness. Shrinkage is a term usually applied to contraction of volume of packaged frozen dairy products, a defect caused by the loss of overrun air. The product shrinks from every direction, pulling away from the sides and top of the container. Sandiness is manifested as a powdery and gritty sensation, which can be perceived on the tongue even after the product has melted. This de

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defect is due to the presence of large lactose crystals. Some factors to initiate the development of sandy texture are high lactose content and high and, perhaps, fluctuating temperatures. Dry whey contains a greater amount of lactose (72%) than does NFDM (52%) or other common source of MSNF. This fact has caused some concern that the use of dry whole whey might cause sandiness in frozen dairy desserts. This is the reason why partially delactosed whey has been used in frozen desserts [Anon (1979), Martinez and Speckman (1988)].

Crowe (1960) replaced 50, 75 and 100% of MSNF with dry whole whey in vanilla and strawberry ice cream mix containing 11% solids non-fat (SNF). No preference for the flavor of either control samples or samples containing whey was found. Frazeur (1959) found that substitution of dry sweet whey at 25, 50 and 75% level for MSNF did not affect the consumer acceptance of vanilla ice cream. A taste panel could not differentiate ice cream containing dry whey replacing the MSNF up to 75% from ice cream containing no whey. Leighton (1944) compared five vanilla ice creams containing 8% butterfat, 6.4% SNF and 15% sugar, which had different source of the SNF. In the first ice cream, all SNF came from NFDM, whereas the others contained sweet whey solids to an amount equalling 1, 2, 3 and 4% of the mix. The body and texture of samples containing 1% whey solids were equal or slightly better than the control, whereas the samples containing more whey solids were found inferior than the control. In no case, however, were undesirable flavors noted. Similar substitution experiments, with mixes of higher fat and SNF content than those of the previous experiments, gave the following optimum whey solids content: i) 10% fat and 8% SNF ice cream 1.6% whey solids; ii) 12% fat and 9.6% SNF ice cream 2.3% whey solids; and iii) 14% fat and 8% SNF ice cream 3% whey solids. Excellent sherbets of 2.6% fat and 2.4% SNF, where 78% of the SNF came from whey solids were also produced. These sherbets were not noticeably different from the control samples made entirely with MSNF.

Reid with Shaffer (1947) found that excellent chocolate and strawberry ice creams and good vanilla ice cream can be obtained, even when 90.9% of the MSNF are replaced by dehydrated whole whey solids. At this high level of substitution the vanilla flavored ice creams had a slight heat flavor and their texture was ranked as "good" after 30 and 40 days of storage at -14°F (-25.6°C). The substitution levels of whey solids for MSNF tested were 9.1, 18.2, 27.3, 45.5, 63.6 and 90.9%. Vanilla ice cream kept for 4 days in the hardening room and then transferred to cabinets at 5.2°F (-14.9°C) The samples with 63.6 and 90.0% substitution of whey solids for MSNF had slight heat flavor, good texture and excellent body after 10 days of storage, whereas after 30 and 40 days at 5.2°F (-14.9°C) slight sandiness was reported.

Potter and Williams (1949) used dry sweet whey (95% total solids), plain condensed whey (60% total solids), sweetened condensed whey (80% total solids, 40% sugar and 40% whey solids) and fluid whey (6.4% total solids) from Cheddar and Swiss cheese to formulate sherbets containing 4.42-5% whey solids. The finished products possessed fine flavor, body and texture. Among several advantages to be gained through the use of spray dried whey powder in ice cream reported by Rosenberger and Nielsen (1955) were a smoother body and texture, a higher melting resistance and easier incorporation in mixes than NFDM. The same researchers also reported that the flavor of the ice cream may be slightly inferior, when whey powder is used.

Frazeur (1967) substituted electrodialyzed dry sweet whey and excellent and average flavor dry wheys for MSNF in ice cream, ice milk, soft-serve ice milk and shake mixes at 25% level and in sherbet at 64.7% level. He found that the flavor of ice cream, ice milk, soft-serve ice milk and milk shake samples which contained electrodialyzed dry whey was equal to the flavor of control samples. However, statistically significant differences between the flavor scores of control samples and samples containing the dried whey of average flavor were found. No significant difference in body and texture occurred due to the use of any of the whey products. For the sherbet samples the flavor, body and texture was significantly improved by the presence of all the whey products. Storage of sherbet samples at 3°F (-16.1°C) for nine weeks did not change the relative differences among flavor, body and texture scores for all sherbet samples. Storage did, however, decrease, flavor, body and texture scores for all sherbet samples.

In a sensory study of the previous mentioned frozen desserts conducted by Frazeur and Harrington (1967) consumers responded to orange sherbet in a manner which was not observed with any of the other frozen dairy products that were tested. They indicated significant overall and flavor preferences for samples which contained some form of dry whey. However, the smoothness of the control sherbet samples was preferred. The results indicated that the use of electrodialyzed dry whey is to be preferred in sherbets and in soft-serve ice milk, an excellent flavor quality dry whey should be used in sherbet, should not be used in ice cream and can be used in ice milk, soft-serve ice milk or milkshake mix and an average flavor quality dry whey probably should not be used in any frozen dairy dessert, with the single exception of sherbets.

Arnold *et al.* (1976) compared the effect of using various levels of dried sweet whey and partially delactosed whey solids in ice cream formulations. Characteristics that were evaluated included flavor and texture of the finished ice cream. Three levels of replacement were used, 20, 35 and 50%. All levels of replacement of MSNF by either type of whey had little effect on samples held no longer than four weeks. The results of this study indicated that use of up to

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35% replacement MSNF with dried sweet whey may be acceptable in ice cream mix formulations. To avoid adversely affecting flavor and texture of ice cream, partially delactosed whey powder with a high mineral content would need to be used at levels lower than 20% replacement of MSNF.

In a study conducted by Guy (1978), vanilla-flavored ice creams of 38% total solids containing 12% fat and 0.14% stabilizer were prepared with different levels of sweet whey (0-11%) with either 67 or 79% hydrolyzed lactose, different levels of sugar (10-15%) and different levels of MSNF (5-11%), the three ingredients totaling 26%. The initial hedonic flavor and texture scores of ice creams containing up to 5.5% of either of the wheys were not significantly different from those of the controls. Increasing both types of wheys solids above 5.5% significantly decreased mix viscosity and hedonic flavor scores and increased the saltiness of the ice cream. Texture scores fell less rapidly than flavor scores, although whey contributed to a softer-bodied ice cream, as measured by compressibility tests. The sweetness of all test samples were comparable to the control. Heat-shock stabilities of the ice creams containing up to 5.5% whey were good; they were poorer for those with higher levels of whey and for some of the controls.

Dry sweet whey has often been used successfully in ice cream at low concentrations, but WPC show the most promise in replacing NFDM. A study, conducted by Huse *et al.* (1984), evaluated the limits of the proportion of WPC that could be used in ice cream manufacture. The use of WPC rather than whey powder would allow the maintenance of high protein levels in the formulated ice cream. The level of replacement of MSNF with whey solids was 0, 50 and 100%. Fifty percent replacement of MSNF with whey solids had little effect on the sensory qualities of the ice cream. The use of only WPC to supply the SNF gave a poorer textured ice cream with some increase in iciness and significantly decreased smoothness, creaminess and fullness of flavor. The flavor of this ice cream was also very flat and more cooked due to high proportion of heat labile whey protein. Samples containing whey solids had slightly better resistance to heat shock with no increase in iciness score and only a slight decrease in smoothness after the applied heat shock treatment.

In a study conducted by Parsons *et al.* (1985), ice cream was made from mixes in which 100% or 50% of the MSNF was provided by WPC, WPC and dried sweet whey (DSW) or DSW and sodium caseinate (CAS). Trained panelists found no significant differences in flavor, body and texture among the ice creams, but in a 14-week evaluation by 52 randomly selected families the DSW-CAS ice cream was found inferior in flavor compaerd to the other products. The consumer study rated the WPC and WPC/DSW ice creams as equal or slightly better than the MSNF control ice cream at both 50 and 100% replacement. The panelists made various comments about the samples containing WPC, such as being "creamier" and "smoother" tasting. They also indicated that the ice cream samples containing the whey blend were sweeter and very similar in taste to soft serve ice cream. In a preliminary study conducted by Coder and Parsons (1979) similar results were obtained.

Flavor problems associated with the use of Cheddar cheese whey in the formulation of ice cream mix were investigated by Bodyfelt *et al.*(1979). An ice cream model system was used to study the effects of varying whey quality and quantity and extent of heat processing on the flavor profile of the final product. Whey "fingerprint" compounds were identified by headspace gas liquid chromatography/mass spectroscopy (GLC/MS) analysis of varied quality whey powders. The chemical compounds that appeared most representative of the heated, stale off-flavor of dried whey included four different pyrazines, m-pentanol, dimethyltrisulfide, 2-furfural, benzaldehyde, 2-furfuryl alcohol and dimethylsulfone.

The sales potential of whey products is not only determined by the whey processing technique, but also by the quality of the whey available. Generally, the value of the whey is increased in relationship to the decreased concentration of lactic acid in the whey. Whey from Cottage cheese is difficult to process and generally is disposed of without value adding processing, whereas sweet whey from Swiss or Emmanthaler cheese is in special demand [Christensen (1976)].

Watrous *et al.* (1991) found that the use of concentrated acid whey, both neutralized and unneutralized, to contribute 8.9% by weight in the serum solids in vanilla flavored ice cream resulted in a product which could not be differentiated from an ice cream product containing no whey solids and an ice cream product containing 24.7% sweet whey solids by weight of the serum solids. The use of concentrated neutralized and unneutralized acid whey to contribute 26.6% by weight of the serum solids in vanilla flavored ice cream resulted in a product of poor texture, overrun and color. Experiments with neutralized acid whey found that it can be used to contribute 17.7% by weight of the serum solids, without impairment of any undesirable sensory properties to the ice cream.

In a work that has been done by Patel and Harper (1977), acid whey was concentrated to about 20% total solids by reverse osmosis and was used to replace 10-25% of the MSNF in ice cream with basic composition 10% milk fat, 12.5% MSNF, 14% sucrose and 0.3% stabilizer and emulsifier. Compared to the control ice cream, the experimental sample with 10-15% replacement had higher viscosity after processing and after 20 and 44 hours aging and exhibited higher pseudoplasticity. Partial replacement of MSNF did not affect freezing time, but resistance to melting was increased, with the 20% replacement showing the greatest resistance. No statistically significant differences were obtained in organoleptic evaluation.

Igoe *et al.* (1973) used Cottage cheese whey in ice cream mixes and found it unacceptable when more than 1% of the SNF were provided by acid whey. In this study, the SNF were standardized at 11.25% by weight for all mixes. In the control mix, these solids were derived from skim milk, whereas in the other mixes whey solids were substituted for varying amounts of skim milk solids, so that the 11.25% level was maintained. 1%, 2%, 2.8% and 3% by weight of whey solids were incorporated into the ice cream, representing substitution levels of 8.9%, 17.7%, 24.7% and 26.7% respectively. The whey ingredient was fresh Cottage cheese whey concentrated to 29% solids in a vacuum pan. Concentrated neutralized acid whey and sweet whey were also used for comparison. The sensory panel could not distinguish between ice cream containing 1% acid whey solids and the control. At the 2% level, however, ice cream with acid whey solids was easily differentiated with a strong preference shown for the control. At the 3% level the flavor and texture properties were so obviously different that sensory testing was not necessary. The results also showed that ice cream with 2% neutralized acid whey solids was much preferred over that containing 2% of unneutralized acid whey, but the authors did not recommend the use of neutralized acid whey at levels higher than 2%. Ice cream with 2% acid whey was readily distinguished from ice cream containing 2.8% by weight of sweet whey, but when the comparison involved neutralized acid whey, the differences found were not statistically significant.

Potter and Williams (1949) made sherbet using Cottage cheese whey containing 6.4% total solids, which resulted in a product with 4.42% whey solids. The researchers found that the final product possessed a smooth body and texture and was more refreshing than the sherbets made with solids from milk or ice cream mix, and that no citric acid needed to be added to the mix when Cottage cheese whey was used.

Hekmati and Bradley (1979) used Cottage cheese whey in sherbet as a replacement for water. Sherbet formulations were prepared containing as high as 65.4% whey as a diluent. Flavor, body and texture were rated excellent in all sherbets evaluated. However, the sample prepared with the highest level of acid whey (65.4%) showed slight masking of the pineapple flavor of the sherbets.

Direct-set Cottage cheese whey was used by Demott and Sanders (1980) for the manufacturing of sherbet. Three sherbet mixes containing (i) 28.5% milk and 17.2% skim milk (control), (ii) 44.7% whey and 8.3% ice cream mix and (iii) 46.1% whey and 9.5% half-and-half were compared. The same amount of citric acid was added to all mixes before freezing. The last two mixes had higher titratable acidity (0.86 and 0.85% versus 0.61% for the control), slightly lower pH (3.5 and 3.5 versus 4.0 for the control) and slightly higher total solids (31.7 and 32.0 versus 31.1%). An expert panel was unable to detect any defect attributable to the whey in sherbet samples prepared by mixes (ii) and (iii) and an untrained panel detected no differences among the sherbets. The conclusion of this study was that direct-set whey may be used to replace some of the water and milk solids in sherbets without adversely affecting their flavor. Demott noted in one of his other studies that whey from direct acidification process does not have the "whey taint" associated with cultured whey. It has also been reported that making whey products immediately after the whey is separated from the curd eliminates deterioration caused during storage [McGugan *et al.* (1979)].

EXPERIMENTAL PROCEDURE

PREPARATION OF WHEY PROTEIN CONCENTRATES

Two hundred forty gallons (908.4 L) of direct-set Cottage cheese whey were supplied by Country Fresh Inc. [Grand Rapids, MI] and were processed the same day they were produced to minimize spoilage problems. The whey was ultrafiltered and diafiltered in the Kock Membranes S-1 ultrafiltration pilot system [Wilmington, MA] after the necessary cleaning and sanitation of the system.

The temperature of the system during the ultrafiltration/diafiltration was kept at 130±2°F (54±1°C), and the pressure drop between the inlet and outlet valve was 10±1 psi (68.95±6.90 kPa). During the operation of the system the volumetric rate of the permeate was determined as Q=0.413gal/min (1.563L/min).

When the whey was concentrated to about 25 gal (94.63 L), 100 gal (378.5 L) of soft water were added to the tank for diafiltration in order to decrease the lactose and mineral levels of the product. The operation was interrupted when the whey was at the level of 25 gal in the tank. The concentration factor of the process, which is the ratio of the volume of the whey before and after ultrafiltration was CF=250/25=10 and the total weight of the concentrated product was 177.5 lbs (80.51kg). The product was collected in marked plastic bags with caps and kept in the freezer at temperature -13°F (-25°C), to minimize spoilage.

TOTAL SOLIDS DETERMINATION

The total solids of the original acid whey, the WPC, the different orange sherbets and sherbet mixes were determined by the Mojonnier method [AOAC (1990)].

FAT DETERMINATION

The fat content of the acid whey, the WPC, the cream and the sherbet mixes was determined by the Mojonnier method [AOAC (1990)] with some modification. For the whey protein concentrate and the sherbet mixes no recommendation for the amount of reagents was found in the literature [Newlander and Atherton (1964)]. Thus the whey protein concentrate, because of its acid nature, was treated as acid whey and 3ml of ammonium hydroxide were used, and the sherbet mixes were treated as ice cream with fat content similar to that of fresh milk. The samples of sherbet mix examined were 10 g and the amount of reagents added was: 5 ml water, 3 ml ammonium hydroxide, 10 ml alcohol, 25 ml ethyl ether, 25 ml petroleum ether for the first extraction and 5 ml alcohol, 15 ml ethyl ether and 15 ml petroleum ether for the second extraction.

TOTAL NITROGEN DETERMINATION

Total nitrogen was determined by the Kjeldahl nitrogen method [AOAC (1990)]. The nitrogen determination system used in this study was composed of the Tecator 40/1016 digester, the Buchi 322 distillation unit, the Buchi 342 control unit, the Metrohm 614 impulsomat, the Metrohm 632 pHmeter and the Metrohm 655 Multi-Dosimat unit [Buchi Laboratories, Flawil, Switzerland]. From the volume of HCl consumed for each sample and the blank the % total nitrogen was calculated by using the following equation:

$$\%\ TN = \frac{(HCl_s - HCl_b)}{Sample\ weight} \times A \times Normality HCl$$

where:
HCl_s = volume of HCl consumed for each sample (ml)
HCl_b = volume HCl consumed for the blank (ml)
Sample weight = weight of tested sample (g)
A = 1.4007 (g/mol).

NON-PROTEIN NITROGEN DETERMINATION

The preparation of the samples for the non-protein nitrogen (NPN) determination is described by Partridge (1983). It was assumed that all the proteins are insoluble in 12% TCA and therefore, NPN was determined as soluble nitrogen in 12% TCA filtrate prepared from each sample.

The Sorvall RC-5B Refrigerated Superspeed Centrifuge (Du Pont Co., Wilmington, DE) was used in this determination and the samples were subjected to 13,000 RPM (Relative Centrifugal Force: 20,000xg) [Cooper (1977)].

pH DETERMINATION

The pH of the original acid whey, the WPC, the sherbet mixes and the sherbets was determined using the Corning pH/ion meter 145 with the Corning semi-micro combination electrode [Medfield, MA]. The pH meter was calibrated with Buffar pH 7.0 and pH 4.0 buffer standard solutions (Mallinckrodt Inc., Paris, KY).

TITRATABLE ACIDITY

The titratable acidity of the WPC, the sherbet mixes and the sherbets was determined with the Nafis apparatus (Meyer-Blanke Co., St. Louis, MO) described by AOAC (1990).

PREPARATION OF SHERBET MIXES

Four sherbet mixes (Table 5) were prepared, one control, containing no whey (sherbet mix A), one with 25% substitution of whey solids for MSNF (sherbet mix B), one with 50% substitution (sherbet mix C) and one with 75% substitution (sherbet mix D). All mixes contained 1.5% milkfat, 3.4% solids non-fat (SNF), 20.0% sucrose, 9.0% corn syrup solids (CSS), 0.3% stabilizer/ emulsifier (STEM) and 34.2% total solids. The only difference they had was the source of the SNF.

Table 5. Formulation of the sherbet mixes.

Sherbet mix A	Sherbet mix B	Sherbet mix C	Sherbet mix D
1.5% fat	1.5% fat	1.5% fat	1.5% fat
3.4% MSNF	2.55% MSNF	1.7% MSNF	0.85% MSNF
20% sucrose	20% sucrose	20% sucrose	20% sucrose
9% CSS	9% CSS	9% CSS	9% CSS
0.3% STEM	0.3% STEM	0.3% STEM	0.3% STEM
0% whey solids	0.85% whey solids	1.7% whey solids	2.55% whey solids

The ingredients used in the sherbet mixes are presented in Table 6. The calculation of the required amount of WPC for each sherbet mix was based on the solids non-fat (SNF) of these ingredients. The solids non-fat of the cream were calculated from its total solids and its fat content. The stabilizer/emulsifier (STEM) used in this study, known by the brand name Kontrol [Germantown Mfg., Broomall, PA] contains mono- and diglycerides, cellulose gum, guar gum, polysorbate 80, carrageenan and sodium silico-gluminate. The CSS used, known by the brand name Maizo [American Maize Prod. Comp., Hammond, IN] was a 42 Dextrose equivalent (DE) product. Table 7 shows the amount of each ingredient used for the preparation of 80 lb (36.29 kg) of sherbet mix A, B, C and D.

All ingredients were mixed together in a 10 gal (37.85 L) container and were pasteurized with continuous stirring at 175°F (79.5°C) for 5 min. Then the mixes were homogenized at 1500 and 500 psi (10,342.5 and 3,447.5 kPa) for the first and second stage, respectively, in a homogenizer made by Manton-Gaulin Mfg. Co. Inc., type 75K (Everett, MA). The mixes were then collected in plastic bags, cooled down to 40°F (4.44°C) with ice and stored overnight in a cooler at 40°F (4.44°C).

Table 6. Ingredients used in the formulation of sherbet mixes.

Ingredients	Composition (% w/w)
Cream	36.60±0.26 fat, 41.80±0.26 total solids
NFDMS	4.66±0.09 moisture
WPC	0.11±0.01 fat, 5.53±0.10 total solids
Granulated sugar	
Corn syrup solids 42 DE	4.49±0.09 moisture
Stabilizer/emulsifier (STEM)	4.79±0.01 moisture
Tap water	

Table 7. Amount of ingredients used for 36.29 kg of sherbet mix A, B, C and D.

Sherbet mix A	Sherbet mix B	Sherbet mix C	Sherbet mix D
1.49 kg cream	1.47 kg cream	1.45 kg cream	1.44 kg cream
1.21 kg NFDM	0.89 kg NFDM	0.57 kg NFDM	0.24 kg NFDM
no WPC	5.69 kg WPC	11.38 kg WPC	17.07 kg WPC
7.26 kg sucrose	7.26 kg sucrose	7.26 kg sucrose	7.26 kg sucrose
3.42 kg CSS	3.42 kg CSS	3.42 kg CSS	3.42 kg CSS
0.11 kg STEM	0.11 kg STEM	0.11 kg STEM	0.11 kg STEM
22.80 kg water	17.45 kg water	12.10 kg water	6.75 kg water

FREEZING OF THE SHERBET MIXES

The sherbet mixes were frozen in the Gelmark model 160 pilot plant continuous freezer [Alfa-Laval, Hoyer, Italy] with 43% overrun. Before freezing, 75.8 ml Bloomfield orange sherbet base [Kraus & Co. Inc., Oak Park, MI], 12 ml 50% w/w citric acid solution and 8 ml orange food color [Kraus & Co. Inc., Oak Park, MI] were added to 10 lbs (4.536 kg) of each mix. The mixes were frozen and the sherbet was packaged in paperboard 16T5 pint containers (Ne-style, Sealright Co. Inc., Fulton, NY) and hardened at -13°F (-25°C). After a week, the sherbets were transferred and kept in another freezer at 0°F (-17.8°C) to approximate the temperature of home freezers.

OVERRUN DETERMINATION

The overrun of the different sherbets was calculated during the freezing. The equation used was the following:

$$\% OR = \frac{W_{mix} - W_{sher}}{W_{sher}} \times 100$$

where:
% OR = % overrun (dimensionless)
W_{mix} = mass of a certain volume of mix (g)
W_{sher} = mass of the same volume of sherbet (g).

DETERMINATION OF THE RHEOLOGICAL PROPERTIES OF THE SHERBET MIXES

The rheological properties of the sherbet mixes were tested in the Haake RV12 concentric cylinder viscometer [Haake Buchler Instruments, Saddle Brook, NJ] using the MV cup with the MV-I sensor and a M500 measuring head. The sherbet mixes were tested two days after they were prepared. During this period, they were aged at 40°F (4.44°C). Two tests were run on each mix. The time-dependency of the rheological properties of the samples was tested by the first test , while the best rheological model for the description of the mixes was developed for the time-independent samples by the second test. Each test was performed in triplicate.

A material has a time-dependent behavior, if when subjected to a constant shear rate, the shear stress increases (for rheopectic materials) or decreases (for thixotropic materials) over time. The time-dependent thickening of the fluid is known as rheopexy, whereas the time-dependent thinning as thixotropy.

The viscometer was set at 40°F (4.44°C) by using the Haake C water bath [Haake Buchler Instruments, Saddle Brook, NJ]. The reason for this setting was that the sherbet mixes were kept in the cooler at 40°F (4.44°C). For the time-dependency test, the viscometer was set up to rotate for 10 min at the constant angular velocity of 100 min^{-1}. The torque was measured every 12 sec (the 10 min period was divided into 50 intervals) and the diagram of torque versus time was obtained. For the second test, the angular velocity was gradually increased from 0 to 500 min^{-1}, by using a Haake PG 142 programmer [Haake Buchler Instruments, Saddle Brook, NJ]. The angular velocity was increased in small intervals for low values and bigger intervals for high values. For each angular velocity value the torque applied to the sample was recorded by the computer unit of the viscometer. The shear stress was calculated based on standard procedures and the shear rate based on the Krieger method [Steffe (1992), Whorlow (1979)]. The shear stress versus shear rate diagram was obtained in addition to the raw data table and the statistical analysis of the data. The properties of the mix samples were measured over shear rate range up to 1100 s^{-1}.

MELTING RESISTANCE TESTS

After the paperboard container was pealed off, one pint of each sherbet was placed into a large funnel inserted in a graduated cylinder. The melting took place in a temperature controlled incubator at 100.4±2°F (38±1°C). A Rapid-Flo 6.5 in single gauze faced milk filter (Johnson-Johnson, Chicago, IL) was used in the funnel, which retained the foam, letting only the liquid sherbet pass. The volume of melted product was recorded every 5 min, and a graph was obtained by plotting the average volume of sherbet collected versus time. Two replications were performed on each sherbet.

SENSORY EVALUATION

The objective of this study was to measure the overall flavor and texture acceptability of the sherbets by consumers and compare some of their sensory attributes. The final products were tested for flavor and texture acceptability using a 9-point hedonic scale (Appendix C, Table C.1), where 1 = "dislike extremely" and 9 = "like extremely". For sweetness, creaminess and iciness a multiple paired comparison test was used. The acceptance tests were conducted 8 days after the sherbet mixes were frozen, whereas the iciness, sweetness and creaminess were tested 9, 10 and 11 days, respectively after the sherbets were frozen. The questionnaires were developed and the trays with the samples were set the day before the test. The panels for the flavor and the texture acceptance test consisted of 48 untrained members of Michigan State University (MSU) including faculty and students. For the sweetness, creaminess and iciness tests trained panelists were used. The sweetness panel consisted of 5 people (4 females and 1 male), the creaminess panel of 5 people (4 females and 1 male) and the iciness panel of 6 people (4 females and 2 males). Each test was conducted individually, in order to eliminate any biases.

The tests were performed in a sensory evaluation laboratory. The panelists were sitting in individual booths, which were lighted properly with bright white light. The room was free of odors, reasonably quiet and comfortably warm. The efforts made to reduce experimental error during the tests, in addition to the above mentioned controlled atmosphere conditions, were: precise instructions for the panelists, avoidance of bias by cleansing the palate with water before and after tasting each sample, identical preparation of the samples and balanced order of presentation [Larmond (1987), Ott (1990)].

Each tray had the following items:

- One sample for the acceptance tests (sherbet A, or B or C or D) and two samples for the multiple paired comparison test.
- One questionnaire (Tables C.1-C.3 in Appendix C).
- One pencil.
- One cup of tap water at room temperature.

- One napkin.
- One expectoration cup.

The samples were served in 1 oz. plastic souffle cups, type P100 (Solo Cup Co., Urbana, IL) covered with plastic snap-on lids, No. PL1 (Solo Cup Co., Urbana, IL). The cups were marked with a random three digit number. They were filled with a scoop of sherbet, put on trays and placed in the freezer the day before the test [Larmond (1987), Meilgaard *et al.* (1987a), Stone and Sidel (1985)].

The panelists were instructed to rinse their mouth with water after tasting each sample, in order to avoid any influence from the previously sampled sherbet. For the same reason, a monadic sequential presentation order was used for the acceptability tests, where each sherbet was presented to the panelists alone accompanied by a new questionnaire. The panelists were also asked to write comments. All 24 possible combinations of sample presentation were used to eliminate the order effect. With the term "order effect" the effect on the results of the presentation order of the samples to each panelist is meant.

The paired comparison attribute tests were performed in triplicate. All replications were performed the same day to eliminate possible intensity changes of the attributes over time. The Scheffe multiple paired comparison test was used. In this test the panelists were asked to indicate the size of the difference detected. All samples were compared with every other sample (6 possible pairs for the 4 sherbets), and all pairs were presented to all judges. Half of them tasted one sample of each pair first, the other half tasted the same sample second (balanced design). The order of presentation of the 6 pairs was randomized for each judge and a 7-point scale (Appendix C, Table C.3) was used [Larmond (1987), Ott (1990)].

The hypotheses, and the worksheets for all tests are presented in Appendices D and E, respectively.

STORAGE STABILITY

The storage stability of frozen dairy products can be reflected as changes in the overall flavor or texture. In order to determine the stability of the products during storage at 0°F (-17.8°C), which is the temperature of a commercial type retail freezer, the sherbets were evaluated for their flavor acceptance after 31 and 122 days of storage and for their texture acceptance after 31 days of storage. Forty eight untrained panelists, students and faculty of MSU, were used for each test. The four different sherbets were also compared for iciness by the expert panel after 32 days of storage.

HEAT-SHOCK STABILITY

Two weeks after the freezing of the sherbets, 15 pints of each sherbet sample were taken out of the freezer at 0°F (-17.8°C) and left at room temperature at 78±2°F (25.6±1°C) for 30 min. Then the sherbets were put back to the freezer. The same procedure was repeated for 10 consequent days. A week after this treatment, an evaluation of the flavor and texture acceptance and iciness of sherbets was conducted, from the results of which the heat-shock stability of the sherbet samples was compared.

PANEL TRAINING

Trained panelists were used for the iciness, creaminess and sweetness sensory attribute tests. These attributes are more difficult to evaluate, because everyone has a different perception about them. The purpose of the training procedure was to create a sensory panel for each attribute, in which each panelist was trained to recognize certain characteristics of the frozen dessert, such as iciness, creaminess or sweetness.

Twenty four people (students and faculty) participated in this training. The steps of the training procedure follow:

- Explain and define which attributes were of interest.
- Prepare sherbets different in iciness, creaminess or sweetness, by using different amounts of stabilizer/emulsifier, fat or sweetener, respectively.
- Develop a series of sensory tests, to discern the ability of the panelists to distinguish differences. Testing started with large differences in iciness, creaminess and sweetness among samples. As testing progressed, differences among samples within subsequent trials were of less magnitude than previous trial.
- At the end of each test, the panelists were told the composition and/or treatment of the samples they had been tasting, and the characteristics of the samples being tested for were emphasized. The panelists could ask questions about the samples or the specific sensory test used and could retaste the samples, in order to be able to recognize the above mentioned characteristics.
- At the end of the training period, which included 7 tests for each at-

tribute, the panelists who gave the most correct answers (at least 5 out of 7) and were able to find high and low differences in iciness, creaminess or sweetness became the members of the three trained panels. The iciness panel was composed of 6 panelists, whereas the creaminess and sweetness panels consisted of 5 panelists each.

The sensory tests that are usually used for panel training are the triangle and the duo-trio test. In this project two more tests were used, the paired comparison and the ranking test. The duo-trio test was used alone for the training in sweetness, whereas the others were used for the training in iciness and creaminess.

In the triangle test, the panelists tasted three samples, two of which were identical, and were asked to identify the odd sample [Larmond (1987)]. In this study the panelists were also asked at the end of the test, which sample was the iciest (or creamiest) in order to make sure that they could not only find the odd sample, but they were also able to sense the iciest (or creamiest) sample. The possible combinations of the presentation order of the three samples were six and they were used four times, because the initial panel consisted of 24 panelists. Each sample was presented to the panelist in a cup with a three digit code number written on it. Two code numbers for each sample were selected, so that each tray had three differently coded samples, although two of them were identical.

A paired comparison test was used when a triangle test could not be performed or when a lower difficulty level for a specific test was desired. The panelists were given two coded samples and were asked to identify the iciest (or creamiest). There were two possible order presentations of the samples (A-B, B-A) [Larmond (1987)].

In the ranking test three coded different samples were given to the panelists who were asked to rank them from iciest to least icy (or from creamiest to least creamy). In the duo-trio test, three samples were presented to each panelist. One was labeled R (reference) and the others were coded. One of the coded samples was identical to R. Each panelist was asked to identify which of the two samples was different from R [Larmond (1987), Meilgaard *et al.* (1987a)]. The panelists were also asked to identify the sweeter sample at the end of each test.

The same samples were sometimes served to the panelists more than once (in different days), in order to check their ability to differentiate between trials. All sensory tests were performed under red light conditions, to allow the panelists to concentrate on the attribute in question, rather than appearance. The final form and schedule of each test were developed after the previous test was over and its results were studied.

Training the iciness panel

Iciness was defined as the sensation that the ice crystals left in the mouth. The number and size of the ice crystals influence the iciness of the sample. The larger number and size of ice crystals, the icier the product is.

The composition and treatment of the samples used for the panel training in iciness are shown in Table 8. Three different stabilization/emulsification systems (STEM) were used in order to obtain differences in iciness. The Kontrol STEM has already been discussed. The Dariloid 300 [Kelco Merck Co., Inc., Chicago, IL] was only stabilizer containing gum guar, zhanthan gum and carrageenan. The Rhicoid 200 [Kelco Merck Co., Inc., Chicago, IL] was a

Table 8. Composition and treatments of sherbets used for the iciness panel training.

Sample	Composition	Treatment
vanilla ice cream	10.5% fat, 10% MSNF, 12.5%sucrose, 2.5% CSS, 0.25% Kontrol	**homemade**
commercial vanilla ice cream	as above	**continuous freezer**
SH1	1.5% fat, 3.72% MSNF, 20% sucrose, 9% CSS, **0.5% Kontrol**	batch freezer
SH2	1.5% fat, 3.72% MSNF, 20% sucrose, 9% CSS, **no STEM.**	batch freezer **heat shock**
SH3	as SH1	home freezer
SH4	1.5% fat, 3.72% MSNF, 20% sucrose, 9% CSS, **0.1% Dariloid 300**	batch freezer
SH5	1.5% fat, 3.72% MSNF, 20% sucrose, 9% CSS, **0.2% Dariloid 200,0.2% Kontrol**	batch freezer
SH6	1.5% fat, 3.72% MSNF, 20% sucrose, **13% CSS, 0.5% Rhicoid**	batch freezer

STEM system containing mono- and diglycerides, gum guar, zhanthan gum and carrageenan. The recommended amounts of these STEM for use in sherbets were: for Kontrol 0.30-0.50%, for Rhicoid 200 and Dariloid 300 less than 0.30%. Table 9 shows the samples compared, the sensory tests performed and the percentage of the correct answers on each test.

In the first test, the homemade vanilla ice cream was compared to commercial vanilla ice cream. The difference in iciness between these samples was high, because the homemade ice cream was whipped by hand resulting in slow freezing, whereas the commercially prepared product was frozen quickly in a continuous freezer. Therefore, large ice crystals were developed in the homemade ice cream and they were very easily detected.

Table 9. Tests performed for the iciness panel training.

Test #	Samples	Sensory test	% Correct responses
1	home made vanilla ice cream & commercial vanilla ice cream	triangle test	95.5
2	SH1-SH2	paired comparison	92
3	SH1-SH3	paired comparison	95.5
4	SH4-SH5	triangle	33.3
5	SH5-SH6	triangle	43.5
6	SH4-SH5	triangle	52.2
7	SH1-SH4-SH6	ranking	54.6

The differences of the samples in the second test was that SH2 contained no STEM and it was heat shocked (left out of the freezer at room temperature for 30 min for ten consequent days), whereas SH1 contained STEM and it was not heat shocked. The treatment and the composition of SH2 resulted in formation of bigger ice crystals in this sample than in SH1.

SH1 was compared to SH3 in the third test. Both sherbets had the same composition, but the first was frozen in a laboratory batch freezer, whereas the second in a home freezer, in which bigger ice crystals were developed.

The difference between SH4 and SH5 used in the forth test was the type and amount of STEM used. SH4 was made with 0.1% Dariloid 300, whereas SH5 with the combination of 0.2% Dariloid 300 and 0.2% Kontrol, so SH5 was better stabilized and developed smaller ice crystals and therefore smoother texture.

The differences between SH5 and SH6 used in the fifth test was the type and amount of STEM and the amount of CSS used. SH6 contained 13% CSS, whereas SH5 contained 9%, and this ingredient when added at higher levels gives smoother texture to the final product. SH6 was also overstabilized, since Rhicoid 200 was used at almost double concentration than the recommended. This test was rather difficult, mainly because SH5 was also a very smooth product.

The sixth test was a repetition of test 4. The last test consisted of three samples already tested, SH1, SH4 and SH6. Both SH1 and SH6 were very smooth products and contained 0.5% STEM, however SH6 contains Rhicoid 200, which is not used at higher than 0.3% level.

Training the creaminess panel

Creaminess was defined as the coating of the mouth left after the sample has been swallowed. The more the sample coats the mouth after swallowed, the creamier it is. The creaminess of a sample is very much influenced by its fat content.

Although the samples compared in the first test (Table 11), a premium commercial vanilla ice cream and a vanilla ice milk were quite different in fat content (Table 10), only 50% of the panelists found the premium vanilla ice cream creamier, which was considered as the right response. After the test the panelists tasted some more of each sample and tried to sense the difference in creaminess. A paired comparison test was used, because the samples were quite different in flavor, and the odd sample in a triangle test would be easily recognized.

The samples SH1 and SH8 that were used in the second test had different fat content. SH8 with 3% fat was very creamy, though above the legal maximum 2% for fat content [CFR (1990c)], whereas SH1 was a legal sherbet.

In the third test, SH8 and SH7, having 3 and 2% fat, respectively were compared in a triangle test. Although the 1% difference in fat is big, both sherbets were creamier than the usual commercial sherbets, so the panelists found this test difficult. Test 4 was found much easier, although the fat difference between the sample was only 0.5%, because SH7 was richer than the usual sherbet. Test 5 was a repetition of test 3, but this time an easier sensory test was used (paired comparison), in order to check how many panelists were able to

Table 10. Composition of the samples used for the creaminess panel training.

Sample	Composition
premium vanilla ice cream	more than 10% fat (exact composition unknown)
ice milk	4% fat (exact composition unknown)
SH1	1.5% fat, 3.72% MSNF, 20% sucrose, 9% CSS, 0.5% Kontrol
SH7	2% fat, 3.72% MSNF, 20% sucrose, 9% CSS, 0.5% Kontrol
SH8	3% fat, 3.72% MSNF, 20% sucrose, 9% CSS, 0.5% Kontrol

Table 11. Tests performed for the creaminess panel training.

Test #	Samples	Sensory test	% Correct responses
1	premium vanilla ice cream & ice milk	paired comparison	50
2	SH1-SH8	paired comparison	100
3	SH7-SH8	triangle	45
4	SH1-SH7	triangle	76
5	SH7-SH8	paired comparison	75
6	SH7-SH8	triangle	34.8
7	SH1-SH7-SH8	ranking	31

find the creamiest sample between the 2 and 3% fat sherbets. The sixth test was an exact repetition of test 3. For the last test SH1, SH8 and SH7 were compared. The difficulty of this test lied on the small difference of the creaminess of SH7 and SH8 and the difficulty of the ranking test itself.

Training the sweetness panel

Sweetness was defined as the taste stimulated by sucrose and other sugars, such as fructose, glucose, etc. and by other sweet substances, such as saccharin, aspartame and acesulfam K [Meilgaard *et al.* (1987b)]. The first two tests (Table 12, 13) were easy, because the difference in sugar composition between SH9-SH12 and SH9-SH15 was 5%, which is considered a big difference. Test 3 was also easy (4% difference in sugar content between SH11-SH14). Tests 4 and 5 were harder and the last two tests were the most difficult, because there was only 1% difference in sugar content between SH9, SH10 and SH9, SH13.

Table 12. Composition of the samples used for the sweetness panel training.

Sample	Composition
SH9	1.5% fat, 3.4% MSNF, 20% sucrose, 9% CSS, 0.3% Kontrol
SH10	1.5% fat, 3.4% MSNF, 21% sucrose, 9% CSS, 0.3% Kontrol
SH11	1.5% fat, 3.4% MSNF, 22% sucrose, 9% CSS, 0.3% Kontrol
SH12	1.5% fat, 3.4% MSNF, 25% sucrose, 9% CSS, 0.3% Kontrol
SH13	1.5% fat, 3.4% MSNF, 19% sucrose, 9% CSS, 0.3% Kontrol
SH14	1.5% fat, 3.4% MSNF, 18% sucrose, 9% CSS, 0.3% Kontrol
SH15	1.5% fat, 3.4% MSNF, 15% sucrose, 9% CSS, 0.3% Kontrol

Table 13. Tests performed for the sweetness panel training.

Test #	Samples	Sensory test	% Correct responses
1	SH9-SH12	duo-trio	75
2	SH9-SH15	duo-trio	100
3	SH11-SH14	duo-trio	66.7
4	SH9-SH11	duo-trio	83.3
5	SH9-SH14	duo-trio	83.3
6	SH9-SH10	duo-trio	54.4
7	SH9-SH13	duo-trio	36.4

RESULTS & DISCUSSION

TOTAL SOLIDS & FAT DETERMINATION

The desired fat and total solids content for the sherbet mixes were 1.5% and 34.2% and the actual values (Table 14) were similar, confirming that mix ingredients were added at the desired quantities and were properly prepared. The percent fat and total milk derived solids of all sherbets meet the

Table 14. Total solids and fat content of acid whey, WPC, sherbet mixes and sherbets.

Sample	Total Solids (%) *	Fat content (%)**
Acid whey	6.78±0.04%	0.03±0.01%
WPC	5.53±0.09%	0.11±0.01%
Sherbet mix A	34.29±0.05%	1.52±0.05%
Sherbet mix B	34.69±0.20%	1.57±0.04%
Sherbet mix C	34.26±0.11%	1.48±0.04%
Sherbet mix D	34.64±0.19%	1.51±0.03%
Sherbet A	34.00±0.03%	
Sherbet B	34.63±0.08%	
Sherbet C	34.45±0.18%	
Sherbet D	34.54±0.31%	

* Average of 6 replications for acid whey and WPC, 5 for sherbet mixes, 3 for sherbets.
** Average of 5 replications.

standards of identity (1%<%milkfat<2% and 2%<total milk derived solids<5%) [CFR (1990c)].

The acid whey contained 6.78% total solids and 0.03% fat (Table 14). The concentration factor of the ultrafiltration/diafiltration procedure was CF=10. The total solids and fat content of the ultrafiltered/diafiltered product were 5.53% and 0.11%, respectively. The low total solids content resulted from the removal of most of the lactose and ash during ultrafiltration/diafiltration. The rest of the solids (protein and fat) were concentrated.

TOTAL, NON-PROTEIN & PROTEIN NITROGEN

Table 15 presents the data for the protein and non-protein nitrogen obtained by the Kjeldahl protein method and the protein nitrogen, obtained by the subtraction of the non-protein from the total nitrogen. The data suggested that the total, protein and non-protein nitrogen contents increased from sherbet mix A to sherbet mix D, as the percentage of substitution of the WPC for MSNF in the sherbets increased from 0 to 75%. Therefore, the WPC added to the sherbets contained more protein than the MSNF. By using the factor 6.28 to convert the %PN to % protein, the values 1.17 and 1.66% protein were determined for sherbet A and D, respectively. The increase based on the protein content of the control sherbet A was about 42%. Besides the quantity of the protein, the quality should also be considered. The average protein efficiency ratio of whey protein is higher than that of casein and other proteins (the PER are 3.2, 2.5 and 1.8 for whey protein, casein and soy protein, respectively) [Muller (1976), Weiner (1977)]. Therefore, the addition of whey in the sherbets resulted in a product of the same or higher nutritional quality than a

Table 15. Percentage of total (TN), non-protein (NPN) and protein nitrogen (PN) of whey, WPC, sherbets and sherbet mixes.

Sample	%TN*	%NPN*	%PN
Acid whey	0.103±0.001	0.025±0.002	0.078±0.004
WPC	0.498±0.011	0.059±0.001	0.438±0.011
Sherbet mix A	0.202±0.001	0.016±0.001	0.186±0.001
Sherbet mix B	0.217±0.001	0.017±0.001	0.200±0.001
Sherbet mix C	0.235±0.001	0.020±0.001	0.215±0.002
Sherbet mix D	0.291±0.004	0.027±0.001	0.264±0.005
Sherbet A	0.196±0.006		
Sherbet B	0.200±0.009		
Sherbet C	0.215±0.009		
Sherbet D	0.312±0.018		

* average of 3 replications

regular sherbet containing no whey. The MSNF contained approximately 35% protein [Carter *et al.* (1982)], whereas the WPC used in this study contained approximately 50% protein on a dry basis (calculated based on the total solids and the protein content of the WPC found as %PN x 6.28).

pH AND TITRATABLE ACIDITY

The pH of the sherbets and the sherbet mixes (Table 16) was reduced as the substitution of WPC for MSNF in sherbets was increased, which was expected, since the WPC had a low pH. For the same reason, the titratable acidity increased from sherbet A to sherbet D. The WPC had higher pH than the acid whey, because during ultrafiltration lactic acid was removed. The pH of the mixes were found much higher than the pH of the sherbets, because before freezing, citric acid was added as part of the flavoring system. The TA for sherbet should not be less than 0.35% [Code of federal regulations (1990c)], therefore sherbet A (TA = 0.33) needed to be more acid to meet the standards of identity for the acidity of sherbets.

Table 16. pH and titratable acidity of acid whey, WPC, sherbet mixes and sherbets.

Sample	pH (at °C)*	Titratable acidity (as % lactic acid)**
Acid whey	4.14±0.01 (25°C)	
WPC	4.83±0.01 (25°C)	0.40±0.01
Sherbet mix A	6.95±0.01 (4°C)	0.05±0.01
Sherbet mix B	6.60±0.02 (4°C)	0.06±0.01
Sherbet mix C	6.18±0.01 (4°C)	0.11±0.01
Sherbet mix D	5.65±0.01 (4°C)	0.17±0.02
Sherbet A	4.68±0.01 (25°C)	0.33±0.01
Sherbet B	4.44±0.01 (25°C)	0.36±0.01
Sherbet C	4.21±0.01 (25°C)	0.38±0.01
Sherbet D	4.01±0.01 (25°C)	0.46±0.01

* Average of 4 replications
** Average of 3 replications

DETERMINATION OF THE RHEOLOGICAL PROPERTIES OF THE SHERBET MIXES

The sherbet mixes were first tested for time-dependency. The results obtained from the concentric cylinder viscometer were in the form of a diagram of the torque versus time, for time 0 through 10 min. Figure 2 shows the diagram obtained for sherbet mix C. The rest of the sherbet mixes had similar behavior as that of sherbet mix C. These data suggested that there was no time-dependency, since the torque remained the same for the period of 10 min during which the samples were subjected to constant shear rate (constant angular velocity of the concentric cylinder) over time. Therefore, a time-independent rheological model of each mix could be determined. Using angular velocity and torque data, the shear stress and shear rate were calculated based on standard methods [Steffe (1992), Whorlow(1979)]. Then the shear stress versus shear rate diagram was plotted and two time-independent rheological models were tested: the linear model ($y = a+bx$) and the power law model ($y = ax^b$). The constants for these two models, the correlation coefficient, r^2, and the standard deviation were given by the computer.

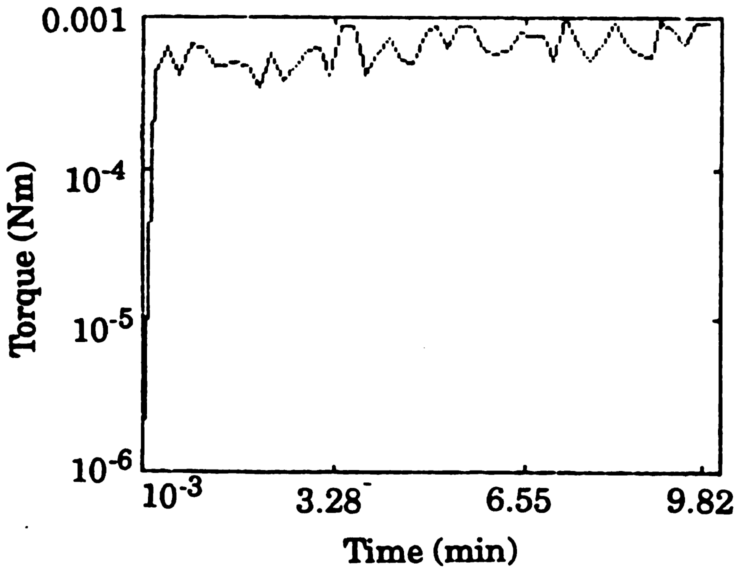

Figure 2. Torque versus time diagram for sherbet mix C.

The Herschel-Bulkley model given by equation (1) is a general rheological model. From this model the Newtonian, the Bingham plastic and the Power law models can be derived (they are simplifications of the Herschel-Bulkley model). Equations (2) and (3) and (4) describe these models.

$$\sigma = \sigma_0 + K\dot{\gamma}^n \quad (1)$$

$$\sigma = \eta\dot{\gamma} \quad (2) \qquad \sigma = \sigma_0 + \eta_{pl}\dot{\gamma} \quad (3) \qquad \sigma = K\dot{\gamma}^n \quad (4)$$

where:
σ= shear stress (N/m^2)
$\dot{\gamma}$= shear rate (1/s)
σ_0= yield stress (N/m^2)
K= consistency coefficient (Ns^n/m^2)
n= flow behavior index (dimensionless)
η= viscosity (Pa s)
η_{pl}= plastic viscosity (Pa s)

Most food preparations follow one of these models, so the analysis was limited to them. For this study only shear rates from 0-240 s^{-1} were used to simulate the mechanical conditions in mouth during mastication [Sherman (1988)]. Sherman determined the shear rate and shear stress associated with the oral evaluation of the viscosity of foods and found that more viscous foods were subjected to much lower shear rates and higher shear stresses than less viscous foods. So the mechanical conditions during mastication depend on the viscosity of the food preparation, but the shear rate usually lies below 100 s^{-1}. The comparison of the rheological behavior of the sherbet mixes to the creaminess of the final products was of interest, therefore the higher than 240 s^{-1} shear rate data were not used in this study. Such data are useful, however, for engineering calculations. From the raw data at low shear rates (Table

G.1 in Appendix G) and a standard mathematical method the constants and the r^2 for the linear and the power law model were calculated (Table 17).

Table 17. Rheological constants for the linear and the power law model at 40°F (4.44°C).

Sample (replication)	Linear model			Power law model		
	a(N/m^2)	b(Pas)	r^2	a	b	r^2
Sherbet mix A (1)	0.1997	0.0284	0.9948	0.0824	0.7817	0.9775
Sherbet mix A (2)	0.2874	0.0298	0.9995	0.0748	0.8280	0.9975
Sherbet mix A (3)	0.0993	0.0287	0.9972	0.0664	0.8215	0.9839
Sherbet mix B (1)	0.0252	0.0328	0.9994	0.0485	0.9143	0.9947
Sherbet mix B (2)	0.1968	0.0313	0.9993	0.0693	0.8438	0.9947
Sherbet mix B (3)	0.0695	0.0355	0.9988	0.0789	0.8295	0.9884
Sherbet mix C (1)	0.0486	0.0291	0.9992	0.0370	0.9520	0.9976
Sherbet mix C (2)	0.1577	0.0282	0.9996	0.0698	0.8167	0.9899
Sherbet mix C (3)	0.0757	0.0234	0.9968	0.0332	0.9321	0.9947
Sherbet mix D (1)	-0.2667	0.0247	0.9859	0.0395	0.8551	0.9239
Sherbet mix D (2)	-0.2058	0.0277	0.9948	0.0249	0.9958	0.9852
Sherbet mix D (3)	-0.0419	0.0271	0.9974	0.0373	0.9228	0.9890

Both linear and power law models were found adequate, since they both gave very good correlation coefficients ($r^2 > 0.97$) for all sherbet mixes and all replications (Table 17). The linear model ($y = a+bx$) gave slightly better r^2 and was easier to work with. Therefore, this model was used for the data analysis. Both the Newtonian and the Bingham plastic models are linear models, but for the Newtonian model there is no yield stress (σ_0). Yield stress is the stress required to initiate flow, when applied to a fluid. In this case, the constant a played the role of the yield stress, and it was a very small number for all sherbet mixes (average values: 0.195, 0.097, 0.094, -0.171 for sherbet mixes

A, B, C and D, respectively). Additionally, the negative yield stress calculated for sherbet mix D has no physical meaning. Practically *a* could be set at 0, and then equation (3) when $\sigma_0 = 0$, became equation (2) which described the Newtonian fluids, and η_{pl} became the viscosity η of the fluid. Constant *b* for the linear model in Table 17 describes the viscosity η of the sherbet mixes. This constant was statistically tested, in order to check if there was significant difference among the average viscosity of each sherbet mix. A complete randomized design and one way analysis of variance (ANOVA) was used. The ANOVA table for the viscosity of the sherbet mixes is given in Table H.1 in Appendix H [Larmond (1987), O'Mahony (1986)]. The viscosity values used for this analysis were in cP (where 1 Pa s = 1000 cP).

Significant differences among the viscosities of the sherbet mixes at $p<0.05$ were found. The least significant difference test, known as Tukey's test, was used to determine which of the means for the viscosity of the sherbet mixes were significantly different. The mean values of the viscosities for sherbet mixes A, B, C and D are given in Table 18. Larmond (1987) and O'Mahony (1986) describe the procedure followed in Tukey's test.

Table 18. Tukey's test results for the viscosities of sherbet mixes at 40°F (4.44°C).

	Sherbet mix			
	B	**A**	**C**	**D**
Average Viscosity*	33.20a**	28.97ab	26.90b	26.50b

* Average viscosity is the mean of three replications.

** Different letters next to means indicate significant difference at $p<0.05$.

At 5% level of significance the sherbet mix B was found more viscous than the sherbet mixes C and D, but no significant difference was found among the rest of the samples. The viscosity of an ice cream or generally a frozen dessert mix depends on its composition, especially the fat and the stabilizer/emulsifier content. Guy (1978) found that the viscosity of ice cream mix containing whey solids from hydrolyzed sweet whey was decreased when whey solids replaced more than 50% of the MSNF. Patel and Harper (1977) found that ice cream mixes containing acid whey concentrated to 20% total solids by RO replacing 10-15% of the MSNF had higher viscosity than the control. The data for the present study showed a decrease in the viscosity from sherbet mix A to sherbet mix C and D, but the only significant difference was that between the viscosities of sherbet B with C and D. The higher viscosity of sherbet B may be attributed to its slightly higher fat content (1.58% versus 1.52, 1.48, 1.51% of sherbet mix A, C, D respectively) or to interaction of proteins at different levels of substitution of whey solids for MSNF. The sulfhydryl group of β-lactoglobulin has been implicated in the formation of complexes with κ-casein upon heating, in model systems. β-lactoglobulin may penetrate the casein micelle, thereby inducing the formation of internal disulfide bonded complexes with κ-casein upon heating [Farrell and Douglas (1983)]. Concentration dependency of the formation of these complexes may account for the peak in the viscosity of sherbet mix B.

MELTING RESISTANCE OF SHERBETS

The melting resistance of the sherbets at 38°C (100.4°F) is shown in Figure 3 as the volume of melted sherbet versus time. The data suggested that sherbet A melted faster than the other sherbets throughout the duration of the experiment (three hours). The graphs for sherbets C and D seemed to be very similar, at least for the first 150 min of the experiment, whereas sherbet B seemed to melt a little more than sherbets C and D after two hours. The overall means of the volume of melted sherbet for all replications and all times for each sherbet were used to determine if there was significant difference in the melting resistance among the sherbets. The Tukey's test (Table 19) was then used to determine which sherbets had significantly different melting resistance. The experimental model used for the statistical analysis was a completely randomized design for factor A (different sherbets) with a split plot on factor B (time) [Petersen (1985)]. The ANOVA table for the melting resistance of the sherbets is shown in Appendix H (Table H.2).

Table 19. Tukey's test results for the melting resistance of sherbets at 38°C (100.4°C).

	Sherbet			
	A	B	D	C
Average volume*	97.946a**	85.929b	80.714b	80.643b

* Average volume is the mean of volumes of melted sherbet for all times and replications.
** Different letters next to means indicate significant difference at $p<0.05$.

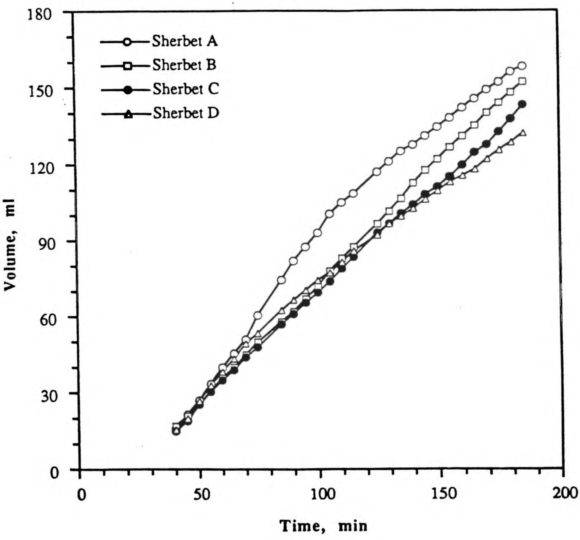

Figure 3. Melting resistance of sherbets at 38°C (100.4°F).

The results (Table H.2 in Appendix H)) indicated that the melting resistance of the sherbets differ significantly at 0.1% level of significance. The results from the Tukey's test indicated that the melting resistance of sherbet A was significantly lower than that of sherbet B, C and D at $p<0.05$. No significant differences in melting resistance among sherbets B, C and D were found. The resistance of sherbets to melting, therefore, was increased by the substitution of WPC for MSNF. The level of substitution was not so important, at least for replacement values more than 25%. The data suggested that the whey solids decreased the freezing point of the mix less than the MSNF decreased the freezing point of the control sherbet mix. So, even though all sherbets were held at the same temperature, those containing whey melted at a higher temperature. The higher level of lactose in the control would seem to explain this phenomenon. The whey particles may also act by binding the water particles, so again the melting of the sherbet could be delayed. The water holding capacity of the whey particles has also been reported in the literature by Mathur & Shahani (1979). Increase of the melting resistance due to addition of acid WPC (obtained by reverse osmosis) in an ice cream mix has also been reported in the literature by Pater and Harper (1977). Huse et al. also found that ice cream containing WPC from sweet whey had slightly better resistance to heat shock than ice cream containing no whey. Rosenberger and Nielsen (1955) have reported increased melting resistance for ice creams containing spray dried whey powder in comparison to control ice cream containing no whey.

A result of an increase of melting resistance would be the reduction of texture changes due to heat shocks that the final products might be subjected to during handling. This increase, however, should be within limits, so that the sherbet melts nicely in the mouth.

SENSORY EVALUATION OF SHERBETS

The raw data of this experiment were analyzed statistically, in order to determine if there were differences among the acceptability of the sherbets and their iciness, creaminess and sweetness characteristics. For the acceptability tests, the randomized complete block design was used and two way ANOVA was performed [Larmond (1987), O'Mahony (1986)]. The ANOVA tables for all the sensory tests are given in Appendix H.

Flavor acceptability of sherbets

Difference in the flavor acceptability of the sherbets was found at 0.1% level of significance (Table H.3 in Appendix H). Sherbet B received the highest score, but it was not different from sherbet A (control), as the Tukey's test showed (Table 20). Sherbets A and B were found more acceptable in flavor than sherbet D, whereas sherbets A-C were not different. It should be mentioned, however, that all scores were higher than 5, which in the 9-point hedonic scale means "neither like nor dislike" (Table C.1). The highest score (7.02) in the same scale means "like moderately", whereas the lowest (5.69) is between "like slightly" and "neither like nor dislike". To be rated acceptable and eventually marketed a product should receive a score of at least 7.0 on the 9-point hedonic scale [Ott (1992)]. Therefore, sherbet B seemed to be a promising product for the sherbet market.

Some of the most characteristic panelists' comments follow.

- For sherbet A: tasted great, was very creamy, needed more orange flavor, too sweet, could be fruitier, had good mouthfeel.

Table 20. Tukey's test results for the flavor acceptability of sherbets after 8 days of storage.

	Sherbet			
	B	A	C	D
Flavor score*	7.02a**	6.56ac	6.15bc	5.69b

* Flavor score is the mean of the scores received by 48 panelists.
** Different letters next to scores indicate significant difference at $p<0.05$.

- For sherbet B: had good flavor, was very creamy, tangier than sherbet A, had more orange flavor than sherbet A but still needed more, sweet, did not leave bad aftertaste.
- For sherbet C: had a weird aftertaste, tasted like cream cheese, was too creamy, good tangy flavor, good mouthfeel, flavor was a little off.
- For sherbet D: tasted like cream cheese instead of orange sherbet, was creamy, had an unusual aftertaste, the sweetness is just great, very strong tangy flavor, more refreshing, had funny flavor, was the worst of all.

All comments are presented in Appendix F. Although all sherbets received favorable and unfavorable comments for their flavor, sherbets C and D received more unfavorable comments. Panelists found that these sherbets had a unusual, funny, unpleasant flavor or aftertaste. Panelists mentioned that these sherbets tasted like Cream cheese, or orangy Cottage cheese and some others found their flavor terrible. There were, however, panelists who liked these products very much, because of their tart, fruity and not too sweet flavor. Table 21 shows the percentage of responses for the flavor of each sherbet in each category in the 9-point hedonic scale. Fifty six and twenty five hundredth percent of the panelists liked sherbet A moderately to extremely, whereas sherbets B, C and D were liked moderately to extremely by 75, 54.17 and 47.92% of the panelists, respectively. This comparison shows that even sherbets C and D were considered acceptable by half of the panelists and could potentially be marketed.

Table 21. Percentage number of responses in each category of the 9-point hedonic scale for the flavor of each sherbet.

Points in hedonic Scale	Sherbet A (% responses)	Sherbet B (%responses)	Sherbet C (%responses)	Sherbet D (%responses)
Like extremely	6.25	20.83	8.33	4.17
Like very much	25	25	22.92	20.83
Like moderately	25	29.17	22.92	22.92
Like slightly	18.75	10.42	14.58	8.33
Neither like nor dislike	14.6	0	2.08	8.33
Dislike slightly	8.3	8.33	18.75	18.75
Dislike moderately	2.1	4.17	4.17	8.33
Dislike very much	0	0	4.17	4.17
Dislike extremely	0	2.08	2.08	4.17

Texture acceptability of sherbets

Differences in the texture acceptability of the sherbets at 0.1% level of significance were found (Table H.4 in Appendix H). Table 22 summarizes the results of this test.

Table 22. Tukey's test results for the texture acceptability of sherbets after 8 days of storage.

	Sherbet			
Texture score*	**B**	**A**	**D**	**C**
	7.42a**	7.33a	6.31b	6.13b

* Texture score is the mean of the scores received by 48 panelists.
** Different letters next to means indicate significant difference at $p<0.001$.

In texture, sherbets A and B were found significantly more acceptable than sherbets C and D. The average scores for sherbets A and B were close to "like moderately", whereas the average scores for sherbets C, D were close to "like slightly". Sensory analysts consider scores such those received for sherbets A and B good enough for marketing of a new product [Ott (1992)]. From the panelists' comments and the researcher's observation, it seemed that the whey solids imparted to the sherbet a crumbly body. Sherbets C and D tore apart when scooped. Some of the most common comments obtained by the sensory panel follow. All verbatim are given in Appendix F.

- For sherbets A, B: were very smooth and creamy, had pleasant texture, were soft, spooned well, had more like ice cream texture, melted nicely in mouth.
- For sherbet C: not as smooth as it should be, hard, icy consistency, texture good for sherbet, spoon went in hard, crumbly texture, did not melt in mouth smoothly.
- For sherbet D: Not as smooth texture, icy, gritty, felt rough to the tongue and roof of mouth, hard, more frozen, broke apart, did not melt in mouth as easy as the others.

The observations concerning the crumbly body of sherbets C and D can be explained by the difference in protein composition of the MSNF and WPC. Milk solids non-fat contain approximately 27% casein and 8% lactalbumin, whereas WPC contain no casein and 13% lactalbumin. Casein gives body or substance to dairy products, such as ice creams or cheese, whereas lactalbumin is not able to contribute the same tactual properties and, in fact, after being heated in processing (for frozen desserts in pasteurization) imparts to the food preparation a short or crumbly body [Carter *et al.* (1982)]. However, at 25% level of substitution of WPC for MSNF the texture acceptance of the sherbet did not differ from control.

The harder texture of sherbets C and D observed by many panelists can be attributed to possible higher freezing point of these products. Higher freezing point results in harder products, which are not easily scooped. Good texture, however, is described differently by different people, so there were panelists in this study, who found the texture of sherbets C and D more acceptable, because it was icier, less smooth and the products did not melt very fast, whereas others liked sherbets A and B more, because they were smoother. Table 23 shows the percentage of the number of responses for each category in the 9-point hedonic scale for texture. The texture of sherbets A and B were liked moderately to extremely by 81.25 and 83.33% of the panelists, respectively, whereas the corresponding percentages for sherbets C and D were 47.91 and 54.16, respectively. The fact that about 50% of the panelists liked the flavor and the texture of sherbets C and D moderately to extremely may indicate two target markets with two different products.

Table 23. Percentage number of responses in each category of the 9-point hedonic scale for the texture of each sherbet.

Points in hedonic scale	Sherbet A (% responses)	Sherbet B (%responses)	Sherbet C (%responses)	Sherbet D (%responses)
Like extremely	20.83	10.42	6.25	8.33
Like very much	37.5	45.83	20.83	18.75
Like moderately	22.92	27.08	20.83	27.08
Like slightly	10.42	10.42	18.75	22.92
Neither like nor dislike	0	4.17	8.33	2.08
Dislike slightly	2.08	2.08	16.67	12.5
Dislike moderately	4.17	0	6.25	4.17
Dislike very much	0	0	2.08	2.08
Dislike extremely	2.08	0	0	2.08

Iciness, creaminess and sweetness comparison of sherbets

The iciness, creaminess and sweetness panels consisted of 6, 5 and 5 trained panelists, respectively. In order to obtain more data and make the tests more reliable all multiple paired comparison tests were performed in triplicate. The data were treated as if they had been obtained by 18, 15 and 15 panelists for the iciness, creaminess and sweetness test, respectively. To make sure that there were no significant sample-panelist interactions, the results were analyzed first by analysis of variance with interaction [O'Mahony (1986)]. This method checks whether the panelists are consistent with their answers on a specific pair of samples among the three replications. The analysis of variance table for the ANOVA with interaction for the iciness comparison test is given in Appendix H (Table H.5). The analysis showed that the interaction sample-panelist (axA) was not significant at 5% level of significance. This was another proof of the trained panel's ability to distinguish between differences in iciness. The regular analysis for the Scheffe test could be performed. An average value for each sherbet was calculated in this analysis. The values were relative and their sum for all sherbets must be 0. The exact procedure for the data analysis are given by Larmond (1987). The Tukey's test table is given in the following:

Table 24. Tukey's test results for the iciness of sherbets after 9 days of storage.

	Sherbet			
Iciness score*	**D**	**C**	**A**	**B**
	0.720a**	0.640a	- 0.399b	- 0.961b

* Iciness scores are reported as main effects of treatments [Larmond (1987)].
** Different letters next to means indicate significant difference at p<0.01.

Significant differences in iciness among the sherbets were found at 0.1% level of significance (Table H.6). The order effect, however, was found not significant. The panelists found sherbets D and C icier than sherbets A and B. The higher iciness of sherbets D and C was easily observed even when the samples were spooned or scooped. The fact that sherbets D and C were icier does not mean that they were bad products. In fact some panelists found the least icy samples smoother than a sherbet should be. Characteristic panelists' comments are given below. These comments are in agreement with the comments obtained by the untrained panelists who judged the sherbets for texture acceptability.

- Sherbets A, B are very fine products.
- Sherbets C, D have slightly detectable iciness, but are both fine and smooth and are very good products.

- Sherbet D is much icier than B, but it is not an icy sherbet, it is quite fine and smooth.
- Even the appearance and taste of D is icier.
- Sherbets C and D feel colder.
- I prefer the texture of C better (compared to A and B), even though it is icier.
- Sherbet B is too smooth.

The addition of WPC, therefore, in the sherbets increased their iciness. The iciness is influenced by the STEM content, the mixing conditions during freezing of the mixes and the temperature conditions during storage. In this study, the above factors were the same for all sherbets. The different composition of the WPC and MSNF might have led to this difference in iciness. The protein composition of the WPC is probably responsible for the crumbly body of the sherbets with 50 and 75% substitution of WPC for MSNF. The same factor might be a possible cause also for the difference in iciness. Sherbet B, however, was found not significantly different than the control sherbet A in iciness. So the substitution of WPC for MSNF at a 25% level did not influence the iciness of the final product.

The results for the sweetness test were also analyzed by the ANOVA with interaction and no significant interaction axA was found. The order effect was found not significant, whereas the main effect was significant at $p<0.001$ (Table H.7), so the sweetness of the sherbets was different at this level of significance. The Tukey's test (Table 25) showed that sherbet A was the sweetest, although not significantly different than sherbet B. Sherbet A was sweeter than sherbets C and D and sherbet B was sweeter than sherbet D, whereas sherbets B-C, C-D were not different in sweetness.

Table 25. Tukey's test results for the sweetness of sherbets.

	Sherbet			
Sweetness score*	**A**	**B**	**C**	**D**
	0.792a**	0.170ac	- 0.411bc	- 0.551b

* Sweetness scores are reported as main effects of treatments [Larmond (1987)].
** Different letters next to means indicate significant difference at $p<0.05$.

The difference in sweetness can be attributed to the increase of the acidity of the sherbets as the level of the replacement of MSNF by WPC increases. The tart flavor covered the sweetness of the sherbets, so that the control sherbet containing no whey was the sweetest, whereas those with the lower pH were the least sweet. Some of the panelists preferred the least sweet samples, because they found their tartness more acceptable for a sherbet product. Some panelists found the sweetness of sherbet A and B more intense than it should be. Since sweetness is an important constituent of the flavor of a frozen dessert, it should have played an important role in the flavor acceptability of the sherbets. This was shown by the large number of the untrained panelists' comments (Appendix F) related to the sweetness of the samples. Some of the trained panelists' comments follow.

- Sherbets C, D are both sour.
- Sherbet D has a sour taste, that may mask the sweetness.
- Sherbet D was a good in sweetness product.
- Sherbet A was extremely sweet.
- Sherbet D has a more orangy, fruity flavor.

The substitution of WPC from acid whey for MSNF resulted in less sweet and more tart products. The same sherbets were also found fruitier, which suggested that the acid enhanced the orange flavor.

Another flavor and texture constituent of frozen desserts is creaminess. Analysis of the raw data by ANOVA with interaction showed that there were no panelist-sample interactions. The presentation order of the samples was found not significant, whereas the sherbets were found different in creaminess ($p<0.001$) (Table H.8). The Tukey's test (Table 26) showed that sherbets A and B were creamier than sherbets C and D ($p<0.01$). The WPC addition to the sherbet mixes seems to influence the creaminess intensity of the sherbets at levels of substitution higher than 25%. The panelists' verbatim showed that sherbets A and B were creamier than the average commercial sherbet. The WPC may have covered the creamy feeling of the sherbets by making them more refreshing, due to their higher acidity, lower sweetness and higher iciness. The products with high WPC content, therefore, seemed less rich.

The comparison of the creaminess data with the rheological data (Tables 26 and 18) suggested that sherbet B was creamier and more viscous than sherbets C and D, whereas sherbet A was creamier but not more viscous

Table 26. Tukey's test results for the creaminess of sherbets.

	Sherbet			
Creaminess score*	**A**	**B**	**D**	**C**
	0.788a	0.567a	-0.554b	-0.801b

* Creaminess scores are reported as main effects of treatments [Larmond (1987)].
** Different letters next to means indicate significant difference at $p<0.01$.

than sherbets C and D. A creamier sherbet had been expected from a more viscous sherbet mix. The data, however, are not enough to support this assumption. Further research is necessary for the investigation of the relationship between creaminess and viscosity.

HEAT SHOCK STABILITY TESTS

Differences among the sherbets in flavor acceptance ($p<0.01$), texture acceptance ($p<0.001$) and iciness ($p<0.001$) were found (Table H.9, H.10 and H.11). The Tukey's test (Table 27) showed that sherbet C was more acceptable in flavor than sherbet D ($p<0.01$), but no other differences among the samples were found. All scores were higher than 5 ("neither like nor dislike") and lower than 7 ("like moderately") and no flavor deterioration was reported by the panelists. The panelists' comments for the flavor of the heat shocked sherbets were similar to those obtained in the first flavor acceptance test. The texture acceptability of the heat shocked sherbet D was lower than that of the other sherbets. The average texture acceptance scores (Table 27) indicated that, even after the heat shock treatment, sherbets A and B had acceptable texture (scores > 7). Therefore, the heat shock treatment did not measureably influence their texture. Sherbet C, however, was found not different from sherbets A and B in both flavor and texture acceptance tests. This is probably due to simultaneous changes in the flavor and texture of all sherbets.

For the iciness of the sherbets, ANOVA with interaction showed that there was no panelist-sherbet interaction. The iciness mean scores indicated that all sherbets, except sherbet B, were not different in iciness. Sherbet B was found the least icy.

Table 27. Tukey's test results for the flavor and texture acceptance and the iciness of sherbets after a heat shock treatment.

	Sherbet			
	A	B	C	D
Flavor score*	6.29ab***	6.31ab	6.71a	5.50b
Texture score*	7.15a***	7.23a	6.71a	5.56b
Iciness score**	0.028a***	-0.736b	0.167a	0.542a

* Flavor and texture scores are the means of scores received by 48 panelists.
** Iciness scores are reported as main effects of treatments [Larmond (1987)].
*** Different letters next to means indicate significant difference at $p<0.01$.

STORAGE STABILITY TESTS

The flavor and texture acceptance scores and the iciness scores for the sherbets after the storage period are given in Table 28, whereas the corresponding ANOVA tables are shown in Appendix H (Tables H.12-H.15). After 31 days of storage (Table 28) sherbet A was found more acceptable in flavor than sherbet C only ($p<0.05$), whereas all the other sherbets were found not different. The scores for all sherbets were lower than 7 and higher than 5 (between "like moderately" and "neither like nor dislike"). After 122 days of storage, sherbets A, B and C did not differ in flavor acceptability and only sherbet D was found less acceptable in flavor ($p<0.05$).

The texture scores of sherbets A and B were above 7 ("like moderately"), which indicated that the 31 days of storage did not change the degree of liking of their texture. Sherbet C, however, was found not different in texture acceptability from sherbets A and B.

Table 28. Tukey's test results for the flavor acceptance, texture acceptance and iciness of sherbets after storage.

	Sherbet			
	A	**B**	**C**	**D**
Flavor score*				
after storage for				
31 days	6.65a****	6.27ab	5.73b	5.85ab
122 days	6.85a****	7.42a	6.88a	5.88b
Texture score**				
after storage for				
31 days	7.27a****	7.31a	6.73a	5.85b
Iciness score***				
after storage for				
32 days	-0.547c****	-0.656c	0.848a	0.355b

* Flavor score is the mean of the scores received by 48 panelists.
** Texture score is the mean of the scores received by 48 panelists.
***Iciness scores are reported as main effect of treatments [Larmond (1987)]
**** Different letters next to means indicate significant difference at $p<0.05$.

For the iciness test performed after 32 days of storage no panelist-sample interaction was found. After this storage period sherbets C and D were still the iciest. The data suggested that sherbets A and B were not different in iciness, so if there was any change, it was probably of the same intensity for both samples. This was in agreement with the texture acceptance results, where sherbets A and B were not different. Sherbet C, however, was found the iciest in this test, although its texture was found to be at the same degree acceptable as that of sherbets A and B.

The texture acceptability is very closely related to the iciness of the sherbets, however it is not related only to this attribute. Some of the panelists'comments showed that other attributes, such as creaminess, hardness and resistance to melting are also very important for their decision. The influence of these other attributes may have resulted in this disagreement between the texture acceptance and the iciness results for sherbet C. The panelists' comments for the iciness of the sherbets after 9 and 32 days of storage were similar, which indicated that the iciness changes were probably small.

COMPARISONS

The average scores for all the flavor acceptance tests (after 8, 31, 122 days of storage and after the heat shock treatment) and all the texture acceptance tests (after 8, and 31 days of storage and after the heat shock treatment) are shown schematically in Figures 4 and 5.

Comparison among the data of Figure 4 shows that even after 122 days of storage at 0°F (-17.8°C) and after a heat shock treatment the flavor acceptability of the sherbets was always between "like moderately" and "neither like nor dislike". However, in all cases, sherbet D had scores lower than 6 (" like slightly").

The flavor of a sherbet depends on many factors, such as the sweetness, tartness, richness, e.t.c. Although the sherbets differed in some of these flavor constituents, their flavor acceptability was not that different. This could be attributed to the fact that different people have different perception about what good flavor is. Therefore, they scored the sherbets based on this perception. The important point from this study of the flavor acceptability of the sherbets was that no product had a noticeable spoiled flavor due to the heat shock

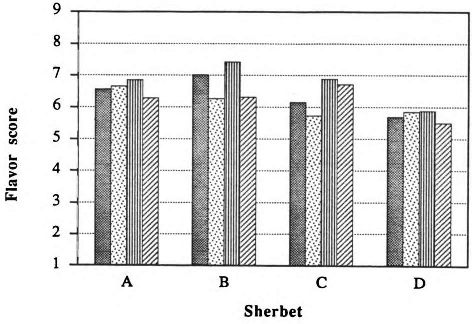

Figure 4. Flavor acceptance of sherbets after 8 (▩), 31 (⛆), 122 (▥) days of storage and after the heat shock treatment (▨). (1 = dislike extremely, 9 = like extremely on the 9-point hedonic scale).

treatment or the storage. Only one panelist found the flavor of sherbet A "not as fresh", after storage for 122 days. The "funny" or "unusual" taste or after-taste of sherbets C and D reported by many panelists was not developed during the heat shock treatment or the storage, but it was a characteristic that these sherbets also had when they were first evaluated. Apparently, these undesirable characteristics had their origin in the whey itself.

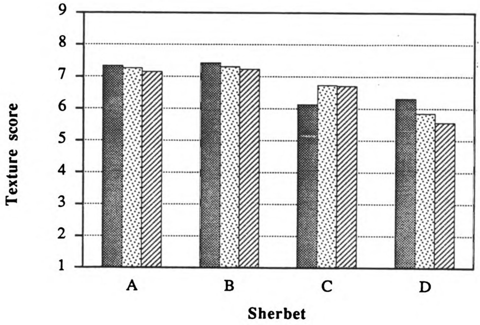

Figure 5. Texture acceptance of sherbets after 8 (▩) and 31 (⁙) days of storage and after the heat shock treatment (▨). (1 = "dislike extremely", 9 = "like extremely" on the 9-point hedonic scale).

In all cases sherbet B had slightly higher texture scores than A (Figure 5), although not significantly different. Sherbet D was always less acceptable in texture acceptability than sherbets A and B. The importance in this comparison was that sherbet C, after storage for 31 days or after the heat shock treatment had texture acceptability not different than sherbets A and B (Table 28 and 27). This could be attributed to a simultaneous change of the texture of all sherbets, which was more intense for sherbets A and B. This explanation, for the texture scores after the heat shock treatment, is in agreement with the melting resistance results, where sherbet A was found to melt significantly faster than the rest of the sherbets. So, during the heat shock treatment of the sherbets, sherbet A melted the most and, therefore, it was subjected to more intense changes in texture in comparison to the other sherbets. This probably resulted in a product at the same degree acceptable in texture as sherbet C. It should be noted, however, that the texture acceptabilities of sherbets A and B were always higher than 7 in the 9-point hedonic scale, which indicated that even after the heat shock and 31 days of storage these products were considered marketable. Some untrained panelists, however, reported that sherbet A had many ice crystals after the heat shock treatment. Therefore the verbatim from the texture tests after the heat shock treatment are presented in Appendix F, separate from the other comments.

Table 29 summarizes all the iciness results. After the heat shock sherbet A became icier, as the data suggested, (some of the trained panelists' comments were also showing that), and it was not different in iciness from sherbets C and D. Since its resistance to melting was found the lowest, it melted the most, and therefore it had the highest textural change. After the sherbet was put back again at 0°F, it probably developed larger ice crystals than those it originally had, which made it comparable to the iciest sherbets, C and D.

Table 29. Tukey's test results for the iciness of sherbets after 9 and 32 days of storage and after a heat shock treatment.

	Sherbet			
Iciness score* after	**D**	**C**	**A**	**B**
storage for 9 days	0.720a**	0.640a	-0.399b	-0.961b
storage for 32 days	0.355b**	0.848a	-0.547c	-0.656c
heat shock	0.542a**	0.166a	0.028a	-0.736b

* Iciness scores are reported as main effects of treatments [Larmond (1987)].
** Different letters next to means indicate significant difference at $p<0.05$.

FURTHER DISCUSSION ON THE PANELISTS' COMMENTS

The most common comment for the flavor of sherbets A and B was that they were very sweet, very creamy and did not have enough orange flavor. They were characterized as bland by many panelists. In contradiction, sherbets C and D were found better in sweetness, acid and orange flavor intensity, but there were many comments about an undesirable aftertaste, a Cream cheese flavor and, in some cases, a bitter taste. Most of the panelists were able to detect that there was something unusual added to sherbets C and D. The bitter flavor can be attributed to the amino acids, the peptides and the higher content of calcium salts contained in WPC [McGugan *et al.* (1979)]. A dry feeling after tasting sherbets C and D was also reported, which is probably due to the higher water holding capacity of the WPC.

The above comments show that sherbets A and B could be further improved in flavor, by adding more citric acid and probably orange sherbet base in their mixes before freezing and/or by reducing the sucrose content.

This would increase the tart and orangy flavor, which was very desirable, and decrease the sweetness intensity. Addition of citric acid would also increase the titratable acidity of sherbet A, which was lower than the standard value of 0.35% for sherbets [CFR (1990c)]. For sherbets C and D, however, the Cottage cheese whey flavor was very noticeable, and probably only the addition of more orange sherbet base (to cover the whey flavor) could make these products more acceptable in flavor. The amount of citric acid added to sherbet D could be slightly decreased, since many panelists found this sherbet too tart. A different flavoring system could also probably better cover the whey flavor of sherbets C and D and improve their flavor acceptability.

Most of the panelists found sherbets A and B too soft, and some commented on the very fast melting of sherbet A. These two sherbets would probably be very good, if served in a dish, since it was reported that they were easily spooned and scooped. Sherbets B, C and D could be also served on a cone, since they do not melt fast. It should be taken into account, however, that sherbets C and D tore apart easily, which is not an acceptable characteristic for a frozen dessert.

The panelists' comments suggested that sherbets A and B were softer than sherbets C and D. As previously discussed, the hardness of a frozen dessert is related to its freezing point. Since all sherbets were kept at the same temperature, the comments about hardness suggested that the freezing point of the sherbets increased from sherbet A to sherbet D. The freezing point is related to the soluble solids content of the mixes. The higher lactose and salt content of the MSNF probably resulted in a higher freezing point depression than the WPC, so the sherbets containing more WPC were harder.

CONCLUSIONS AND RECOMMENDATIONS

This study suggested that the substitution of direct-set Cottage cheese whey ultrafiltration retentates for 25% of the MSNF in orange sherbet resulted in a product (sherbet B) of similar flavor and texture acceptability, iciness, creaminess and sweetness to the control (sherbet A) containing no whey solids. This product received flavor and texture acceptability scores good enough for consideration of marketability. The sherbets with 50 and 75% substitution of whey solids for MSNF (sherbets C and D) were less acceptable in flavor and texture and icier in comparison to the control sherbet and the sherbet with 25% level of substitution. But they had a tart and less sweet flavor and an icier texture which were desirable characteristics for 50% of the panelists. The fact that about 50% of the panelists liked the flavor and/or texture of these products moderately to extremely indicates that there are probably two potential markets, one for sherbets A and B and one for sherbets C and D.

All sherbet mixes exhibited Newtonian fluid behavior at low shear rates. Sherbet mix B was found more viscous than sherbet mix C and D, but no other differences in viscosities were found. The use of acid whey in the formulation of the sherbets increased their melting resistance and protein nitrogen content. Increase in protein nitrogen content, and therefore protein content, would be of interest from the marketing point of view.

No flavor deterioration attributable to the heat shock treatment or the storage for 31 and 122 days was reported by the panelists and sherbets A and B received good texture scores (greater than 7 in the 9-point hedonic scale) even after the heat shock treatment or the storage for 31 days. These results indicated that sherbets A and B were quite stable products.

The potential marketing of all three sherbets containing whey, or at least of sherbets B and C should be further investigated. Changes of the composition of the sherbets, such as decrease of the amount of sweeteners in sherbets A and B or increase of the amount of citric acid added to them and decrease of the amount of citric added to sherbet D would probably result in more acceptable products with higher market potentials. The use of a different flavoring system or modification of the system used could also result in more acceptable products. The same research could be conducted by keeping the amount of acid constant in all sherbets, in order to eliminate the influence of the different sweetness and acidity on the product flavor.

Another area that needs to be further investigated is the relationship between the viscosities of the sherbet mixes and the creaminess of the final sherbet products. More data are necessary for such a relationship. Additionally, the presence of protein interactions and their influence on the viscosity of the sherbet mixes could be studied.

The freezing points of the mixes should be determined and correlated to the melting resistance and iciness results. There are equations that predict the freezing point of every mix, when its exact composition is known and could be used to make comparisons with the experimentally determined values.

Finally, the economics of the whole procedure should be investigated, taking into consideration the capital and operational costs of the ultrafiltration process itself, the cost of the membrane replacement, the cost of the milk solids non-fat in comparison to acid whey and the cheese manufacturers' savings resulting from the minimal treatment of whey before it is used in a sherbet formulation.

APPENDICES

APPENDIX A

DRY WHEY ANALYTICAL STUDY

Table A.1. Average vitamin, mineral and amino acid contents of sweet-type dry whey [ADPI (1991)].

Vitamins		Minerals		Amino Acids (grams)	
A (I.U.)	137	Calcium (mg)	774	Lysine	1.10
C (mg)	1.0	Phosphorus (mg)	1010	Isoleucine	0.74
E (mg)	0.06	Sodium (mg)	1266	Histidine	0.25
Thiamine/B_1 (mg)	0.5	Potassium (mg)	1030	Leucine	1.20
Riboflavin/B_2 (mg)	2.1	Magnesium (mg)	192	Arginine	0.32
Pyridoxine/B_6 (mg)	0.6	Zinc (mg)	1.7	Tyrosine	0.34
Cobalamin/B_{12} (mcg)	2.4	Iron (mg)	0.9	Tryptophan	0.30
Pantothenic Acid (mg)	11.6	Copper (ppm)	2.0	Phenylalanine	0.43
Biotin (mcg)	35.0	Iodine (ppm)	6.6	Aspartic Acid	1.35
Niacin (mg)	1.3	Lead (ppm)	1.3	Alanine	0.50
Folic Acid (mg)	0.01	Mercury (ppm)	0.02	Threonine	0.05
Choline (mg)	101	Selenium (ppm)	0.06	Cystine	0.20
		Cadmium (ppm)	0.11	Serine	0.66
		Arsenic (ppm)	0.65	Valine	0.73
				Glutamic Acid	2.24
				Methionine	0.23
				Proline	0.05
				Glycine	0.24

*Values per 100 grams dry whey

Table A.1. Average vitamin, mineral and amino acid contents of sweet-type dry whey [ADPI (1991)].

Vitamins	
A (I.U.)	137
C (mg)	1.0
E (mg)	0.06
Thiamine/B_1 (mg)	0.5
Riboflavin/B_2 (mg)	2.1
Pyridoxine/B_6 (mg)	0.6
Cobalamin/B_{12} (mcg)	2.4
Pantothenic Acid (mg)	11.6
Biotin (mcg)	35.0
Niacin (mg)	1.3
Folic Acid (mg)	0.01
Choline (mg)	101

Minerals	
Calcium (mg)	774
Phosphorus (mg)	1010
Sodium (mg)	1266
Potassium (mg)	1030
Magnesium (mg)	192
Zinc (mg)	1.7
Iron (mg)	0.9
Copper (ppm)	2.0
Iodine (ppm)	6.6
Lead (ppm)	1.3
Mercury (ppm)	0.02
Selenium (ppm)	0.06
Cadmium (ppm)	0.11
Arsenic (ppm)	0.65

Amino Acids (grams)	
Lysine	1.10
Isoleucine	0.74
Histidine	0.25
Leucine	1.20
Arginine	0.32
Tyrosine	0.34
Tryptophan	0.30
Phenylalanine	0.43
Aspartic Acid	1.35
Alanine	0.50
Threonine	0.85
Cystine	0.20
Serine	0.66
Valine	0.73
Glutamic Acid	2.24
Methionine	0.23
Proline	0.85
Glycine	0.24

*Values per 100 grams dry whey

Table A.2. Average vitamin, mineral and amino acid contents of acid-type dry whey [ADPI (1991)].

Vitamins		Minerals		Amino Acids (grams)	
A (I.U.)	107	Calcium (mg)	2279	Lysine	1.15
C (mg)	0.3	Phosphorus (mg)	1516	Isoleucine	0.66
E (mg)	0.05	Sodium (mg)	1022	Histidine	0.31
Thiamine/B_1 (mg)	0.5	Potassium (mg)	1885	Leucine	1.26
Riboflavin/B_2 (mg)	1.8	Magnesium (mg)	247	Arginine	0.33
Pyridoxine/B_6 (mg)	0.6	Zinc (mg)	7.7	Tyrosine	0.37
Cobalamin/B_{12} (mcg)	2.5	Iron (mg)	1.4	Tryptophan	0.29
Pantothenic Acid (mg)	11.8	Copper (ppm)	5.3	Phenylalanine	0.44
Biotin (mcg)	34.0	Iodine (ppm)	8.6	Aspartic Acid	1.23
Niacin (mg)	1.0	Lead (ppm)	1.9	Alanine	0.50
Folic Acid (mg)	0.03	Mercury (ppm)	0.03	Threonine	0.59
Choline (mg)	95	Selenium (ppm)	0.03	Cystine	0.26
		Cadmium (ppm)	0.14	Serine	0.57
		Arsenic (ppm)	0.59	Valine	0.63
				Glutamic Acid	2.22
				Methionine	0.21
				Proline	0.77
				Glycine	0.20

*Values per 100 grams dry whey

APPENDIX B

PRODUCTION AND UTILIZATION OF WHEY

Table B.1. Estimated U.S. fluid whey and whey solids production by type and resulting quantity of whey solids further processed [ADPI (1991)].

	1984	1985	1986	1987 [2]	1988[2]
			[1]		
Sweet-type Whey Production					
Cheese Production[3]	4,674	5,025	5,209	5,344	5,572
Calculated Fluid Whey[4]	42,066	45,255	46,881	48,096	50,148
Calculated Whey Solids[5]	2,734	2,940	3,047	3,126	3,259
Acid-type Whey Production					
Cottage Cheese Production[3]	603	960	970	945	938
Calculated Fluid Whey[4]	3,618	5,760	5,820	5,670	5,628
Calculated Whey Solids[5]	235	374	378	369	366
Total Whey Production (fluid basis):	45,684	51,015	52,701	53,766	55,776
Total Whey Production (solids basis):	2,969	3,316	3,425	3,495	3,625
Whey Solids Further Processed:					
A-Concentrated Whey Solids[6]	130	51	47	29	37
B-Dry Whey					
- Human Food	725	812	890	866	940
- Animal Feed	173	175	141	231	197
C-Modified Dry Whey Products					
- Reduced Lactose Whey &	60	96[8]	90[8]	107[8]	122[8]
Reduced Minerals Whey	28				
- Whey Protein Concentrate[9]	96	105	78	94	136
D-Whey Solids in Wet Blends	136	136	116	134	128
E-Whey Solids Utilized for Lactose[10]	198	197	216	242	258
Total Whey Solids Further Processed (A+B+C+D+E):	1,546	1,572	1,578	1,706	1,818
Total Whey Solids Further Processed as % of Total Whey Production (solids basis):	52.1%	47.4%	46.1%	48.8%	50.2%

1 Volume figures in million lbs.
2 Revised.
3 Agricultural Statistics Board, NASS, USDA .
4 Whey Production: approximately 9 lb/1 lb cheese produced (except Cottage).
Approximately 6 lb/1 lb Cottage cheese produced.
5 Average Total Solids content of whey: 6.5%.
6 Average Total Solids Content of Concentrated whey: 40%.
7 Data not available.
8 Reduced Lactose and Reduced Minerals Whey combined to avoid disclosure of individual plant operation.
9 Reported as Partially Delactosed/Demineralized Whey through 1981.
10 Approximately 1.6 lbs whey solids utilized/1 lb lactose produced.

Table B.2. Utilization of whey and whey products in animal feeds[1]. Comparison of 1989 and 1988 end-uses[2] [ADPI (1991)].

Market Category	1989 Sweet-Type	1989 Acid-Type	1989 Total	1989 Percent	1988[3] Sweet-Type	1988[3] Acid-Type	1988[3] Total	1988[3] Percent
Dairy/Calf/Cattle Feeds								
Concentrated Whey	58.0	-	58.0	7.6%	43.4	-	43.4	5.8%
Dried Whey	271.1	7.0	278.1	36.5%	332.7	1.0	333.7	44.3%
Dried Whey Product	34.2	-	34.2	4.5%	47.9	-	47.9	6.4%
Whey Protein Concentrate	75.4	-	75.4	9.9%	85.8	-	85.8	11.4%
Whey Solids in Whey Blends	12.1	-	12.1	1.6%	11.3	-	11.3	1.5%
Poultry Feeds								
Concentrated Whey	-	-	-	-	-	-	-	-
Dried Whey	4.1	-	4.1	0.5%	5.5	-	5.5	0.7%
Dried Whey Product	-	-	-	-	-	-	-	-
Whey Protein Concentrate	-	-	-	-	-	-	-	-
Whey Solids in Whey Blends	0.1	-	0.1	0.1%	-	-	-	-
Swine Feeds								
Concentrated Whey	7.9	-	7.9	1.0%	7.9	-	7.9	1.0%
Dried Whey	236.3	0.8	237.1	31.1%	117.4	4.9	122.3	16.2%
Dried Whey Product	1.1	-	1.1	0.1%	6.2	-	6.2	0.8%
Whey Protein Concentrate	4.3	-	4.3	0.6%	4.1	-	4.1	0.5%
Whey Solids in Whey Blends	7.9	-	7.9	1.0%	8.5	-	8.5	1.1%
Pet Foods								
Concentrated Whey	1.7	-	1.7	0.2%	3.6	-	3.6	0.5%
Dried Whey	32.8	-	32.8	4.3%	57.2	4.5	61.7	8.2%
Dried Whey Product	-	-	-	-	0.6	-	0.6	0.1%
Whey Protein Concentrate	1.4	-	1.4	0.2%	2.3	-	2.3	0.3%
Whey Solids in Whey Blends	0.8	-	0.8	0.1%	0.4	-	0.4	0.1%
Other Feeds								
Concentrated Whey	-	-	-	-	-	-	-	-
Dried Whey	1.8	-	1.8	0.2%	1.5	-	1.5	0.2%
Dried Whey Product	0.8	-	0.8	0.1%	0.3	-	0.3	0.1%
Whey Protein Concentrate	0.2	-	0.2	0.1%	0.3	-	0.3	0.1%
Whey Solids in Whey Blends	-	-	-	-	-	-	-	-
Feed Use, Undesignated	2.2	0.1	2.3	0.3%	5.7	-	5.7	0.7%
Total	754.2	7.9	762.1	100.0%	742.6	10.4	753.0	100.0%

1/ Includes both direct and indirect sales.
2/ Volume figures in millions of pounds.
3/ Revised

APPENDIX C

QUESTIONNAIRES FOR THE SENSORY EVALUATION TESTS

Two questionnaires for a flavor acceptance test are given here. The questionnaires for the texture acceptance test were similar. The first of the two questionnaires given here was presented first - third to the panelists, whereas the second was always the questionnaire given with the last sample to each panelist.

For the comparison tests, one questionnaire for iciness is given here. The questionnaires for the other attributes tested were similar. For these questionnaires, the sample code numbers were hand written, because they were different for each panelist and for each session.

Note 1: The scores corresponding to the 9-point hedonic scale divisions (for the acceptance tests) are written on the first questionnaire next to the scale.

Note 2: The scores corresponding to the 7-point Scheffe pair comparison scale (for the compari son tests) are written on the first questionnaire next to the scale.

Table C.1. Questionnaire (1) for the flavor acceptance test.

Panelist #:

Name: ______________________________ Date: ___________

Characteristic tested: Flavor acceptance

INSTRUCTIONS

- You are given a coded sample of orange sherbet. Before tasting the sample, please rinse your mouth with some water.
- Check how much you like or dislike the flavor of this sample.

Code: 511

__like extremely	(9)
__like very much	(8)
__like moderately	(7)
__like slightly	(6)
__neither like nor dislike	(5)
__dislike slightly	(4)
__dislike moderately	(3)
__dislike very much	(2)
__dislike extremely	(1)

Comments:

After finishing this portion of the panel, please show the "ready" card in your booth. Another sample will be served to you.

Table C.2. Questionnaire (2) for the flavor acceptance test.

Panelist #:

Name: ___________________________ Date:__________

Characteristic tested: Flavor acceptance

INSTRUCTIONS

- You are given a coded sample of orange sherbet. Before tasting the sample, please rinse your mouth with some water.
- Check how much you like or dislike the flavor of this sample.

Code: 511

__like extremely
__like very much
__like moderately
__like slightly
__neither like nor dislike
__dislike slightly
__dislike moderately
__dislike very much
__dislike extremely

Comments:

When you finish, show the "finished" card in your booth. Thank You very much for your time and consideration.

Table C.3. Questionnaire for the iciness comparison test.

Panelist #:

Name: ____________________________ Date: ______________

Characteristic tested: Iciness

INSTRUCTIONS

- You are given two coded samples of orange sherbet. Before tasting each sample, please rinse your mouth with some water.
- Taste the products in the following order: 575, 392.
- Examine these two samples of orange sherbet for iciness.
- Indicate the degree of difference in iciness between the two samples by checking one of the following statements.

575	is extremely icier than	392	______	(+3)
575	is much icier than	392	______	(+2)
575	is slightly icier than	392	______	(+1)
	no difference		______	(0)
392	is slightly icier than	575	______	(-1)
392	is much icier than	575	______	(-2)
392	is extremely icier than	575	______	(-3)

Comments:

APPENDIX D

HYPOTHESES FOR THE SENSORY EVALUATION TESTS

Hedonic Scale for Flavor Acceptance

Null: There is no difference in flavor acceptability among sherbets A, B, C and D.

Alternative: There is difference in flavor acceptability among sherbets A, B, C and D.

Hedonic Scale for Texture Acceptance

Null: There is no difference in texture acceptability among sherbets A, B, C and D.

Alternative: There is difference in texture acceptability among sherbets A, B, C and D.

Scheffe Paired Comparison Scale for Iciness Comparison

Null: There is no difference in iciness among sherbets A, B, C and D.

Alternative: There is difference in iciness among sherbets A, B, C and D.

Scheffe Paired Comparison Scale for Sweetness Comparison

Null: There is no difference in sweetness among sherbets A, B, C and D.

Alternative: There is difference in sweetness among sherbets A, B, C and D.

Scheffe Paired Comparison Scale for Creaminess Comparison

Null: There is no difference in creaminess among sherbets A, B, C and D.

Alternative: There is difference in creaminess among sherbets A, B, C and D.

APPENDIX E

WORKSHEETS FOR THE SENSORY EVALUATION TESTS

Table E.1. Flavor acceptance test worksheet.

Type of test:	Hedonic Scale
Sample Identification	**Sample Code number**
Sherbet A (control)	511
Sherbet B (25% replac.)	637
Sherbet C (50% replac.)	126
Sherbet D (75% replac.)	918

Panelist number	**Order of Presentation**			
1, 25	A B C D - 511	637	126	918
2, 26	A B D C - 511	637	918	126
3, 27	A C B D - 511	126	637	918
4, 28	A C D B - 511	126	918	637
5, 29	A D B C - 511	918	637	126
6, 30	A D C B - 511	918	126	637
7, 31	B A C D - 637	511	126	918
8, 32	B A D C - 637	511	918	126
9, 33	B C A D - 637	126	511	918
10, 34	B C D A - 637	126	918	511
11, 35	B D A C - 637	918	511	126
12, 36	B D C A - 637	918	126	511
13, 37	C A B D - 126	511	637	918
14, 38	C A D B - 126	511	918	637
15, 39	C B A D - 126	637	511	918
16, 40	C B D A - 126	637	918	511
17, 41	C D A B - 126	918	511	637
18, 42	C D B A - 126	918	637	511
19, 43	D A B C - 918	511	637	126
20, 44	D A C B - 918	511	126	637
21, 45	D B A C - 918	637	511	126
22, 46	D B C A - 918	637	126	511
23, 47	D C A B - 918	126	511	637
24, 48	D C B A - 918	126	637	511

Table E.2. Texture acceptance test worksheet.

Type of test:	Hedonic Scale
Sample Identification	**Sample Code number**
Sherbet A (control)	224
Sherbet B (25% replac.)	718
Sherbet C (50% replac.)	478
Sherbet D (75% replac.)	975

Panelist number	**Order of Presentation**			
1, 25	A B C D - 224	718	478	975
2, 26	A B D C - 224	718	975	478
3, 27	A C B D - 224	478	718	975
4, 28	A C D B - 224	478	975	718
5, 29	A D B C - 224	975	718	478
6, 30	A D C B - 224	975	478	718
7, 31	B A C D - 718	224	478	975
8, 32	B A D C - 718	224	975	478
9, 33	B C A D - 718	478	224	975
10, 34	B C D A - 718	478	975	224
11, 35	B D A C - 718	975	224	478
12, 36	B D C A - 718	975	478	224
13, 37	C A B D - 478	224	718	975
14, 38	C A D B - 478	224	975	718
15, 39	C B A D - 478	718	224	975
16, 40	C B D A - 478	718	975	224
17, 41	C D A B - 478	975	224	718
18, 42	C D B A - 478	975	718	224
19, 43	D A B C - 975	224	718	478
20, 44	D A C B - 975	224	478	718
21, 45	D B A C - 975	718	224	478
22, 46	D B C A - 975	718	478	224
23, 47	D C A B - 975	478	224	718
24, 48	D C B A - 918	126	637	224

- **Prepare questionnaires and write the panelist numbers on them. Put questionnaires in right order (4 for each panelist).**
- **Prepare samples.**
- **Serve panelists. Make sure they taste all samples, in the right order.**
- **Collect questionnaires, measure and record responses.**
- **Analyze data using 2-way ANOVA. Use Tukey's test to find which samples are significantly different.**

Note: The steps followed for all acceptance tests were the same, only the sample code numbers were different.

Table E.3. Iciness comparison test worksheet (test performed after 9 days of storage).

Type of test: Scheffe Pair Comparison Test

Sample Identification	**Sample Code number**		
	Session 1	*Session 2*	*Session 3*
Sherbet A (control)	575, 123, 377	284, 511, 212	439, 898, 779
Sherbet B (25% replac.)	392, 891, 789	686, 583, 983	167, 154, 849
Sherbet C (50% replac.)	968, 455, 254	194, 748, 834	448, 221, 633
Sherbet D (75% replac.)	289, 345, 458	414, 719, 855	435, 659, 324

Panelist number	**Order of Presentation (*session 1*)**					
1	D-A	C-B	B-D	D-C	A-C	B-A
2	A-B	D-B	A-D	C-A	C-D	B-C
3	B-D	B-A	A-C	C-B	A-D	D-C
4	C-D	D-B	B-C	C-A	D-A	A-B
5	C-B	A-D	A-C	D-C	B-D	A-B
6	C-A	B-C	D-A	B-A	C-D	D-B

Panelist number	**Order of Presentation (*session 2*)**					
1	A-C	C-B	B-A	D-C	B-D	A-D
2	C-A	D-A	D-B	B-C	C-D	A-B
3	D-B	C-D	C-A	C-B	B-A	A-D
4	B-D	D-A	B-C	D-C	A-B	A-C
5	A-D	B-D	C-D	C-B	B-A	C-A
6	D-C	A-B	D-A	B-C	D-B	A-C

Panelist number	**Order of Presentation (*session 3*)**					
1	B-A	C-A	B-D	A-D	D-C	C-B
2	D-A	B-C	A-C	D-B	C-D	A-B
3	C-A	B-A	C-B	B-D	A-D	C-D
4	A-B	D-C	D-B	B-C	D-A	A-C
5	D-A	D-B	D-C	A-C	A-B	B-C
6	C-A	A-D	B-D	B-A	C-D	C-B

- Prepare questionnaire, write sample codes in appropriate order and panelist number on them.
- Put the 6 questionnaires that every panelist will take in each session in right order and staple them together.
- Prepare samples.
- Serve panelists.
- Collect questionnaires, record responses.
- Analyze data using ANOVA with and without interaction [O'Mahony (1976), Larmond (1977)].

Note 1: Three code numbers are required for each sample in each session, because all panelists taste all 6 possible pair, of sherbets, in which the same sample are presented 3 times to each panelist. So, each time the same sample is presented to a panelist, no matter if it is in the same session, or in different sessions, it should have a different code number. This way the panelist will not be biased.

Note 2: All comparison tests were performed the same way, so here only the sample code numbers and the presentation order will be given for the rest of the comparison tests.

Table E.4. Sweetness comparison test worksheet (test performed after 10 days of storage).

Type of test:	Scheffe Pair Comparison Test		
Sample Identification	**Sample Code number**		
	Session 1	*Session 2*	*Session 3*
Sherbet A (control)	693, 767, 688	233, 142, 857	253, 824, 128
Sherbet B (25% replac.)	355, 883, 761	875, 722, 156	442, 993, 615
Sherbet C (50% replac.)	865, 549, 256	117, 733, 513	599, 389, 853
Sherbet D (75% replac.)	542, 824, 484	937, 247, 197	121, 866, 793

Panelist number	**Order of Presentation (*session 1*)**					
1	A-B	C-B	B-D	C-A	A-D	D-C
2	B-C	B-A	D-B	D-A	A-C	C-D
3	D-B	D-A	C-A	D-C	C-B	B-A
4	A-C	B-D	D-C	B-C	A-D	A-B
5	C-B	B-D	B-A	A-D	C-A	D-C

Panelist number	**Order of Presentation (*session 2*)**					
1	D-A	D-B	B-C	A-C	C-D	A-B
2	A-C	A-B	D-C	B-D	A-D	C-B
3	B-A	D-B	D-A	C-A	C-D	B-C
4	B-A	D-A	C-B	D-B	C-A	C-D
5	A-D	A-B	D-C	B-C	B-D	A-C

Panelist number	**Order of Presentation (*session 3*)**					
1	D-C	A-B	B-C	A-C	A-D	D-B
2	D-A	C-B	B-A	C-D	B-D	C-A
3	B-D	A-C	D-C	C-B	D-A	A-B
4	C-D	D-A	B-C	B-A	C-A	D-B
5	B-A	C-A	C-D	C-B	A-D	B-D

Table E.5. Creaminess comparison test worksheet (test performed after 11 days of storage).

Type of test:	Scheffe Pair Comparison Test		
Sample Identification	**Sample Code number**		
	Session 1	*Session 2*	*Session 3*
Sherbet A (control)	651, 173, 851	989, 738, 411	824, 978, 127
Sherbet B (25% replac.)	144, 377, 856	629, 365, 487	336, 164, 263
Sherbet C (50% replac.)	831, 981, 638	268, 292, 585	763, 776, 299
Sherbet D (75% replac.)	927, 838, 734	531, 972, 437	722, 924, 471

Panelist number	**Order of Presentation (*session 1*)**					
1	B-C	C-D	D-A	A-C	B-D	B-A
2	C-B	D-B	D-C	C-A	A-B	A-D
3	D-C	C-A	A-B	C-B	D-B	A-D
4	A-C	B-A	D-A	B-D	B-C	C-D
5	C-B	C-A	D-C	D-B	D-A	B-A

Panelist number	**Order of Presentation (*session 2*)**					
1	B-D	C-D	A-D	A-C	B-C	A-B
2	C-A	D-C	B-D	D-A	B-C	B-A
3	A-B	D-B	A-D	A-C	C-B	C-D
4	D-C	B-D	B-C	B-A	D-A	C-A
5	D-B	A-C	A-D	C-D	C-B	A-B

Panelist number	**Order of Presentation (*session 3*)**					
1	B-A	A-C	D-B	B-C	D-A	D-C
2	C-A	C-D	A-D	A-B	C-B	B-D
3	C-D	C-A	D-B	B-C	D-A	A-B
4	A-D	B-D	C-B	A-C	B-A	D-C
5	D-C	A-B	C-B	D-A	B-D	C-A

Table E.6. Iciness comparison test worksheet (test performed after a heat shock treatment).

Type of test:	Scheffe Pair Comparison Test		
Sample Identification	**Sample Code number**		
	Session 1	*Session 2*	*Session 3*
Sherbet A (control)	313, 572, 890	141, 227, 695	885, 714, 519
Sherbet B (25% replac.)	691, 418, 225	775, 137, 632	869, 323, 448
Sherbet C (50% replac.)	979, 622, 544	719, 148, 242	912, 827, 213
Sherbet D (75% replac.)	375, 785, 449	981, 263, 699	240, 834, 578

Panelist number	**Order of Presentation (*session 1*)**					
1	D-A	B-C	A-C	D-C	D-B	A-B
2	A-D	C-D	B-D	B-A	C-A	C-B
3	B-C	B-A	D-B	D-A	A-C	C-D
4	A-B	B-D	A-D	D-C	C-A	C-B
5	A-D	C-A	C-B	C-D	A-B	B-D
6	D-A	B-A	D-C	A-C	B-C	D-B

Panelist number	**Order of Presentation (*session 2*)**					
1	C-A	B-C	D-A	B-D	D-C	B-A
2	C-B	A-C	A-D	C-D	A-B	D-B
3	D-B	A-C	B-A	D-A	C-B	D-C
4	C-A	B-C	B-D	C-D	A-B	A-D
5	C-B	A-D	B-A	D-B	D-C	A-C
6	D-A	B-C	C-A	C-D	A-B	B-D

Panelist number	**Order of Presentation (*session 3*)**					
1	A-D	A-B	D-B	C-D	A-C	C-B
2	B-C	B-D	D-C	C-A	B-A	D-A
3	B-C	C-A	D-C	A-B	B-D	D-A
4	A-C	B-A	C-B	C-D	A-D	D-B
5	D-C	D-B	A-C	A-D	A-B	B-C
6	D-A	C-D	C-B	C-A	B-D	B-A

Table E.7. Iciness comparison test worksheet (test performed after 32 days of storage).

Type of test:	Scheffe Pair Comparison Test		
Sample Identification	**Sample Code number**		
	Session 1	*Session 2*	*Session 3*
Sherbet A (control)	392, 968, 289	214, 884, 705	696, 811, 115
Sherbet B (25% replac.)	575, 121, 470	129, 258, 607	180, 316, 926
Sherbet C (50% replac.)	837, 716, 931	356, 101, 448	621, 504, 730
Sherbet D (75% replac.)	309, 662, 583	167, 127, 566	113, 239, 521

Panelist number	**Order of Presentation (*session 1*)**					
1	B-C	A-D	C-D	A-C	D-B	B-A
2	D-C	A-B	D-A	C-A	B-D	C-B
3	A-C	D-B	C-B	D-A	D-C	B-A
4	B-D	C-A	B-C	C-D	A-D	A-B
5	C-B	D-C	A-B	B-D	C-A	D-A
6*	C-D	A-D	D-B	B-A	A-C	B-C

Panelist number	**Order of Presentation (*session 2*)**					
1	A-B	C-B	A-C	C-D	D-A	B-D
2	D-C	B-A	D-B	B-C	C-A	A-D
3	B-A	D-A	B-C	A-C	D-B	C-D
4	A-B	C-B	A-D	D-C	C-A	B-D
5	C-D	D-B	B-C	B-A	C-A	D-A
6	D-C	B-D	A-D	A-B	A-C	C-B

Panelist number	**Order of Presentation (*session 3*)**					
1	B-D	C-B	A-B	C-D	A-D	C-A
2	B-C	D-C	B-A	D-B	D-A	A-C
3	A-D	C-B	C-A	D-B	A-B	C-D
4	B-D	D-A	B-A	A-C	B-C	D-C
5	C-D	B-C	D-B	A-C	A-B	A-D
6	D-A	C-A	D-C	B-D	C-B	B-A

* The sixth panelist did not have the test, so the last row in each session was not used.

APPENDIX F

VERBATIM FROM THE SENSORY EVALUATION TESTS

•Verbatim for the flavor of sherbet A (control)

- The flavor of the sample was not overpowering.
- Very good. Tastes great.
- Tastes fruity, but not very "orangy".
- It does not seem to have the strong orange sherbet flavor.
- Seems creamier.
- Not very tangy.
- This is much too sweet. Not enough orange flavor.
- More milky/chalky quality.
- Mouthfeel is good, but it tastes too sweet.
- A strong orange flavor and a good aftertaste. I place it at the top of the list.
- It needs a little more sweetness.
- Flour like sensation in mouth. Little flavor.
- Creamier than a sherbet should be.
- Too sweet, nice odor.
- Tastes rather bland. I might like a stronger flavor.
- It was not as tangy as most orange sherbets I have tasted. Tasted almost like ice cream.
- I liked it, because it had no strong aftertaste.
- I normally don't like orange sherbet, but this one does not have too strong of an orange taste, it does not taste like baby aspirin.
- Tasted like a candy.
- Fruity, but seems to have a slight aftertaste.
- Did not taste very orangy. It tasted more than eating cream than orange.
- It does not taste like orange sherbet to me.
- A little dull, but tasted very good.
- Not real orange taste.
- Could be more fruity.

- Had good taste. Noticed a slight sweet aftertaste, like that from a sugar substitute.
- Did not taste like orange, tasted like artificial flavor.
- Not as fresh tasting (comment after storage for 122 days).
- Slightly heavy taste.
- Very tasty. Like a creamsicle.
- Excellent flavor.
- Sweet with a lot of orange taste.
- Does not taste like sherbet, too smooth.
- Just the right creaminess, but needs a touch more orange.
- Taste was average, but it left a coated type feeling in my mouth.
- Most natural, good lingering fruit flavor.
- Great taste, somewhat chewable.

• Verbatim for the texture of sherbet A (control)

- The sample was quite smooth.
- Very creamy and smooth.
- Flat texture.
- Creamy, pleasant texture.
- Not as hard as sherbet C.
- Good texture.
- Smoother than usual sherbets.
- The texture was excellent. There was no ice in it. It was very creamy.
- Creamy, almost chewy.
- Too creamy for a sherbet.
- Spoons well.
- Soft texture.
- There was hardly any texture, it melted too quickly in my mouth. A cone would be gone too fast!
- Felt natural.
- Too soft for sherbet.
- It is just right. It does not melt too easily.
- It is a bit dry tasting, almost like it was in the freezer for a while.
- Too smooth. I like it with an icier or less smooth texture.

Comments after the heat shock treatment

- It was totally creamy and smooth.
- Texture very smooth. Not much effort for dissolving or swallowing.
- Smooth, but could be improved.
- More watery, icy.
- More like ice cream than sherbet.
- Nice mouthfeel, did not melt too quickly.
- Many ice crystals. I would prefer it a bit more harder.

• Verbatim for the flavor of sherbet B

- This sample had a very light orange flavor, almost creamy flavor, it was very good.
- It had a very sweet taste, while melting in my mouth.
- Some aftertaste, but not very strong.
- Good flavor, not too acidic.
- It has the right amount of sherbet flavor, yet not too strong.
- Not very tangy.
- Nice orange flavor. Slightly too sweet, but good.
- Strange flavor.
- Has more milky/chalky flavor. The orange flavor seems enhanced.
- Strong milky taste.
- Tastes good, but it almost has too much creamy taste. It tastes too watery.
- Good mouthfeel. Great tangy creamy taste!
- It tastes like real oranges.
- I would prefer it with more orange flavor.
- It would have been extremely good if the taste of orange was more dominant.
- Chalky aftertaste.
- Gummy flavor.
- Too sweet.
- A little creamy aftertaste.
- More orange flavor than sherbet A.
- Tangier than sherbet A.
- Tastes like sherbet, not ice cream. Creamy.
- Not enough orange flavor or sugar. It also left an unpleasant aftertaste.
- It has a sort of a bland taste.
- Very creamy in mouth, tastes good.
- It is not too creamy. It has the right amount of sweetness.
- Left an aftertaste in mouth.
- It was rather watery.
- Very creamy, aftertaste, does not taste as naturally flavored.
- Fruity and creamy.
- Mild flavor.
- It was creamy and tasted like a creamsicle.
- I liked it, however an orange sherbet should have stronger flavor.
- The initial taste was great, but it seemed after it dissolved that there was an aftertaste like medicine. It took away the initial pleasure.
- Very nice and light flavor.
- Not a bad aftertaste and tasted very well.
- Sort of dull.
- It tastes more sherbet, did not leave any aftertaste, but contained a lot of sugar.

- Basically tasted like regular, but good orange sherbet.
- Good strong flavor, no aftertaste.
- Flavor did not have a long lasting power.
- Tasted a little like cream cheese.
- Very creamy. Much too sweet. More sugary than orangey.
- Good, a lot of orange taste.
- Pleasant aftertaste.
- Flavor seemed to last.
- Creamy, good mouthfeel, good flavor.
- It tastes as if cheese was added to it.
- I don't know why I like it so much, but it just tastes like the sherbet you get at the restaurant.
- Slight off flavor. Very bland in orange flavor.
- It tastes little funny.
- I liked the very faint, but noticeable taste.
- Hardly any taste at all.
- It was not too sweet, did not leave any bad aftertaste. Made me want more.

• Verbatim for the texture of sherbet B

- Smooth. Almost silky.
- I like the creamy texture, as opposed to a more icy texture that sherbet usually has.
- Ice crystals present.
- Good texture.
- It is soft and melts in the mouth. I enjoyed it a lot.
- Gummy texture.
- I like the consistency of this sample.
- More like ice cream texture.
- Very similar to sherbet A.
- Not too rough, not too smooth, just perfect.
- It is too creamy and rich for sherbet.
- Spoons well.
- Soft and smooth texture.
- Seemed to be smooth, but broke down in small chunks.
- Firm texture.
- Seems a little gluey.
- Seems too soft for sherbet.
- It is too smooth, I like it with a harsher texture.

Comments after the heat shock treatment

- Texture is somewhat rough.
- Smooth, but a little hard.
- Too crunchy.
- A slight resistance to melt. Firm texture on tongue.
- This sample was excellent. Not too soft not too hard.
- Almost too soft.
- Needs to be a little stiffer.
- Not enough body.
- It seems smoother, less crystalline than usual sherbets.
- Somewhat gummy.
- Iciness and hardness O.K.

- **Verbatim for the flavor of sherbet C**

- Although I liked it, the flavor was quite strong.
- Didn't taste very orangy. Tasted like cream cheese.
- Buttery taste. Left an aftertaste.
- Flavor is appropriately strong.
- Flavor is off.
- Good, but not so much orange flavor.
- Very good flavor.
- Not very tangy.
- This has a slightly sweet aftertaste. Good flavor.
- Too sweet for me. Good strong orange flavor, though.
- There is a strange feeling after I ate the sherbet.
- Weird aftertaste. Not much orange flavor.
- It is not sweet enough, it has too much cream or milk, it tastes filmy.
- Good mouthfeel, less creamy, but very good tangy taste. Does not taste too sweet, which is the way I like sherbet. This one was my favorite.
- Too creamy.
- Chalky aftertaste and too strong of a flavor and texture.
- Creamy aftertaste, strong.
- Tastes slightly sour. Sweetness O.K.
- Has profound creamy flavor, outpowers the orange flavor.
- Needs stronger flavor.
- Tangier than sherbet A.
- It has a pretty good flavor, it is not bitter, but it has too strong of an orange flavor.
- Tasted terrible!
- Not very flavorful.
- There is no distinct flavor.
- Flavor was a little off.
- Fruity and sweet.
- Weird aftertaste.
- I liked it, but it was sweet.
- Very good flavor. I would eat this anytime it was offered.
- Vanilla taste to it, did not enjoy the aftertaste.
- Too creamy and has a dry aftertaste.
- Orange flavoring not right.
- Had a nice creamy orange flavor to it.
- This has a very strong orange flavor. It is not very sweet and this is good, because there is more flavor and less sweetness.
- Very creamy for sherbet, which I liked.
- Nice, rich flavor.
- Very tangy flavor, it has a good mouthfeel.

- Tasted a lot like orange flavored cream cheese.
- Extremely good.
- Has cream cheese flavor. Lacks orange.
- Not too sweet and not too creamy.
- Seems watery and light. Like popsicle.
- More refreshing tangy taste.
- Very odd off flavor, when first put in mouth. Also, lacks orange flavor.
- Strong taste at first, but then no taste.
- Stronger taste of something other than orange.
- Good orange flavor.
- Too sweet. Left a weird taste in my mouth.
- Less fruity than D.
- Almost a bitter aftertaste.

• Verbatim for the texture of sherbet C

- Good texture.
- Much more icy, therefore crunchy.
- Not as smooth as it should be.
- Although it was a little too soft, it did not melt in the mouth. Liked it, but not very much.
- Hard.
- Texture not as nice as for sherbet A.
- Tasted like frozen orange yogurt.
- It holds together in the mouth, which gives you a rich and smooth feeling.
- Harder than sherbet B.
- A little bit grainy.
- Icy consistency.
- It was not soft enough, it was too hard.

* • Slightly icy.
- Icy, grainy.
- A little harder than sherbet A.
- Texture good for sherbet.
- A little bit coarse texture.
- Too hard, not smooth.
- Crystals were a bit too large.
- Very creamy (more so than most sherbets).
- Spoon went in hard.
- Does not melt in mouth like sherbet does.
- I would have liked a slightly firmer texture.
- Harder than sherbets A and B.
- A little too crystal like or icy.
- Very clumpy.
- Too thick.
- Kind of chalky.
- Crispy.
- Chunky. Did not melt smoothly.
- Leaves a sort of dry feeling.

Comments after the heat shock treatment

- Smooth texture. Not icy.
- The texture was just right. Easy to swallow.
- Nice and smooth.
- Smooth texture.
- A little bit rough and harder than sherbet B.

- This is the best texture. It is icy, yet creamy enough like normal sherbet.
- Semi grainy.
- Grainy aftertaste.
- Very smooth.
- Clean icy melting in mouth.
- Crumbly texture. Not a smooth meltdown.
- Too watery or slippery.
- Could melt in my mouth a little more.
- Slightly gritty.
- A little clumpy.
- Creamy, but not fatty texture.
- Very hard, crumbling.

• Verbatim for the flavor of sherbet D

- I think the sample's flavor is lacking something.
- Tasted like cream cheese, instead of orange sherbet.
- Strong buttery taste. Does not taste like sherbet.
- Sample had an unusual aftertaste.
- First taste (initial impression) was highly favorable. But an aftertaste lingers which is not good. The smell of the sample was inferior.
- Not enough orange flavor comes through.
- It has more of a sour cream undertone.
- It seemed to have a funny taste to it. Not bad, but funny. Less sweet.
- Good orange flavor. Could be sweeter.
- The first taste is bitter. then you taste nothing.
- I am not sure why I dislike it. Strange flavor.
- Tasted good and not as tart as some I've had before.
- It has an aftertaste like cream cheese.
- Mouthfeel is good. Taste is tangy (good taste!).
- Taste is very good, strong orange flavor. Aftertaste is milky, chalky. It is not too sweet, and this is good.
- Tastes too sour.
- Too creamy.
- Not too sweet. It has a kind of cream cheese taste.
- The worst of all.
- More vanilla taste.
- It had a lemon like flavor, that I did not enjoy.
- Good flavor.
- Tastes a little too creamy.
- Left a chalky aftertaste, and after melting it seemed like a residual was left behind.
- Orange flavor not very intense.
- The sweetness is just great. Tastes slightly sour (great!!). Odor is just enough.
- It really almost tastes like cheese cake. It tastes rich and creamy.
- Rich flavor.
- Tasted good, sweet, tangy mouthfeel.
- A little too bland. It did not taste much like orange.
- It has a bitter taste to it, it tastes like baby aspirin.
- Terrible.
- Has a slight cream cheese taste to it.
- Tastes like sour milk.
- Has a distinct orange flavor, but not strong enough.
- Nice feel on mouth.
- Strange flavor.
- Of all samples, I disliked this one the most. Although it was fruity as sherbet

should be, it had a different flavor to it, that I disliked.

- Bad aftertaste, funny flavor.
- It tasted orange, but is probably not something I would eat regularly. There was not much lingering flavor after it was gone.
- I liked the product a lot, but the aftertaste was different than the product.
- I enjoyed the sweetness of the sample along with the orange flavor.
- Good stuff.
- Too heavy. The consistency is like frozen yogurt.
- Not as creamy.
- Did not taste like orange. Had a bad first impression.
- Taste is good, except a little bit sour.
- I really liked the flavor, it tasted like oranges, but it was not too potent.
- the orange flavor did not taste right, but I can't pick out what it was.
- Chalky taste to it.
- It left a distinct aftertaste in my mouth.
- Had a sort of creamy flavor to it, not really distinct.
- Tasted sour, a lot like cream cheese.
- The first taste was a slightly cream cheese flavor. This does not have much of a lingering aftertaste (which is good).
- At first it does not quite taste completely like orange, but then it does.
- Tasted like custard, not orange sherbet.
- Too milky.
- Tastes more like ice cream.
- A little bit tasteless. I would like more flavor.
- More refreshing, tangy, sherbet taste.
- It tasted the best of all.
- Very strong off flavor. Tastes like orangey cottage cheese.
- It has an off tangy flavor.
- Pretty much perfect.
- Has a harsher flavor. Seems more acidic.
- Needs more orange flavor.
- It did not really taste the way sherbets usually taste.
- Too sweet. As soon as I put it in my mouth I did not like the taste. It was unpleasant.
- Very strong, almost spoiled aftertaste.
- Very sweet, cool and fruity.

• Verbatim for the texture of sherbet D

- Some ice crystals.
- Texture is too smooth, nothing to chew.
- A little less icy would be better.
- Not as smooth.
- Not as soft as the sherbet A, but still good.
- Very smooth.
- Not nice texture.
- Tastes buttery.
- It tears apart in dish.
- Good texture.
- A little gritty.
- King of gummy.
- Very gritty.
- Funny, awkward texture.
- A little hard.
- More body than most sherbets.
- Odd texture.
- Seemed to feel rough to the tongue and roof of mouth.
- It would be especially good for use on a cone. It is firm enough.
- More crystally texture. Very similar to sherbet C.
- Chalky feel, coats mouth with chalk.
- Sort of a gritty or icy tasting at first, but then after it has been in mouth for a few seconds, it has a nice texture.
- Too many ice crystals, not smooth enough.
- Melts away too fast, does not last in your mouth.
- Dissolve way too fast. Clump.
- Harder than the others.
- I prefer the texture of this sample. It was more icy.
- Harsh, more frozen.
- It broke apart and was very icy and rough to my tongue.
- Nice and creamy, but it leaves a sticky, gross aftertaste.
- Very nice texture, although a little too slippery.
- Crunchy.
- Was not bad, but it had lumps. It didn't seem to melt in your mouth as easy as the others.
- It has got a nice icy texture to it. Because it is not extremely smooth.
- After I swallowed it, it left a sort of weird dry sensation in my mouth.

Comments after the heat shock treatment

- It seems to be dry and crumbly. Slightly grainy.
- Seemed icy, not very smooth.
- This sample was much too rough.
- Very gritty and hard.
- Did not hold together.
- Clean, not grainy, more resistant to melting or firmer consistency than sherbet C.
- Texture very good at first, but seemed floury afterwards.
- Starts very icy, but then melts smoothly in your mouth.
- Slight fine light texture.
- Did not melt quite as easily as I expect sherbet to melt.
- Too hard on top, watery, coats tongue.
- I would prefer it less icy.

APPENDIX G

RHEOLOGICAL RAW DATA (SHEAR STRESS / SHEAR RATE) FOR THE SHERBET MIXES

Table G.1. Shear rate and shear stress data for sherbet mixes at 40°F (4.44°C).

Replication number	Sherbet A		Sherbet B		Sherbet C		Sherbet D	
	$\dot{\gamma}$	σ	$\dot{\gamma}$	σ	$\dot{\gamma}$	σ	$\dot{\gamma}$	σ
1	7.694	0.4711	9.612	0.4711	13.33	0.4711	10.12	0.4711
	13.88	0.6779	14.36	0.5144	16.73	0.4957	19.50	0.5191
	25.50	1.174	23.36	0.8187	23.04	0.7302	42.86	0.6317
	40.18	0.9883	35.18	1.129	35.07	1.198	58.36	0.6655
	58.03	1.571	58.22	1.782	58.90	1.619	91.50	1.644
	81.08	2.517	81.52	2.699	81.52	2.346	138.5	3.047
	116.9	3.716	117.0	3.822	116.7	3.479	185.7	4.434
	165.2	5.021	163.7	5.393	164.2	4.904	233.4	5.718
	211.9	6.087	209.9	6.966	211.7	6.171		
2	7.859	0.4711	7.829	0.4711	7.874	0.4711	14.67	0.4711
	14.06	0.6002	14.17	0.5731	19.00	0.6332	23.79	0.5224
	23.26	0.9846	23.26	0.9642	35.11	1.192	35.21	0.8243
	47.10	1.755	35.49	1.409	58.91	1.802	58.23	1.090
	70.60	2.431	58.88	1.871	82.15	2.402	80.80	1.857
	117.4	3.906	81.53	2.718	117.1	3.472	115.8	2.841
	164.8	5.224	117.1	3.986	164.0	4.748	162.9	4.503
	235.2	7.205	164.6	5.365	210.4	6.161	211.9	5.706
			235.7	7.550				
3	8.202	0.4711	8.051	0.5521	16.24	0.4711	12.42	0.4711
	14.11	0.5674	23.99	1.026	35.67	0.962	23.51	0.6077
	24.35	0.9573	35.60	1.304	58.45	1.215	35.22	0.9803
	36.63	0.938	58.61	1.976	81.09	2.020	58.46	1.274
	58.23	1.579	81.60	2.792	117.0	2.932	81.04	2.044
	81.22	2.279	116.6	4.178	165.3	4.073	116.3	3.089
	116.6	3.622	163.8	5.898	211.1	4.887	163.9	4.527
	164.4	4.797	234.9	8.511			211.2	5.670
	210.7	6.181						

APPENDIX H

ANOVA TABLES FOR OBJECTIVE AND SENSORY TESTS

Table H.1. ANOVA table for the viscosities of sherbet mixes.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-value
Between	3	84.76	28.25	6.65*
Within	8	33.97	4.25	
Total	11	118.73		

* Significant difference at $p<0.05$.

Table H.2. ANOVA table for the melting resistance of sherbets at 38°C (100.4°C).

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-value
Sherbet, A	3	11142.906	3714.302	97.4129*
Error	4	152.518	38.129	
Time, B	27	354980.121	13147.412	1788.3532
AB	81	4786.219	59.089	8.0375
Error	108	793.982	7.352	
Total	223	371855.746		

* Significant difference at $p<0.001$.

Table H.3. ANOVA table for the flavor acceptance of sherbets after 8 days of storage.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-value
Judge	47*	407.92	8.68	4.35
Sample	3	46.83	15.61	7.83**
Error	141	281.17	1.99	
Total	191	735.92		

* 48 judges tested, all responded.
** Significant difference at p<0.001.

Table H.4. ANOVA table for the texture acceptance of sherbets after 8 days of storage.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-value
judge	47*	211.33	4.496	2.12
sherbet	3	65.18	21.727	10.26**
Error	141	298.57	2.118	
Total	191	575.08		

* 48 judges tested, all responded.
** Significant difference at p<0.001.

Table H.5. ANOVA with interaction table for the iciness test after 9 days of storage.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-value
Sherbet (a)	5	68.00	13.60	16.88
Judge (A)	5	16.78	3.36	4.17
axA	25	24.22	0.97	1.20*
Error	72	58.00	0.81	
Total	107	167		

* No significant sherbet-judge interaction.

Table H.6. ANOVA table for the Scheffe paired comparison test for the iciness of sherbets after 9 days of storage.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-value
Main effect (sherbet)	3	38.84	12.95	6.527*
Order effect	1	1.836	1.836	0.925**
Error	103	204.324	1.984	
Total	107	245		

* Significant difference among sherbets at $p<0.001$.
** No significant order effect.

Table H.7. ANOVA table for the Scheffe paired comparison test for the sweetness of sherbets.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-value
Main effect (sherbet)	3	67.416	22.472	15.236*
Order effect	1	0.216	0.216	0.147**
Error	85	125.368	1.475	
Total	89	193		

* Significant difference among sherbets at $p<0.001$.
** No significant order effect.

Table H.8. ANOVA table for the Scheffe paired comparison test for the creaminess of sherbets.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-value
Main effect (sherbet)	3	113.47	37.82	32.77*
Order effect	1	1.475	1.475	1.274**
Error	85	98.06	1.154	
Total	89	213		

* Significant difference among sherbets at $p<0.001$.
** No significant order effect.

Table H.9. ANOVA table for the flavor acceptance of sherbets after a heat shock treatment.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-value
Judge	47*	215.83	4.592	1.52
Sherbet	3	36.93	12.311	4.07**
Error	141	426.32	3.024	
Total	191	679.08		

* 48 judges tested, all responded.
** Significant difference at $p<0.01$.

Table H.10. ANOVA table for the texture acceptance of sherbets after a heat shock treatment.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-value
Judge	47*	207.74	4.420	2.01
Sherbet	3	84.81	28.269	12.84**
Error	141	310.44	2.202	
Total	191	602.99		

* 48 judges tested, all responded.
** Significant difference at $p<0.001$.

Table H.11. ANOVA table for the Scheffe paired comparison test for the iciness of sherbets after a heat shock treatment.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-value
Main effect (sherbet)	3	66.22	22.07	18.39*
Order effect	1	0.15	0.15	0.124**
Error	103	123.63	1.20	
Total	107	190		

* Significant difference among sherbets at $p<0.001$.

** No significant order effect.

Table H.12. ANOVA table for the flavor acceptance of sherbets after 31 days of storage.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-value
Judge	47*	331.00	7.043	2.42
Sherbet	3	25.08	8.361	2.87**
Error	141	410.92	2.914	
Total	191	767.00		

* 48 judges tested, all responded.

** Significant difference at $p<0.05$.

Table H.13. ANOVA table for the flavor acceptance of sherbets after 122 days of storage.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-value
Judge	47*	219.74	4.675	1.52
Sherbet	3	59.35	19.783	6.42**
Error	141	434.40	3.081	
Total	191	713.49		

* 48 judges tested, all responded.

** Significant difference at $p<0.001$.

Table H.14. ANOVA table for the texture acceptance of sherbets after 31 days of storage.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-value
Judge	47*	238.17	5.067	1.94
Sherbet	3	66.42	22.139	8.46**
Error	141	369.08	2.618	
Total	191	673.67		

* 48 judges tested, all responded.

** Significant difference at p<0.001

Table H.15. ANOVA table for the Scheffe paired comparison test for the iciness of sherbets after 32 days of storage.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-value
Main effect (sherbet)	3	94.51	31.50	59.22*
Order effect	1	2.28	2.28	4.29**
Error	85	45.21	0.53	
Total	89***	142		

* Significant difference among sherbets at p<0.001.

** Significant order effect at p<0.05.

*** 5 trained panelists participated in this test.

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