THE EFFECT OF SUCROSE AND MILKFAT SUBSTITUTION ON SENSORY TEXTURAL AND PHYSICAL PROPERTIES IN A FROZEN DESSERT SYSTEM

by

STEPHEN E. SPECTER

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Approved by:

Carole S. Setser
Major Professor

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INTRODUCTION

Dietary factors are implicated in the etiology of a number of adverse degenerative diseases. The deleterious effects of fat and sugar consumption, in particular, have received considerable attention in the literature in recent years. Americans typically rely on fat and sugar for an excessive share of the calories in their diet. The U.S. Dietary Guidelines recommend that individuals decrease their intake of fat and simple carbohydrates, e.g., refined and processed sugars such as sucrose and corn syrup (USDA, 1985). Health-conscious consumers are responding by becoming increasingly selective in their food choices in an effort to improve dietary habits.

While many foods of questionable nutritional value are being avoided in favor of more healthful choices, certain favorite foods, usually high in fat, sugar, and relative caloric density, are still widely consumed. To be sure, sweetener and fat consumption offer a striking example of the contradictory nature of food behavior in the U.S. (Cantor and Shaffer, 1974), as many Americans remain unwilling to sacrifice psychological satisfaction in favor of good nutrition.

Ice cream consumption is an excellent example of the complexity of U.S. dietary habits. In 1987, for the ninth consecutive year, record high consumption levels were established for ice cream and other frozen desserts. The total volume of ice cream and related products surpassed 1.4 billion gallons - more than 23.5 quarts /capita per year - and this upward trend appears likely to continue in 1988 (International Ice Cream Association, 1987).

It is doubtful that the popularity of ice cream and other frozen desserts will decline significantly in the near future, even in light of increasing nutritional awareness. Finding a way to modify the food itself would, in all probablity, be simpler than trying to alter consumption behavior. Since about one-quarter of the U.S. population is avoiding or restricting food intake to lose weight, a frozen dessert with reduced levels of fat and/or sugar could apppeal to a sizable market and would be a worthwhile objective from an economic as well as a nutritional standpoint (Dwivedi, 1978).

Changes must clearly be made in the quantities and proportions of the basic ingredients in order to develop a frozen dessert with reduced levels of both fat and carbohydrate. Yet it is well-established that modifying ingredient levels will profoundly alter the basic sensory and physical properties of the finished product (Arbuckle, 1986).

Recent developments in ingredient technology offer new possibilities. High intensity sweeteners, bulking/texture improving agents, and fat substitutes have been developed to compensate for functional properties previously provided by fat and sugar (Anonymous, 1983; LaBarge, 1988). Since the concept of nutritionally engineered foods has emerged only recently, research in food systems such as ice cream still remains largely unexplored. It would be of particular interest, from a nutritional standpoint, to determine the highest levels at which the fat and simple carbohydrate components of ice cream can be replaced while still retaining the sensory and physical attributes of the original product.

LITERATURE REVIEW

The ice cream system

Ice cream is a highly complex food system. Air cells are dispersed in a continuous phase along with embedded ice crystals, partially emulsified fat globules, and dissolved and colloidal solids, such as sugars, minerals, and milk proteins (Arbuckle, 1986). Ice cream is both a foam and an emulsion and exhibits properties of a true solution, a colloidal dispersion, and a suspension. It is, at one time, part liquid, part solid, and part gas. Yet for all its structural and physical complexity, ice cream contains only four essential ingredients: milkfat, milk solids not fat (MSNF), sugar, and water.

FACTORS INFLUENCING ICE CREAM TEXTURE

Structural elements

The principle structural elements of ice cream are ice crystals, air cells, fat globules, and an aqueous, unfrozen phase. The delicate balance of macro and micro surfaces and interfaces built up between these constituents has been extensively investigated (Sherman, 1965; Keeney, 1965, 1982; Thomas, 1981; and others).

The physical properties of ice cream are largely a function of the nature and arrangement of the structural elements. Critical factors include the size and state of aggregation of the fat globules, the level of air incorporation (% overrun), the size of the air cells, the viscosity (i.e., relative solute concentration) of the unfrozen matrix, and, perhaps most importantly, the number and relative size of the ice crystals (Arbuckle, 1940; Dickenson and Stainsby, 1982). The main structural elements of ice cream have been quantified by a number of researchers and are presented in Tables 1 and 2.

Ice crystals. Desirable structure in ice cream is most often qualitatively expressed in terms of textural properties. As stated with elegant simplicity by Sommer (1951), "the texture of ice cream should be smooth." Small, uniformly distributed ice crystals are considered necessary to achieve this end. Texture is perceived as coarse if the ice crystals are greater than 20-40 microns (u) in diameter (Berger, 1976; Keeney, 1979).

Using microscopic techniques to evaluate physical differences between smooth and coarse ice cream, Brainard (1915) concluded that smoothness is a direct function of the size and distribution of ice crystals and that these, in turn, are influenced by the arrangement of solids within the system.

Table 1 - The size of the main components of ice cream[1]

	(According to)		
	Sherman (u)	Arbuckle (u)	Number/gram ice cream
Ice Crystals	20 - 40	31 - 56	7.80×10^{6}
Air Cells	-	144	8.33×10^{6}
Fat Globules	0.5 - 4.0	-	1.53×10^{12}
Wall Thickness			
(between air cells)	30 - 300	121	-
(between fat globules)	-	6 - 8	-

[1] Adapted from Berger, 1976.

Table 2 - Calculated dimensions of ice cream components[2]

	Size			
	Variation (u)	Average (u)	Number/ liter ice cream	Surface/ liter ice cream
Ice Crystals	10 - 75	40	4×10^{9}	20
Air Cells	10 - 150	60	4×10^{9}	45
Fat Globules	0.2 - 2.0	0.6	5×10^{14}	560

[2] Adapted from Nielsen, 1973.

Air cells. The distribution, number, and size of the air cells, as well as the nature of the stabilizing lamellae, influence physical structure and perceived texture. Sommer (1951) found that smooth texture is associated with small air cells. Nielsen (1973) observed that small, uniformly distributed air cells confer smoothness, while large air cells are typically associated with cold-eating, coarse-textured ice cream.

The incorporation of numerous air cells during freezing offers mechanical resistance to formation of large ice crystals. Ice crystals and air cells become smaller as overrun increases (Shama and Sherman, 1966). According to Keeney (1979), when air is uniformly distributed throughout the frozen product, the resulting fine air cell structure has an effect on ice crystal perception akin to milkfat; that is, the air cells provide a lubricating effect, making crystals more difficult to detect. Inadequate aeration causes the product to be wet, hard, and unpleasantly cold, whereas excessive foam leads to a dry, snowy consistency (Keeney and Maga, 1965).

Unfrozen phase. The unfrozen phase is the continuous medium occupying the space between ice crystals and air cells. It contains both concentrated solutes and a partially emulsified network of intact and ruptured fat globules (Thomas, 1981). Water freezes out of the ice cream mix in the form of pure ice, leaving a highly concentrated solution. The moisture held in the unfrozen matrix is not available to participate in ice crystal formation.

Compostional factors

The development of the structural constituents is directly influenced by compositional factors. That is, the building up of the frozen microstructure and resultant textural quality is based in large measure on the interaction of individual mix components.

Role of sugar. Besides being important to palatability, sugars influence freezing properties and melting characteristics. Dahlberg (1925) observed that sucrose confers texture-improving effects by reducing the amount of water frozen into ice crystals. The effectiveness of sucrose as an ice crystal retardant has also been reported by Harper and Shoemaker (1983) and Budiaman and Fenemma (1987).

Low molecular weight solutes, such as sucrose, effectively depress the freezing point of an aqueous system (Baer and Keating, 1987). Present in true solution, sucrose "ties up" a portion of the water, rendering it unable to participate in ice crystal formation during freezing (Arbuckle, 1940). Charley (1982) has suggested that additional water molecules, oriented around hydrated sugar molecules, might also be inhibited from participating in the ice crystal lattice.

Sucrose limits ice crystal size by increasing the amount of liquid which remains unfrozen. As ice crystals form during freezing, water is removed from the unfrozen phase and the solutes become more highly concentrated, increasing viscosity and impeding migration of water molecules to existing ice crystal nuclei.

Sugar is also important to foam structure. Sucrose facilitates adsorptive denaturation of milk proteins at the air-water interface, stabilizing the air cell lamellae and promoting greater air incorporation (Keeney and Maga, 1965). Raising sucrose concentation also increases the viscosity of the continuous phase, enhancing foam stability.

Role of fat. Fat acts as a mechanical barrier to the deposition of water molecules on ice crystals, effectively limiting their size during freezing (Sommer, 1951; Nielsen, 1973). Fat globules also have an indirect influence on the freezing point of the system. Raising the milkfat level results in replacement of water, increasing the concentration of the remaining soluble constituents and thus lowering the freezing point (Baer and Keating, 1987).

Fat droplets influence perception of texture through their lubricating effect on ice crystals, imparting creaminess and decreasing perceived coldness by reducing the sensation of iciness on the palate (Keeney, 1979).

This "smoothing effect," according to Sherman (1965), is noted during sensory evaluation, but is elusive of microscopic or instrumental measurement.

The partially de-emulsified lipid fraction, including solid and liquified globules, stabilizes the foam matrix. Coalesced fat, present at the air-serum interface, also improves the distribution of air bubbles during freezing and promotes incorporation of numerous small air cells. Keeney and Josephson (1958) found that a certain level of emulsion destabilization is necessary to obtain a dry, smooth-textured end-product. Excessive coalescence, however, is associated with formation of unstable air cells and large, unevenly distributed ice crystals (Berger and White, 1973).

Total solids. Sucrose and fat together contribute more than 70% of the total solids in the ice cream mix. According to Sommer (1951), sufficient solids (1) promote smoothness, possibly because solids tie up water of hydration, leading to the formation of smaller ice crystals and (2) decrease the perception of coldness, since less water is converted into ice. Keeney (1982) reported that melting properties, storage stability, and textural characteristics are affected by as little as a 1-2% variation in the level of solids.

Rheology of the unfrozen mix and melted ice cream

Loss or distortion of structure and textural properties occurring as a result of an unstable temperature profile makes ice cream inherently difficult to study in its natural frozen state (Gallant, 1987). For this reason, a number of investigators have focused their attention on the rheological properties of the unfrozen mix and the melting characteristics of frozen ice cream.

Unfrozen mix viscosity measurements have been used by a number of investigators to predict textural properties. Mortenson (1915) found that a higher relative mix viscosity leads to reduced air cell size, increasing overall smoothness. Sommer (1951) reported that small ice crystal growth and improved air incorporation is favored by mixes of high viscosity.

Increasing unfrozen mix viscosity inhibits migration of water molecules and subsequent enlargement of existing crystal nuclei (Mitchell, 1969). An inverse relationship might therefore exist between mix viscosity and the level of coarseness or wateriness in the finished product.

Mix viscosity is directly affected by compositional factors, for example, the nature of the solutes present in the system. Increasing either the number of molecules, e.g., total solids content, or the size of the molecules, will increase viscosity (Smith et al., 1980). According to Cottrell et al. (1980), the capacity of certain types of polysaccharides, such as starch, to restrict ice crystal growth during storage is directly related to their role in increasing mix viscosity. A direct relationship between ice cream texture and mix viscosity, however, has never been demonstrated. No ideal viscosity range has been established. Viscosity is therefore considered to be a mix property that accompanies, rather than is responsible for, optimum textural properties (Arbuckle, 1986).

Melting properties. The melting rate of frozen ice cream indicates the structural integrity of the original product, while textural attributes are thought to be suggested by the appearance of the melt (Whitehead and Sherman, 1967).

Melting properties are influenced by constituents that alter the rheology of the aqueous phase, e.g., hydrocolloids, and the physical properties of the air cell lamellae. The strength of the lamellae are, in turn, governed by (1) the size and distribution of ice crystals and air cells and (2) the nature of the stabilizing lipid membrane formed around each air cell (Sherman, 1966). A rapid melt is caused by an unstable foam and typically implies a coarse, uneven texture.

Extended storage

Fluctuating temperatures inevitably lead to texture defects (Cole, 1932; Harper and Shoemaker, 1983; Wittinger and Smith, 1986). Migratory recrystallization, the tendency for large crystals to develop at the expense of smaller ones, is commonly attributed to fluctuating storage temperatures, and is the primary form of recrystallization occuring in frozen foods (Fennema et al., 1973).

"Heat shock" occurs as the temperature of the frozen product rises, causing the smallest ice crystals to melt. Upon refreezing, water again crystallizes out of solution and is deposited onto the remaining large ice crystals, resulting in coarse texture (Arbuckle, 1940; Keeney, 1979).

Compositional factors play a critical role in textural defects that develop during storage (Nielsen, 1984; Dolan et al., 1985). Ingredients that form intermolecular associations with water influence ice crystal migration and can affect structure and texture. Hydrocolloid stabilizers, e.g., carbohydrate polymers derived from plant gums or starch, are included in commercial ice cream to forestall the negative effects of heat shock.

FOOD TEXTURE STUDIES

Texture is one of the four principle quality factors in food, along with appearance, flavor, and nutrition (Bourne, 1982). Good textural quality is critical to food palatability and acceptance.

Texture is not a single property, but rather a complex of different sensory parameters, an overall impression formed by the senses when identifying and evaluating a number of relevant textural attributes (Brandt et al. 1963). Since most foods exhibit a wide range of physical characteristics, it is more accurate to speak of "textural properties" rather than texture, which incorrectly infers a single parameter.

Sensory evaluation

Descriptive texture studies focus on the effects of certain critical variables, e.g., ingredient levels and processing steps, on types and magnitudes of similarities and differences among samples, and often are used as a basis for determining characteristics important to acceptance (Abbott, 1972).

Descriptive analysis relies on the ability of a group of trained panelists to decide on meaningful textural parameters. A ballot is developed consisting of attributes that qualitatively describe samples representing treatment combinations presented. Descriptors are selected so that they can be identified independently. Otherwise, sensory perception of one attribute may influence perception of another parameter, a phenomenon referred to by Szczesniak (1968) as "cross-influences" of sensory textural measurement.

Agreement among panelists regarding relative perceptions, or "sensory scaling," of selected attributes is critical. Response variation will depend on the degree to which individual panelists can agree on their discrimination of different samples (Levitt, 1974).

Instrumental measurement

A number of researchers have successfully used instrumental methods to evaluate textural properties in terms of well-defined physical parameters. According to Szczesniak (1968), instruments that most closely simulate the conditions used to assess sensory properties show the most consistent correlations with sensory evaluation. Bourne et al. (1966) adopted the Instron Universal Testing Machine (Instron) for use in texture profile studies, noting that instrumental analysis shares with sensory evaluation the need for measuring texture as a collection of parameters, allowing separate values for hardness, smoothness, coarseness, and other attributes.

Sensory vs. instrumental data

Attempts to quantify textural properties of foods through systematic analysis of instrumental data have not always been well-received. What evidence can be provided, argue critics, that instrumental measurements are actually representative of sensory parameters?

Pangborn (1984) asserts that instrumental analyses can supplement, but never substitute for, sensory evaluation, since sensory properties of food - color, flavor, and texture - are, by definition, human sensations. A gas liquid chromatograph separates volatile compounds; a colorimeter records absorbed or transmitted light, and, likewise, an Instron or texturometer measures only resistance to pressure or stress. An instrumental method cannot improve over the accuracy of a sensory method, according to Kramer (1968), since the accuracy of the instrumental measurement can be determined only by the extent to which it agrees with the response measured by sensory evaluation.

Proponents of instrumental texture assessment nevertheless maintain that sensory methods of measuring food quality lack the precision necessary in scientific research. Measuring the underlying dimensions of sensory characteristics by precise instrumental methods, suggests Levitt (1974), would eliminate problems of reproducibility and reliability often associated with panel assessment. In general, the issue of whether to obtain sensory or instrumental measurements (or both) for textural analysis remains a subject of wide dispute (Szczesniak, 1968).

TEXTURE OF FROZEN DESSERTS[1]

Early ice cream research was confined to identifying elements of physical structure and establishing the influence of composition or processing techniques on textural attributes. Current economic and health concerns have shifted the focus to finding ways to replace conventional components, e.g., sugar and fat, with more healthful and/or low cost ingredient alternatives.

Ice cream without sucrose

For many years, sucrose was the only sweetening agent used in ice cream. Recently, other sweeteners have been reviewed as potential replacements.

Alternative carbohydrate sweeteners. Pearson and Ennis (1979) reported on sensory properties of ice cream containing corn sweeteners with dextrose equivalents (DE) ranging from 9 to 44, as evaluated by a 160-member panel. Replacement of sucrose with 28-31 DE high fructose corn syrup (HFCS) at 33% of the total sweetener level received the highest acceptance scores.

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[1] According to U.S. Government Standards of Identity, ice cream must be composed of not less than 10% milkfat and 20% MSNF (FDA, 1978). Frozen desserts is a generic term - implying nothing in regard to compositional factors, although formulations usually do not conform to FDA standards, particularly with regard to fat content.

The influence of selected sweetening agents, used in conjunction with locust bean gum, on ice recrystallization rates was studied by Harper and Shoemaker (1983). High conversion corn syrup, HFCS, and sucrose were found to have varying effects on ice recrystallization rates. Changes in ice crystal size correlated qualitatively with the level of freezing point depression, indicating that the molecular structure of the sweetener influenced the level of water-binding and resultant textural attributes.

The results of Smith and Bradley (1983) on the effect of various sweeteners on the freezing point of frozen desserts were consistent with previous reports in the literature. Low molecular weight sugars, such as glucose and fructose, were found to depress freezing point more than sucrose and relatively low DE (< 42) corn sweeteners.

Kokini and Cussler (1983) attempted to correlate Instron shear rate, an instrumental simulation of the contact friction force between the tongue and food surface, and viscosity with sensory assessment of smoothness and thickness. Estimation of creaminess was made from combined scores for smoothness and thickness. Their results suggest that sensory response can be predicted by instrumentally measured physical phenomena.

Characteristics of frozen desserts sweetened with fructose and lactose were reported by Pihl et al. (1982). Attempts to correlate sensory scores with mix viscosity, level of total solids, and melting properties were met with limited success.

Sensory attributes of frozen desserts with varying sweetener-stabilizer combinations were evaluated fresh and after a ten week storage period using the paired comparison technique by Wittinger and Smith (1986). Samples containing high levels of HFCS were judged icier than those containing low levels or no HFCS.

High intensity sweeteners. McPherson et al. (1978) formulated and evaluated orange sherbert with dextrose and aspartame (APM) for 22 sensory attributes including smoothness, chalkiness, gumminess, and mouthcoating using sensory texture profile analysis. A texture profile of an "ideal" sherbert was developed and used as a comparison reference for experimental formulations. Dextrose/APM combinations did not provide sufficient solids to maintain optimal textural attributes, relative to the reference, particularly after a four week storage period.

APM-corn syrup solids (CSS) sweetener system combinations were evaluated by Goff and Pearson (1983). Mix viscosity, percent overrun, cone penetrometer, and sensory attributes for 32 treatment combinations were measured. They concluded that APM could be used effectively in combination with CSS, depending on the DE (relative level of solids) of the corn syrup. An APM level of 0.06-0.1% in combination with 15% CSS was recommended.

Bulking agents. Interest in reducing the caloric density of foods containing sugar led to the development of high intensity sweeteners; however, sugars provide many functions in frozen desserts in addition to sweetness. Polydextrose, a low-calorie bulking agent approved by the FDA in 1981, was specifically developed to be substituted for sugar and used in combination with high intensity sweeteners.

Polydextrose is a water soluble, non-sweet, randomly-bonded glucan containing small amounts of sorbitol and citric acid. Although recognized as a carbohydrate, polydextrorse is inaccessible to most digestive enzymes and has a net caloric density of one kcal/gram (Pfizer, 1985).

Goff and Jordan (1984) substituted polydextrose-APM combinations for sucrose in a frozen dessert system. Two levels of polydextrose were used, 13.9% and 10.0% (in combination with CSS). Samples were evaluated by a 42-member taste panel for sweetness, smoothness and acceptability. It was concluded that acceptable products could be formulated using polydextrose and APM provided that an upper limit of 12% polydextrose incorporation was not exceeded; above this level polydextrose had a negative impact on flavor.

Lastly, Baer and Baldwin (1984) reported on the influence of polydextrose on freezing point depression. A 15% polydextrose solution decreased freezing point by

0.621^{o}C, whereas the same amount of sucrose produced a drop of 1.064^{o}C. The greater reduction achieved by sucrose was attributed to the relatively higher average molecular weight of PDEX. The freezing point of an aqueous solution varies directly with the number of molecules solute per unit volume. The lower the average molecular weight (at equal concentration), the greater the number of molecules that are available to influence the freezing point.

Clearly, replacing sucrose with a high intensity sweetener such as APM or a bulking agent such as polydextrose is not simply a matter of changing from one ingredient to another. Results from the preceding studies indicate that removing sucrose is likely to result in changes in sweetness, mix viscosity, freezing point depression, and, perhaps most importantly, basic textural characteristics.

Ice cream without fat

While sucrose substitution has received considerable attention in the literature, no reports were found regarding the effect of removing fat on frozen dessert quality. The area has remained untreated presumably because of the lack of acceptable fat substitutes.

Recently, a number of fat-sparing agents have been introduced (LaBarge, 1988; McCormick, 1988). While some quite promising ones such as sucrose polyester and Simplesse are not yet available for independent research, two fat replacers based on modified starches (N-OIL^R and Paselli SA2) have received FDA approval.

Starch-based fat substitutes. N-OIL^R is a dextrin composed of partially hydrolyzed polymers of tapioca starch. According to the manufacturer, N-OIL^R was designed to "partially or totally replace the fat in a number of food systems, including ice cream" (National Starch, 1982).

Paselli SA2 (PSA2) is a maltodextrin composed of enzymatically hydrolyzed polymers derived from potato starch. PSA2 forms a thermo-reversible gel that, according to the manufacturer, "can replace up to 50% of the total fat content in a frozen dessert system" (AVEBE Inc., 1986).

The objective of this study is to assess the effect of milkfat and sucrose substitution on selected physical and sensory properties in a frozen dessert system, as evaluated by sensory and instrumental methods.

MATERIALS AND METHODS

Product formulation

As a result of preliminary investigations, a basic ice cream formulation was developed. Four ingredients - heavy cream, nonfat dry milk, sugar, and water - were combined to produce a model system with the following composition:

Ingredients[1]		**Product Composition**	
Heavy Cream	272 g	Milkfat	12 %
NFDM	72	MSNF	10
Sugar	136	Sucrose	16
Water	370		
	850 g	Total Solids	38 %

Two milkfat substitutes, N-OIL^R and Paselli SA2, and a bulking agent, polydextrose, were selected on the basis of their purported ability to confer bodying and textural properties normally conferred by fat and sugar. Polydextrose is intended to replace the physical properties

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[1] A complete listing of ingredients and suppliers appears in Appendix C, Table C-1.

conferred by sucrose; therefore, APM was included to provide sweetness equivalent to the 16% sucrose control.

The liquid form of polydextrose, polydextrose-N, was used in order to facilitate incorporation into the aqueous unfrozen mix. Since polydextrose-N is in 70% solution, a 1 : 1.43 (sucrose:polydextrose) substitution ratio was used to obtain a 1 : 1 solids exchange with sucrose. Water levels for treatment combinations containing polydextrose were adjusted to compensate for the resultant change in volume.

Twenty-one treatment combinations were prepared with varying levels of milkfat, sucrose, and ingredient substitutes. Formulations for each treatment combination appear in Table 3. Four parts fat were replaced by one part N-OIL^{R} or PSA2 and 3 parts water, i.e., 25% substitution. Fat levels were 100, 66, 33, 0%; sucrose levels were 100, 50, and 0%.[1] The level of nonfat dry milk was adjusted for each treatment combination in order to maintain a constant MSNF level of 10%. Total solids varied according to the fat level in each formulation (Table 4).

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[1] The 100% levels of both fat and sucrose are equivalent to the 12 and 16 percent levels, respectively, present in the control.

Table 3 - Formulation Chart[1]

Treatment Combination	Heavy Cream	NFDM[2]	Sucrose	Water	Polydextrose	N-OIL^{R}[2]	PSA2[2]	Aspartame[3]
1	272	72	136	370	-	-	-	-
2	181	77	136	447	-	8.5	-	-
3	91	82	136	524	-	17.0	-	-
4	0	88	136	603	-	25.5	-	-
5	272	77	136	447	-	-	8.5	-
6	181	82	136	524	-	-	17.0	-
7	91	88	136	603	-	-	25.5	-
8	272	72	68	341	97	-	-	0.4
9	181	77	68	418	97	8.5	-	0.4
10	91	82	68	495	97	17.0	-	0.4
11	0	88	68	575	97	25.5	-	0.4
12	181	77	68	418	97	-	8.5	0.4
13	91	82	68	495	97	-	17.0	0.4
14	0	88	68	575	97	-	25.5	0.4
15	272	72	-	311	194	-	-	0.8
16	181	77	-	388	194	8.5	-	0.8
17	91	82	-	465	194	17.0	-	0.8
18	0	88	-	545	194	25.5	-	0.8
19	181	77	-	388	194	-	8.5	0.8
20	91	82	-	465	194	-	17.0	0.8
21	0	88	-	545	194	-	25.5	0.8

[1] Gram weight for ingredients by treatment combination.
[2] NFDM - nonfat dry milk, N-OIL^{R} - tapioca starch, PSA2 - potato starch.
[3] Equivalent to 0.06% sucrose dry weight.

Table 4 - Percent total solids based on fat level[1]

Fat Level(%)	**% Total Solids**
100	38.0
66	35.0
33	32.0
0	29.0

[1] Changing sucrose levels did not alter percent solids.

Sample preparation

Sample preparation was a two day, multi-step process. The order of preparation for a 850g batch of each treatment combination was randomized within each replication. Each mix was prepared in an identical fashion, as outlined by the flow chart in Figure 1.

Sample evaluation

Sample evaluation was divided into two phases. In phase I, samples were evaluated 48 ± 2 hours after preparation, i.e., fresh. Phase II of the evaluation was conducted after the samples were held for 140 days. All samples were held in a reach-in freezer (Frigidaire, model UFD-18L) and stored at -17 ± 2°C for an identical length of time between phase I and II.

Four treatment combinations were presented each day for three replications over a 27 day evaluation period. Textural properties of all samples were evaluated by instrumental and sensory analysis.

Sensory analysis. Descriptive analysis of selected textural attributes was conducted using five panelists associated with the KSU Sensory Analysis Center. Six hours of specialized training were devoted to familiarizing the panelists with ice cream evaluation techniques, selecting appropriate and meaningful textural parameters, and developing a score sheet (Appendix, Table B-1). Three

Figure 1. Steps and equipment involved in sample preparation

1 **Combine dry ingredients** (NFDM, suc., N-OIL^{R}, PSA[2]) (shake together in closed container - 20 sec).

2 **Hydrate dry ingredients** in distilled water. (Add dry ingredients to water in stainless steel bowl. Agitate with wire whip to facilitate solubilization and dispersion - 30 sec).

3 **Add remaining liquid ingredients** (heavy cream and polydextrose) Agitate - 20 sec.

4 Transfer into 2 quart ice cream canister. Place in water bath[1]. **Pasteurize** at 71°C - 30 min.

5 **Homogenization**[2] - 2 stage (1500,500 PSI).

6 **Aging** - hold mix 18 ± 2 hours at 4°C.

7 **Viscosity** measurement[3] - unfrozen mix (4.4 ± 1°C).

8 **Freezing stage** - place canister in freezer unit[4], surround with brine mixture, ice : salt - 8:1 (mix temperature: 4.4 ± 1°C).
Freeze to 40 ± 5% air incorporation.

9 Transfer frozen mix into 2 oz precoded plastic cups w/ lids; place in storage freezer for **Hardening** (-17°C). Divide into 2 equal groups. Store for subsequent 2-phase evaluation of physical and sensory attributes.

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[1] Braun Thermomix (18 liter). Model 1480.
B. Braun, West Germany.

[2] Microfluidics Lab Homogenizer. Model H-5000.
Microfluidics Corp., Newton, MA.

[3] Viscometer. Model UK-RV8 (spindle #2).
U.K. Viscometers, Ltd., London.

[4] White Mountain Electric Ice Cream Freezer (2 quart).
Model 69-202.
White Mountain Freezer Co., Winchendon, MA.

hours were spent retraining prior to beginning phase II.

Scoring was done on a 60-digit linear scale on a computer screen with descriptive anchors for each sensory parameter. Each scale was delineated at the midpoint. In addition, the consensus position of the control (treatment combination 1) for each descriptor was marked on a supplementary scoresheet and used by panelists as a reference.

Reference sample. A "warm-up" sample was provided at each session to establish a frame of reference for evaluating subsequent samples. Reference samples for each phase were mixed and frozen 48 hours preceding the first session and held for use during first half of the study. A second batch of reference samples was prepared for phase II 48 hours preceding the first session and held for use during the second half of the study. Reference samples may have varied somewhat throughout each evaluation period, since each was subject to a different length of storage; however, it was decided that greater variability would be introduced if fresh reference samples were prepared (and held for an constant length of time) prior to each session.

Sample scoring. The following sensory attributes were evaluated: coldness, softness, coarseness, wateriness, creaminess, gumminess, chalkiness, mouthcoating, and sweetness. (Definitions are given in the Appendix, Table B-2.) Sensory descriptors were listed on the scoresheet in order of evaluation. Unlike flavor notes, whose exact order of detection is troublesome to predict, textural characteristics are perceived in an ordered sequence (Szczesniak, 1963).

Each sensory property was scored by placing a vertical line at the point on the scale which best reflected the magnitude of the panelists' perceived intensity of that property. Responses were recorded on the score sheet and then entered into the computer.

Consistency among panel members to differentiate among samples and to duplicate results was verified by providing examples with high and low levels of each attribute and replicate samples with similar levels. Score sheets were reviewed at the end of each session and after all training was completed.

Sample presentation temperature was monitored using a Minitrend 205 Thermocoupler (Doric Scientific). Each sample was equilibrated to -12 ± 1°C prior to presentation. Unsalted crackers, apples, and deionized distilled water were used by panelists to clear their palates between samples.

Instrumental measurements

Resistance to deformation was measured using the cone penetrometer and plunger attachments on the Instron. The cone penetrometer has been used by investigators to measure resistance to deformation of semi-solid foods and the development of ice crystals in frozen desserts (Haighton, 1959; Nickerson and Pangborn, 1961; Goff and Pearson, 1983).

Use of the cone penetrometer on the Instron required modification of the early method. The force required for the cone to achieve a specified penetration, rather than depth of penetration based on a known force weight, was used to quantify the extent of ice crystal formation.

According to Bourne et al. (1966), softness can be estimated by measuring the degree of deformation under a known compression force. The plunger attachment was used to obtain an instrumental value for softness of the frozen sample. Specifications for Instron operation for cone and plunger measurements (phase I and II) appear in Table 5.

First peak heights represent the force resisting penetration or deformation for the cone or plunger attachments, and these values were used to predict coarseness and softness, respectively. Phase II of the instrumental evaluation required new settings for the Instron full scale load because long-term storage greatly increased resistance to deformation.

Percent air incorporation was measured for each treatment combination using the following formula:

$$\text{percent air incorporation} = \frac{\text{density (unfrozen mix)}}{\text{density (frozen mix)}} \times 100$$

Table 5 - Specifications for Instron operation[1]

Attachments		Phase I		Phase II	
		Cone	Plunger	Cone	Plunger
Load cell	**(kg)**	20	20	20	20
Full scale load	**(kg)**	0.1	1	1	20
Crosshead speed	**(mm/sec)**	50	50	50	50
Chart recorder speed	**(mm/sec)**	200	500	200	500
Penetration depth	**(mm)**	15	5	15	5
Sample temperature	**(°C)**	-15	-12	-15	-12

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[1] Instron Universal Testing Machine.

Density was calculated by taking the weight of the mix in a container of known volume.

Melting characteristics were evaluated according to the method of Nickerson and Pangborn (1961) and Moore and Shoemaker (1983). In this study, melting rate is defined as the volume of drip collected after 30 minutes from a sample placed on a wire mesh over a funnel inserted into a graduated cylinder. Each sample was equilibrated to -15°C immediately prior to beginning measurement. Ambient room temperature was consistently 68 ± 2°F.

Statistical design and data analysis

A randomized complete block experimental design (Table 6) included 21 treatment combinations. Phase II of the data collection was identical to phase I, with the exception of viscosity measurement, as no new mixes were prepared. Mean separations were calculated using Proc GLM (SAS Institute, 1982), since the design was unbalanced because of missing data. All hypotheses were tested for significance at the $p \leq 0.05$ level. Mean values collected during phase I for the 21 treatment combinations were then evaluated for significant differences within each sensory parameter. A similar analysis was carried out for the sensory data from phase II.

Relationship between sensory and instrumental data

Mean values for Instron, viscosity, and melting rate measurements were compared to panelist data to note trends or establish agreement between sensory evaluation and instrumental measurement. Significant relationships between instrumental and sensory data were tested using the Spearman correlation coefficient (SAS Institute, 1982).

Table 6 - Experimental Design[a]

	Fat Level	100	66	33	0	66	33	0
	N-OIL^R Level	0	33	66	100	0	0	0
	PSA2 Level	0	0	0	0	33	66	100
Sucrose Level	Polydextrose Level							
100	0	1[b]	2	3	4	5	6	7
50	50	8	9	10	11	12	13	14
0	100	15	16	17	18	19	20	21

[a] A randomized complete block experimental design including 21 treatment combinations and all possible combinations for two fat substitutes[2] at four levels and a sucrose substitute[3] at three levels(%).

[b] Numbers within the body of the table indicate treatment combinations.

RESULTS AND DISCUSSION

Significant differences among all treatment combinations for each sensory attribute are not reviewed; however, this information has been recorded and appears in Appendix A, Figures A-1a through A-9b. This section focuses on assessment of each treatment combination in relation to the control, as well as paired comparisons between fat replacement trials, N-OIL^R and PSA2, at a given level of sucrose substitution.

Analysis of F-values

F-values of least squares means for each sensory attribute were examined for significance according to treatment, as well as for treatment-panelist (trt-pnlst) and replication-panelist (rep-pnlst) interactions (in Appendix A, Tables A-1 and A-2).

Phase I. Significance by treatment was found for all sensory attributes with the exception of coldness and gumminess. Significant trt-pnlst interactions occurred for chalkiness and mouthcoating; significant rep-panelist interactions were noted for coldness, coarseness, chalkiness, mouthcoating, and sweetness.

Phase II. Significance by treatment was found for all attributes except coldness, gumminess, and mouthcoating.

Significant trt-pnlst interaction occurred only for sweetness; significant rep-pnlst interactions were noted for coldness, coarseness, and sweetness.

Individual panelist scores for each attribute were compared with interactions both by trt and by rep. Treatment effects were determined to be greater than the response variation causing trt-pnlst or rep-pnlst interactions for both phase I and phase II.

Sensory evaluation

Sucrose substitution. Replacement of sucrose with polydextrose was made at the 0, 50, and 100% level. Least squares means for sucrose substitution at the 100% fat level for all sensory attributes from phase I and phase II appear in Tables 7a and 7b, respectively.

No significant differences, when polydextrose replaced sucrose, were noted between treatment combinations for any sensory attributes in phase I. Nearly identical results were recorded in phase II. Replacement of sucrose with the polydextrose-APM combination at 0, 50, or 100% levels resulted in very few significant differences; specifically, only for coldness and softness during phase II.

Fat substitution. Least squares means for N-OIL^R substitution (0, 33, 66, and 100% levels) appear in Tables 8a and 8b. In general, significant differences were found between N-OIL^R trials and the control at all levels of

Table 7 - Comparison of least squares means[1] of sensory attributes for replacement of sucrose with polydextrose[2]

a. Phase I

Sucrose Level (%) **Polydextrose Level**	100 0	50 50	0 100
Sensory Attribute			
Coldness	43.13	41.80	41.40
Softness	21.60	18.13	16.20
Coarseness	9.20	8.33	6.26
Wateriness	8.27	7.66	4.73
Creaminess	40.33	42.86	46.26
Gumminess	2.00	2.06	2.13
Chalkiness	2.00	4.20	2.00
Mouthcoating	39.33	38.63	39.40
Sweetness	41.33	41.13	40.53

---

[1] No significant differences ($p \leq 0.05$ among mean values for any attributes.

[2] Fat level held constant at 100%.

Table 7 - Comparison of least squares means[1] of sensory attributes for replacement of sucrose with polydextrose[2]
b. Phase II

Sucrose Level (%) Polydextrose Level	100 0	50 50	0 100
Sensory Attribute			
Coldness	42.98a	42.67b	40.33ab
Softness	14.65a	14.73b	10.00ab
Coarseness	22.84	22.20	18.93
Wateriness	20.27	22.33	21.00
Creaminess	32.89	31.53	30.27
Gumminess	2.04	2.93	1.93
Chalkiness	26.97	28.27	18.73
Mouthcoating	41.00	40.66	40.60
Sweetness	39.04	40.00	38.20

---

[1] Mean values in a row followed by the same letter are significantly different ($p \leq 0.05$).
[2] Fat level held constant at 100%.

sucrose substitution for both phase I and phase II.

Sensory attributes most affected by substitution of N-OIL^R for fat (all levels) were softness, coarseness, wateriness, creaminess, and chalkiness. Coarseness and wateriness increased while softness and creaminess decreased as more fat was replaced with N-OIL^R. Over half of the means in phase I for N-OIL^R substitution were significantly different from the control ($p \leq 0.05$). Fewer significant differences were found in phase II: slightly less than half of the means were significantly different from the control.

N-OIL^R samples were consistently rated as being chalkier than the control in phase I. After 140 days storage, however, the control became so chalky that it was no longer significantly different from any of the N-OIL^R trials.

Least squares means for PSA2 substitution appear in Tables 9a and 9b. In general, fewer significant differences were noted between PSA2 trials and the control relative to corresponding N-OIL^R trials. Sensory attributes most affected by fat replacement were coarseness, wateriness, and creaminess. About a third of the mean values for PSA2 substitution were significantly different from the control in phase I. The number of significant differences increased to about one-half after extended storage.

While PSA2 trials rarely differed from the control for chalkiness in phase I, many of samples in phase II were rated less chalky than the control. PSA2 might actually inhibit development of chalkiness during extended storage.

Fewer differences were recorded between the control and samples with reduced fat as the level of sucrose decreased, particularly for phase II. Concurrent removal of sucrose and fat might have confounded the effect on sensory attributes. Of course, as more sucrose was removed from the system, the level of polydextrose increased, indicating that polydextrose might be functioning in part as a fat replacer.

Mean values for paired comparisons of N-OIL^R and PSA2 trials appear in Tables 10a and 10b. N-OIL^R samples were significantly more coarse, watery, and chalky and less creamy than identical samples employing PSA2 in phase I. About one third of the means were significantly different between N-OIL^R and PSA2 trials in phase I. By phase II, this had decreased to about one-fifth.

Fewer differences were noted between N-OIL^R and PSA2 trials as the level of sucrose substitution increased. polydextrose again could have conferred fat-sparing properties.

Other attributes. No significant differences were recorded for coldness or gumminess among treatment combinations at any point in the study. Likewise, very few

Table 8 - Comparison of least squares means[1] of sensory attributes for replacement of fat with N-OIL^R at three levels of sucrose substitution in frozen desserts

a. Phase I

Sucrose Level(%)	100				50			0		
Fat Level	100	66	33	0	66	33	0	66	33	0
N-OIL^R Level	0	33	66	100	33	66	100	33	66	100
Sensory Attribute										
Coldness	43.13	41.13	43.74	43.40	42.73	43.41	42.48	44.20	43.00	41.53
Softness	21.60	37.33a	36.62a	35.46a	29.40a	28.78a	28.78a	20.33	27.13	22.06
Coarseness	9.20	33.06a	31.54a	33.40a	19.86a	31.30a	21.24a	20.40a	27.06a	20.66a
Wateriness	8.26	26.80a	28.84a	33.73a	20.13a	30.84a	23.64a	15.93a	26.40a	21.06a
Creaminess	40.33	23.60a	28.80a	20.20a	32.73a	25.16a	28.00a	34.06	25.13a	25.20a
Gumminess	2.00	2.00	1.99	2.00	2.00	1.99	1.99	2.00	2.00	2.00
Chalkiness	2.00	6.07	11.30a	7.26a	2.00	13.83a	20.46a	7.00a	15.93a	26.73a
Mouthcoating	39.33	34.33a	33.90a	32.40a	35.53	33.03a	38.40	38.26	35.60	41.27
Sweetness	41.33	40.80	40.83	38.13	39.73	37.60	39.17	38.93	36.73a	37.26a

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[1] Means in a row followed by the letter a are significantly different from the control ($p \leq 0.05$).

Table 8 - Comparison of least squares means[1] of sensory attributes for replacement of fat with N-OIL^R at three levels of sucrose substitution in frozen desserts
b. Phase II

Sucrose Level(%)	100				50			0		
Fat Level	100	66	33	0	66	33	0	66	33	0
N-OIL^R Level	0	33	66	100	33	66	100	33	66	100
Sensory Attribute										
Coldness	42.98	43.75	43.00	42.17	41.67	44.50	42.51	42.80	43.07	43.27
Softness	14.65	14.72	8.93a	8.55a	9.45a	9.19a	6.85a	13.67	10.66a	7.00a
Coarseness	22.84	44.15a	50.40a	50.34a	39.91a	46.45a	48.18a	26.27	40.07a	47.27a
Wateriness	20.27	41.07a	47.67a	48.57a	37.37a	45.44a	46.34a	28.00a	38.33a	47.53a
Creaminess	32.89	17.66a	8.53a	8.09a	18.69a	12.59a	9.92a	28.33	18.07a	10.67a
Gumminess	2.04	1.90	1.80	2.01	1.87	1.91	1.94	2.00	1.87	1.87
Chalkiness	26.97	27.91	33.20	31.44	21.84	24.44	38.04	21.47	21.53	23.07
Mouthcoating	41.00	40.13	39.40	38.93	38.13	38.03a	40.16	37.60a	37.27a	36.00a
Sweetness	39.04	39.61	37.13	34.84	38.57	38.54	35.78a	37.93	35.00a	33.00a

[1] Means in a row followed by the letter a are significantly different from the control ($p \leq 0.05$).

Table 9 - Comparison of least squares means[1] of sensory attributes for replacement of fat with PSA2 at three levels of sucrose substitution in frozen desserts
a. Phase II

Sucrose Level(%)	100				50			0		
Fat Level	100	66	33	0	66	33	0	66	33	0
PSA2 Level	0	33	66	100	33	66	100	33	66	100
Sensory Attribute										
Coldness	43.13	43.13	42.20	41.41	40.80	45.74	44.80	43.88	42.26	44.01
Softness	21.60	36.46a	24.53	32.18a	22.93	30.45a	25.80	18.22	29.93a	17.78
Coarseness	9.20	24.86a	18.00a	21.67a	11.60	28.94a	18.20a	13.50	15.73	14.77
Wateriness	8.26	19.46a	16.06a	18.70a	9.33	17.44a	20.33a	15.07	16.20a	19.44a
Creaminess	40.33	35.60	33.93a	31.20a	41.93	34.80	30.60a	33.56a	37.26	30.20a
Gumminess	2.00	2.00	2.26	1.99	2.06	1.99	2.00	1.99	2.00	1.99
Chalkiness	2.00	3.93	4.86	15.13a	2.00	2.56	6.73	2.23	4.07	7.83a
Mouthcoating	39.33	34.87	36.67	35.77	40.20	36.70	37.40	35.53	39.27	35.60
Sweetness	41.33	42.86	41.13	37.83	42.93	42.00	36.80a	38.63	40.26	33.73a

---

[1] Means in a row followed by the letter **a** are significantly different from the control ($p \leq 0.05$).

Table 9 - Comparison of least squares means[1] of sensory attributes for replacement of fat with PSA2 at three levels of sucrose substitution in frozen desserts
b. Phase II

Sucrose Level(%)	100				50			0		
Fat Level	100	66	33	0	66	33	0	66	33	0
PSA2 Level	0	33	66	100	33	66	100	33	66	100
Sensory Attribute										
Coldness	42.98	43.40	42.78	42.17	43.07	40.80a	43.33	42.67	42.60	43.33
Softness	14.65	13.47	14.12	10.45a	10.66a	10.00a	7.73a	12.53	15.00	6.47a
Coarseness	22.84	40.13a	32.44a	49.61a	23.47	46.67a	47.47a	21.00	32.73a	43.47a
Wateriness	20.27	36.13a	32.54a	46.20a	23.93	44.00a	46.27a	24.07	30.67a	41.67a
Creaminess	32.89	19.93a	23.62a	10.76a	27.53	14.73a	9.27a	27.40	24.13a	15.93a
Gumminess	2.04	1.93	1.81	1.94	1.87	2.27	2.13	4.93	1.80	1.80
Chalkiness	26.97	31.46	39.87a	19.84	17.13	13.73a	28.53	14.33a	24.46	26.06
Mouthcoating	41.00	40.20	37.40a	38.47	38.80	36.80a	37.27a	39.86	37.53a	37.53a
Sweetness	.04	39.00	40.74	35.91a	39.33	37.06	34.13a	39.47	36.27a	34.20a

---

[1] Means in a row followed by the letter **a** are significantly different from the control ($p \leq 0.05$).

Table 10 - Comparison of least squares means[1] of sensory attributes for replacement of fat with N-OIL^R or PSA2 at three levels of sucrose substitution
a. Phase I

Sucrose Level(%)	100						50						0					
Fat Level	66		33		0		66		33		0		66		33		0	
N-OIL^R Level	33	0	66	0	100	0	33	0	66	0	100	0	33	0	66	0	100	0
PSA2 Level	0	33	0	66	0	100	0	33	0	66	0	100	0	33	0	66	0	100
Sensory Attributes																		
Coldness	41.13	43.13	43.74	42.20	43.40	41.41	42.73	40.80	43.41	45.74	42.48	44.80	44.20	43.88	43.00	42.26	41.53	44.01
Softness	37.33	36.46	36.62	24.53a	35.46	32.18	29.40	22.93a	28.78	30.45	28.78	25.80	20.33	18.22	27.13	29.93	22.06	17.78
Coarseness	33.06	24.86	1.54	18.00a	33.40	21.67a	19.86	11.60	31.30	28.94	21.24	18.20	20.40	13.50	27.06	15.73a	20.66	14.77
Wateriness	26.80	19.46a	28.84	16.06a	33.73	18.70a	20.13	9.33a	30.84	17.44a	23.64	20.33	15.93	15.07	26.40	16.20a	21.06	19.44
Creaminess	23.60	35.60a	28.80	33.93	20.20	31.20a	32.73	41.93a	25.16	34.80a	28.00	30.60	34.06	33.56	25.13	37.26a	25.20	30.20
Gumminess	2.00	2.00	1.99	2.26a	2.00	1.99	2.00	2.06	1.99	1.99	1.99	2.00	2.00	1.99	2.00	2.00	2.00	1.99
Chalkiness	6.07	3.93	11.30	4.86a	15.13	7.26a	2.00	2.00	13.83	2.56a	20.46	6.73a	7.00	2.23	15.93	4.07a	26.73	7.83a
Mouthcoating	34.33	34.87	33.90	36.67	32.40	35.77	35.53	40.20a	33.03	36.70	38.40	37.40	38.26	35.53	35.60	39.27	41.27	35.60a
Sweetness	40.80	42.86	40.83	41.13	38.13	37.83	39.73	42.93	37.60	42.00a	39.17	36.80	38.93	38.63	36.73	40.26	37.26	33.73

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[1] Paired means followed by the letter **a** are significantly different ($p \leq 0.05$).

Table 10 - Comparison of least squares means[1] of sensory attributes for replacement of fat with N-OIL^R or PSA2 at three levels of sucrose substitution
b. Phase II

Sucrose Level(%)	100						50						0					
Fat Level	66		33		0		66		33		0		66		33		0	
N-OIL^R Level	33	0	66	0	100	0	33	0	66	0	100	0	33	0	66	0	100	0
PSA2 Level	0	33	0	66	0	100	0	33	0	66	0	100	0	33	0	66	0	100
Sensory Attributes																		
Coldness	43.75	43.40	43.00	42.78	42.17	42.17	41.67	43.07	44.50	40.80	42.51	43.33	42.80	42.67	43.07	42.60	43.27	43.33
Softness	14.72	13.47	8.93	14.12a	8.55	10.45	9.45	10.66	9.19	10.00	6.85	7.73	13.67	12.53	10.66	15.00a	7.00	6.47
Coarseness	44.15	40.13a	50.40	32.44a	50.34	49.61	39.91	23.47a	46.45	46.67	48.18	47.47	26.27	21.00	40.07	32.73	47.27	43.47
Wateriness	41.07	36.13a	47.67	32.54a	48.57	46.20	37.37	23.93a	45.44	44.00	46.34	46.27	28.00	24.07	38.33	30.67	47.53	41.67
Creaminess	17.66	19.93	8.53	23.62a	8.09	10.76	18.69	27.53a	12.59	14.73	9.92	9.27	28.33	27.40	18.07	24.13	10.67	15.93
Gumminess	1.90	1.93	1.80	1.81	2.01	1.94	1.87	1.87	1.91	2.27	1.94	2.13	2.00	4.93a	1.87	1.80	1.87	1.80
Chalkiness	27.91	31.46	33.20	9.87a	31.44	19.84a	21.84	17.13	24.44	13.73	38.04	28.53	21.47	14.33	21.53	24.46	23.07	26.06
Mouthcoating	40.13	40.20	39.40	37.40	38.93	38.47	38.13	38.80	38.03	36.80	40.16	37.27a	37.60	39.86	37.27	37.53	36.00	37.53
Sweetness	39.61	39.00	37.13	40.74a	34.84	35.91	38.57	39.33	38.54	37.06	35.78	34.13	37.93	39.47	35.00	36.27	33.00	34.20

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[1] Paired means followed by the letter **a** are significantly different ($p \leq 0.05$).

differences were noted for mouthcoating and sweetness. Apparrently, samples were not significantly affected by ingredient variation for these attributes.

Effect of extended storage

Graphical representation of the effects of storage on sensory attributes (phase I vs. phase II) appears in Figures 3a - 3i. (Numerical data appears in Appendix A, Table A-3.) No significant differences were noted in fresh or stored samples for gumminess, mouthcoating, or sweetness. Comparison of phase I and phase II for coarseness, wateriness, creaminess, and chalkiness showed consistent trends. Note how curves for both phase I and phase II follow a similar pattern. The relative position among treament combinations are the same, i.e., nearly identical curves are simply shifted on the Y-axis.

Instrumental measurements

Mean values for viscosity, melting rate, and resistance to deformation of the frozen sample using the Instron appear in Table 11. All measurements, excluding viscosity, were made for phase I and II.

Viscosity of the unfrozen mix ranged from 38.8 to 78.2 Cps; mean = 56.3, median = 53.0. In general, treatment combinations with higher levels of fat, at the 100% sucrose level, had greater viscosity (see Table 12). Treatment

Table 11 - Mean values for physical measurements

Treatment Combination	**Unfrozen Mix Viscosity** (Cps)	**Level of Air Incorporation** (% Overrun)	**Meltdown** (68 ± 2°F) (ml after 30 min)		I N S T R O N (kg/sec)			
					Cone Penetrometer		**Plunger**	
			phase I	phase II	phase I	phase II	phase I	phase II
1	66.7	35.7	22.0	16.3	0.19	1.34	133.3	288.0
2	51.1	48.5	22.0	13.7	0.05	0.39	48.8	346.7
3	45.8	42.4	18.3	12.3	0.11	0.67	66.7	493.3
4	38.8	67.8	18.7	12.7	0.14	0.97	96.7	880.0
5	58.2	51.7	19.7	14.7	0.06	0.54	52.5	333.3
6	51.1	34.7	8.3	11.7	0.15	0.90	89.2	516.7
7	45.1	46.1	22.7	12.3	0.09	0.82	72.0	370.0
8	78.2	21.5	15.0	16.7	0.26	1.13	121.2	390.0
9	53.0	51.0	20.0	13.3	0.15	0.86	112.0	815.0
10	49.8	33.1	17.3	12.0	0.18	0.78	78.3	783.3
11	45.5	67.7	19.3	12.0	0.11	0.77	76.7	690.0
12	74.2	44.9	20.7	13.0	0.35	1.27	126.7	648.0
13	52.8	42.4	16.3	14.3	0.11	0.70	70.0	790.0
14	51.0	35.1	19.7	6.7	0.17	1.14	113.3	813.3
15	77.7	31.2	20.0	14.0	0.34	1.55	138.3	828.0
16	60.2	45.7	18.3	15.7	0.27	1.01	100.8	185.0
17	53.2	50.4	18.7	15.3	0.27	0.93	103.3	696.0
18	49.2	55.5	18.7	16.7	0.30	1.23	154.0	736.7
19	61.7	43.4	16.7	16.7	0.45	1.53	152.5	613.4
20	58.7	41.5	20.0	13.7	0.20	0.84	83.3	530.0
21	59.5	54.6	18.0	8.3	0.32	1.95	212.0	1343.3

Table 12 - Ranked viscosity measurements

Viscosity[1]	Rank	Treatment Combination[2]	Sucrose Level (%)	Fat Level
38.8	1	4[a]	100	0
45.1	2	7[a]	100	0
45.5	3	11[a]	50	0
45.8	4	3	100	33
49.2	5	18	0	66
49.8	6	10	50	33
51.0	7	14[a]	50	0
51.1	8	2	100	66
51.1	9	6	100	33
52.8	10	13	50	33
53.0	11	9	50	66
53.2	12	17	0	33
58.2	13	5	100	66
58.7	14	20	0	33
59.5	15	21[a]	0	0
60.2	16	16	0	66
61.7	17	19	0	66
66.7	18	1[b]	100	100
74.2	19	12	50	66
77.7	20	15[b]	0	100
78.2	21	8[b]	50	100

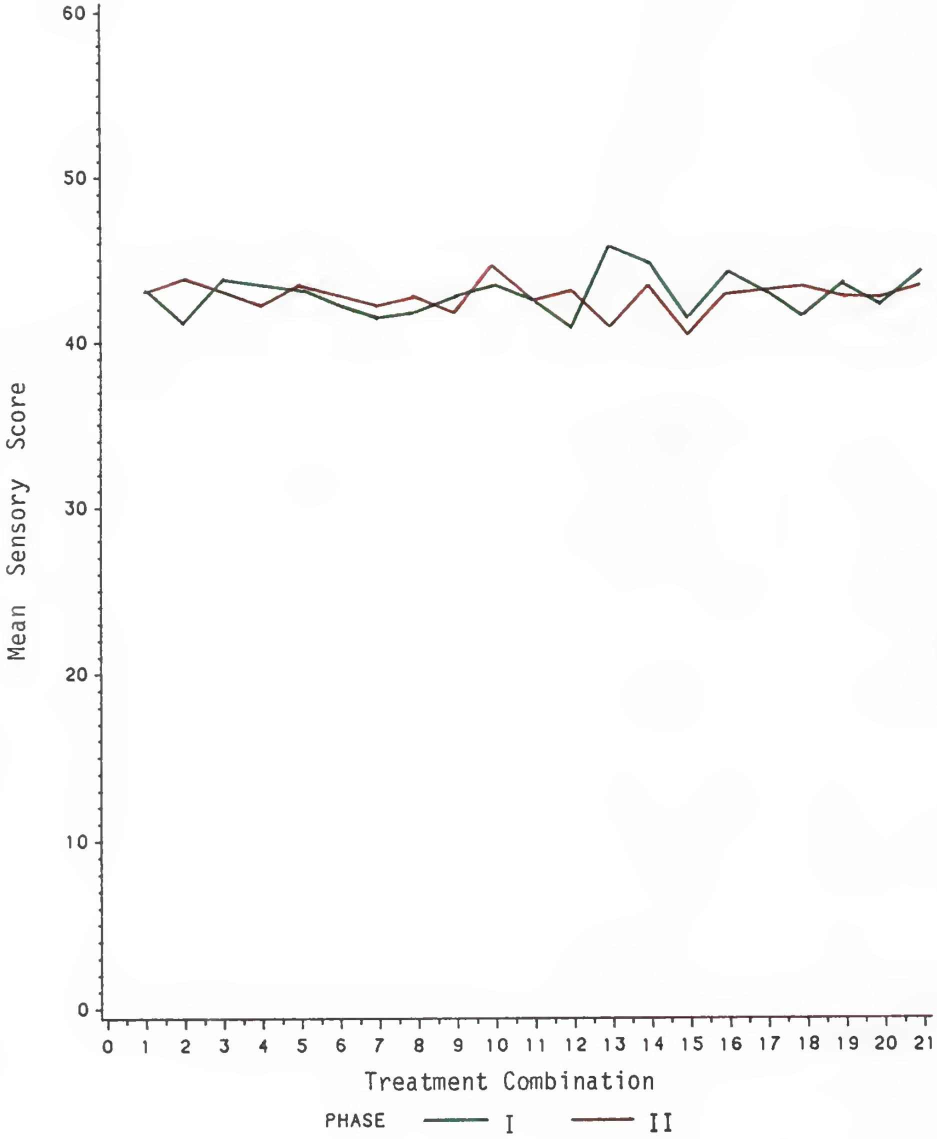
[1] Centipoises; measured using U.K. Viscometer, Model RV8, spindle #2.
[2] Treatment combination numbers given in Table 6.
[a] Fat level 0%.
[b] Fat level 100%.

Figure 2 - Effect of 140-day storage[1] on sensory response[2]

[1] Mean values based on scores from five panelists and three replications.

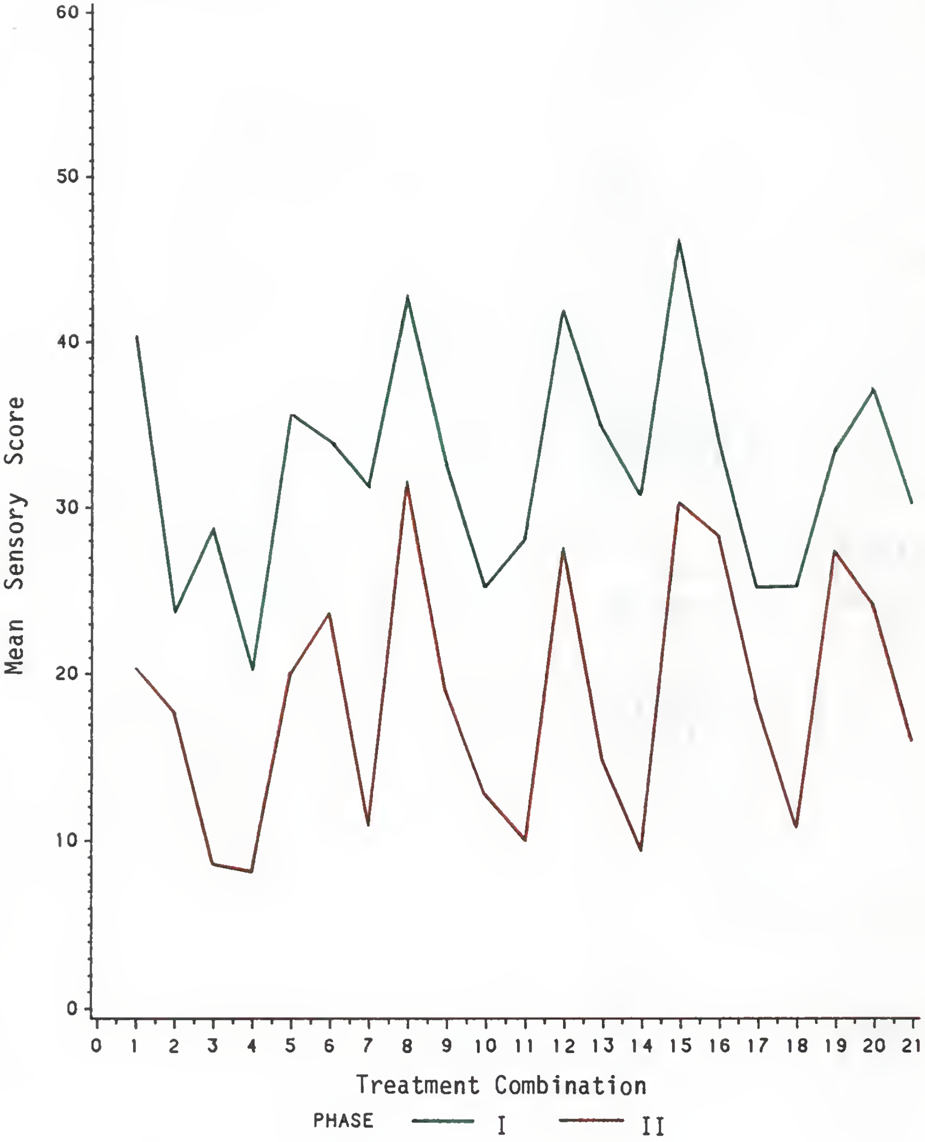
[2] Horizontal axis refers to treatment combination numbers given in Table 6.

a. Coldness

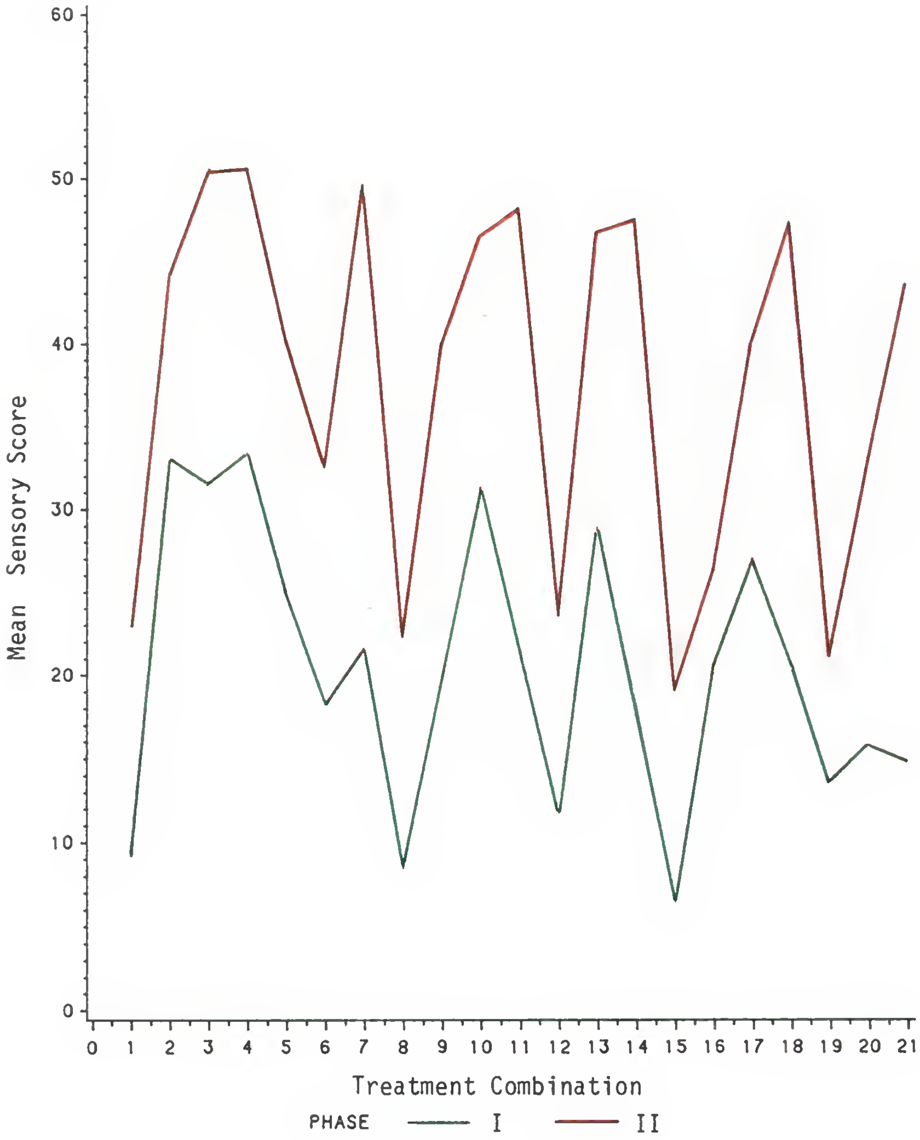


60
50
40
30
20
10
0
Mean Sensory Score
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Treatment Combination
PHASE
I
II

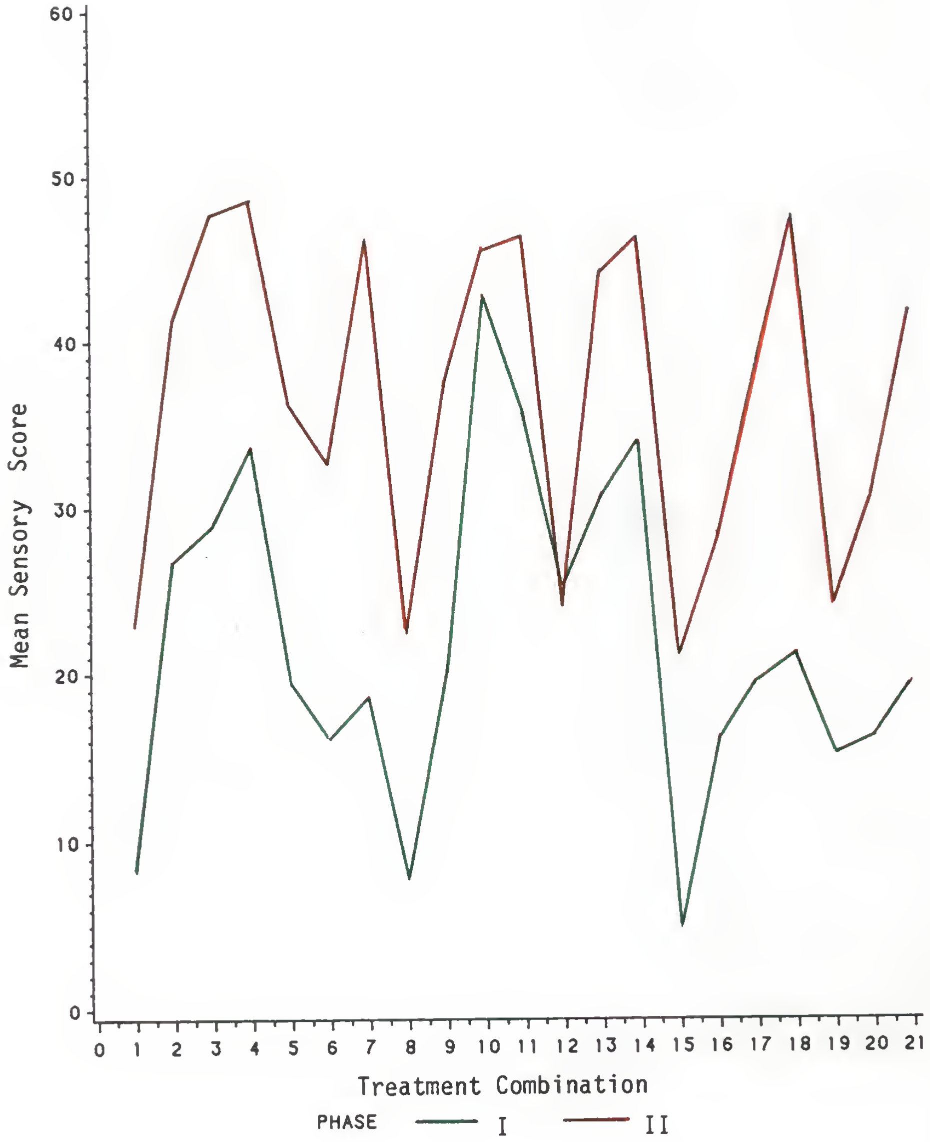
b. Softness


Mean Sensory Score
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Treatment Combination
PHASE
I
II

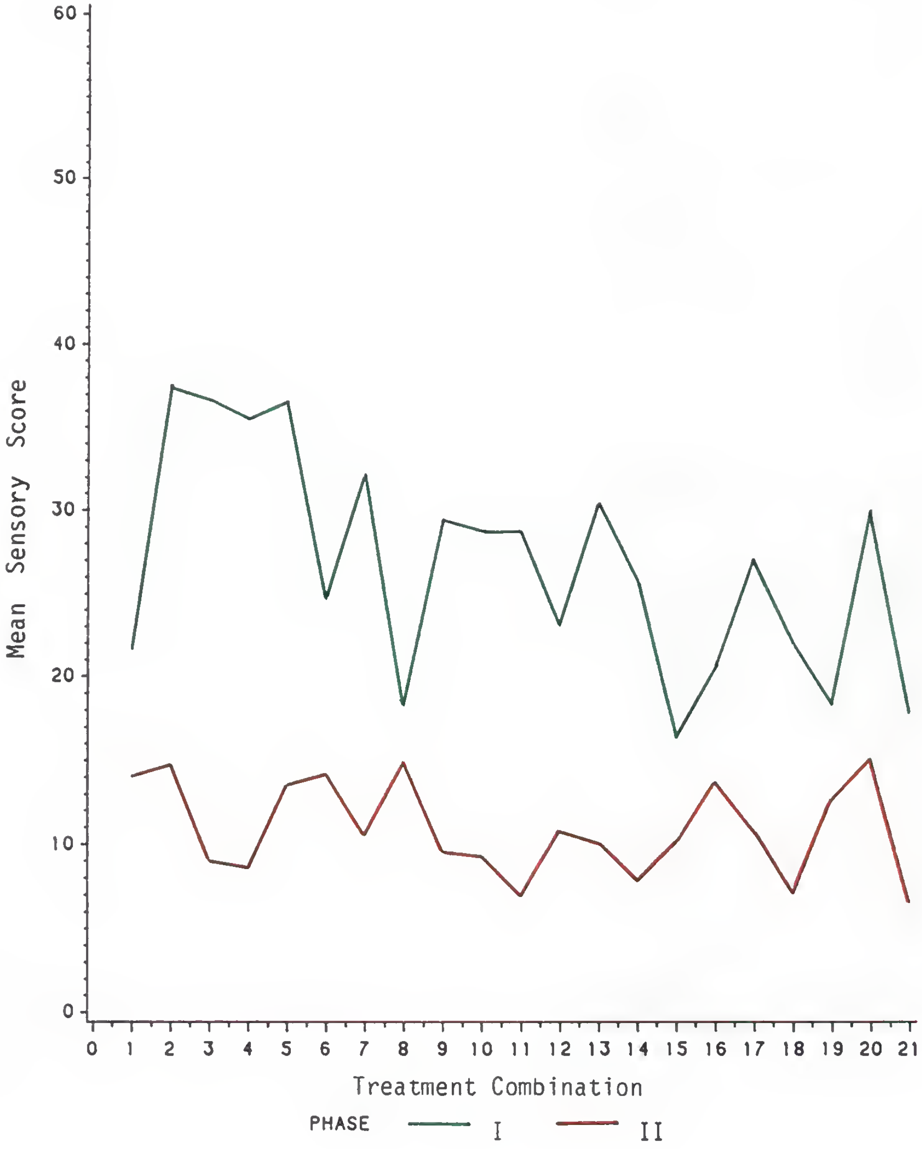
c. Coarseness



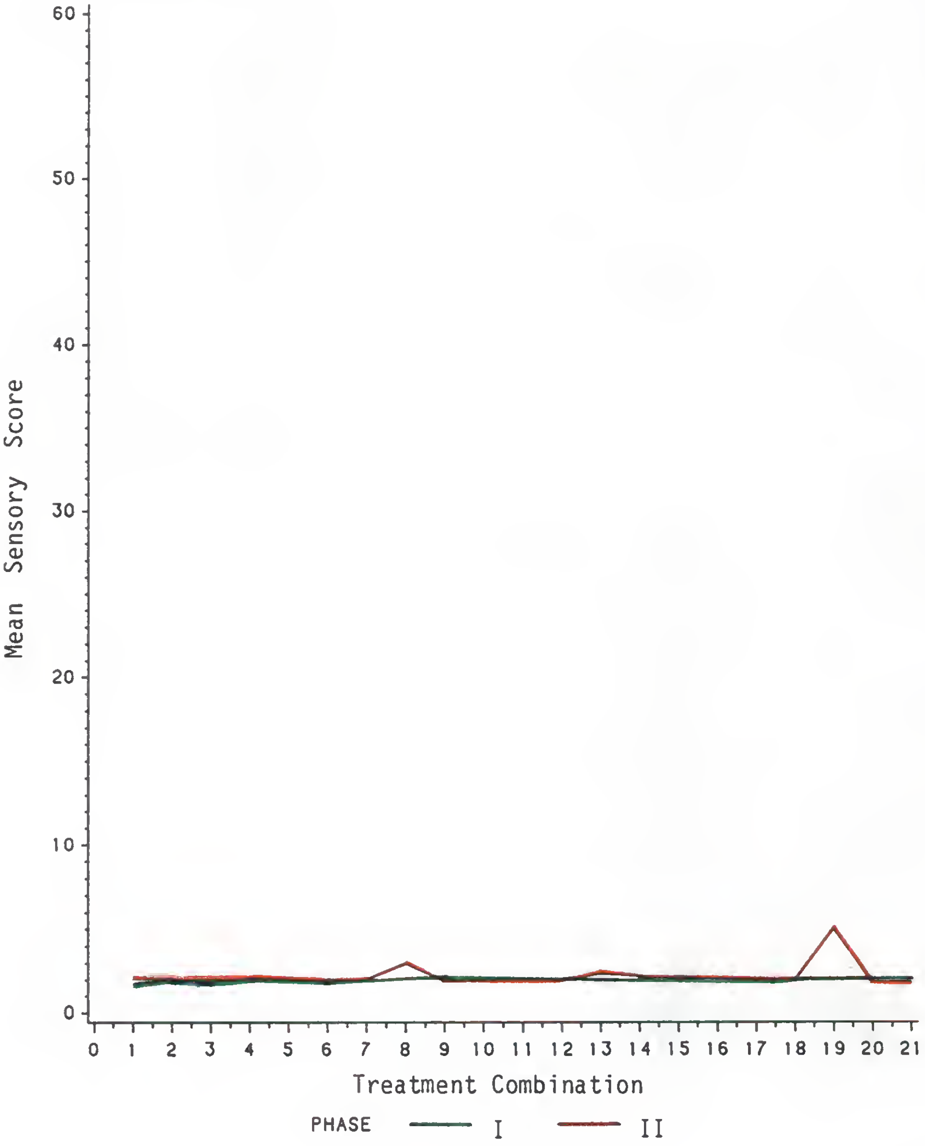
d. Wateriness



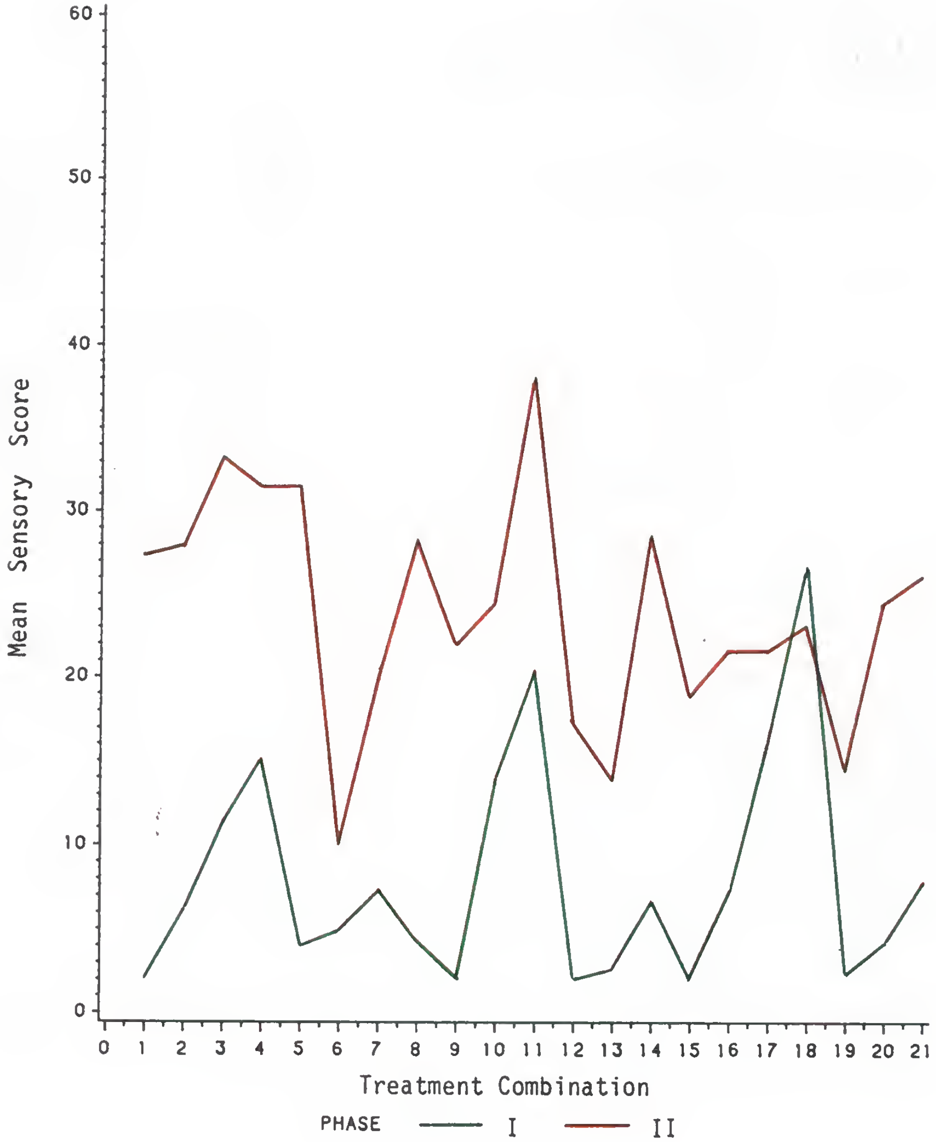
e. Creaminess



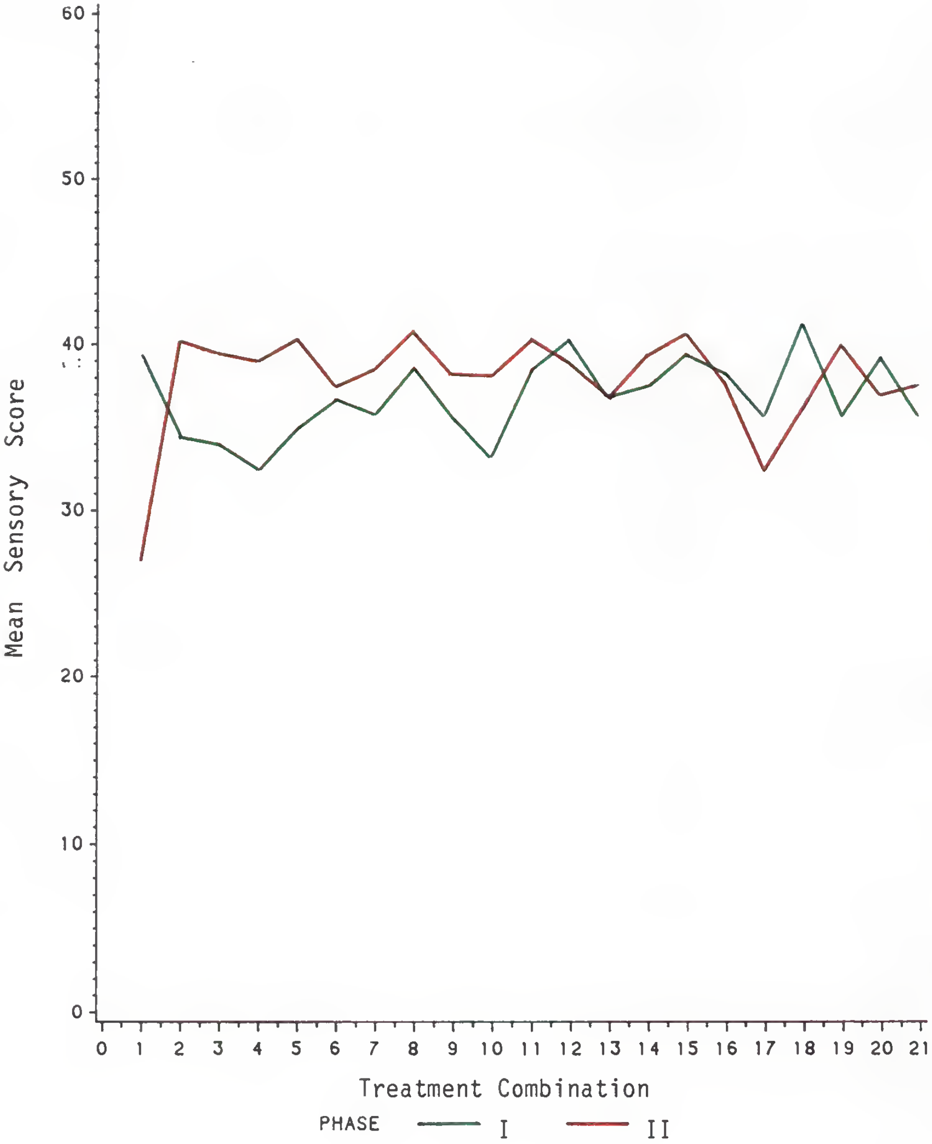
f. Gumminess


Mean Sensory Score
0
10
20
30
40
50
60
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
Treatment Combination
PHASE
I
II

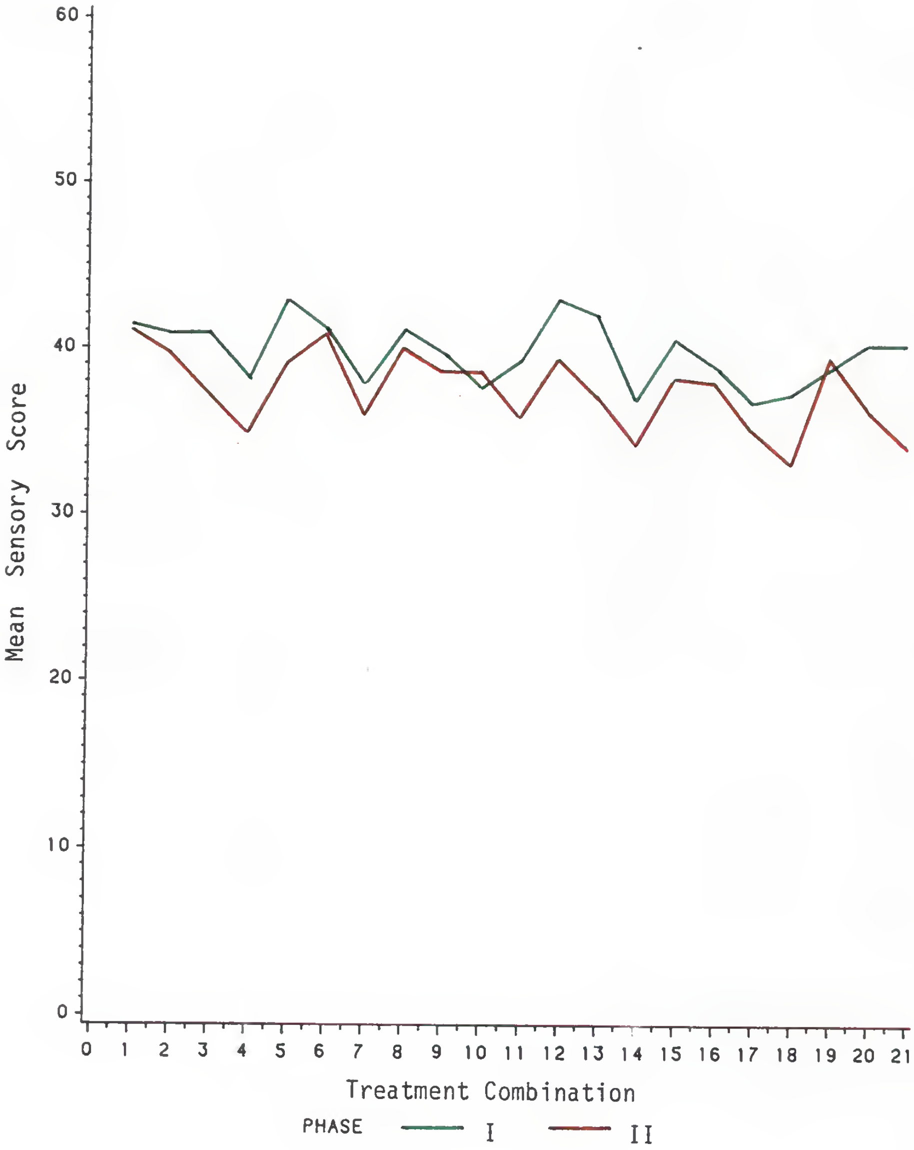
g. Chalkiness



h. Mouthcoating



i. Sweetness


60
50
40
30
20
10
0
Mean Sensory Score
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Treatment Combination
PHASE
I
II

combinations with varying levels of sucrose, at the 100% fat level, fall within a fairly narrow viscosity range. Therefore, viscosity appears to be independent of sucrose concentration.

Melting rate was fairly constant across treatment combinations. Values for phase I ranged from 8.3 to 22.7 ml with an average of 20.3 ml of melted sample collected after 30 min exposure to room temperature. Average melt for phase II was 13.4 ml with values ranging from 6.7 to 16.7. Since very few significant differences were found between treatment combinations in phase I or phase II, meltdown appears to be independent of sugar or fat content.

Resistance to deformation. Data obtained on the Instron for both cone and plunger attachments were inconsistent. No clear trends among treatment combinations within phase I or phase II were observed. It can be seen by comparing phase I and phase II, however, that resistance to deformation for all samples (both attachments) increased after storage. This is in general agreement with the sensory data, where increased values for coarseness and decreased values for softness were recorded after storage.

Figure 3 - Effect of 140-day storage[1] on melting rate[2]

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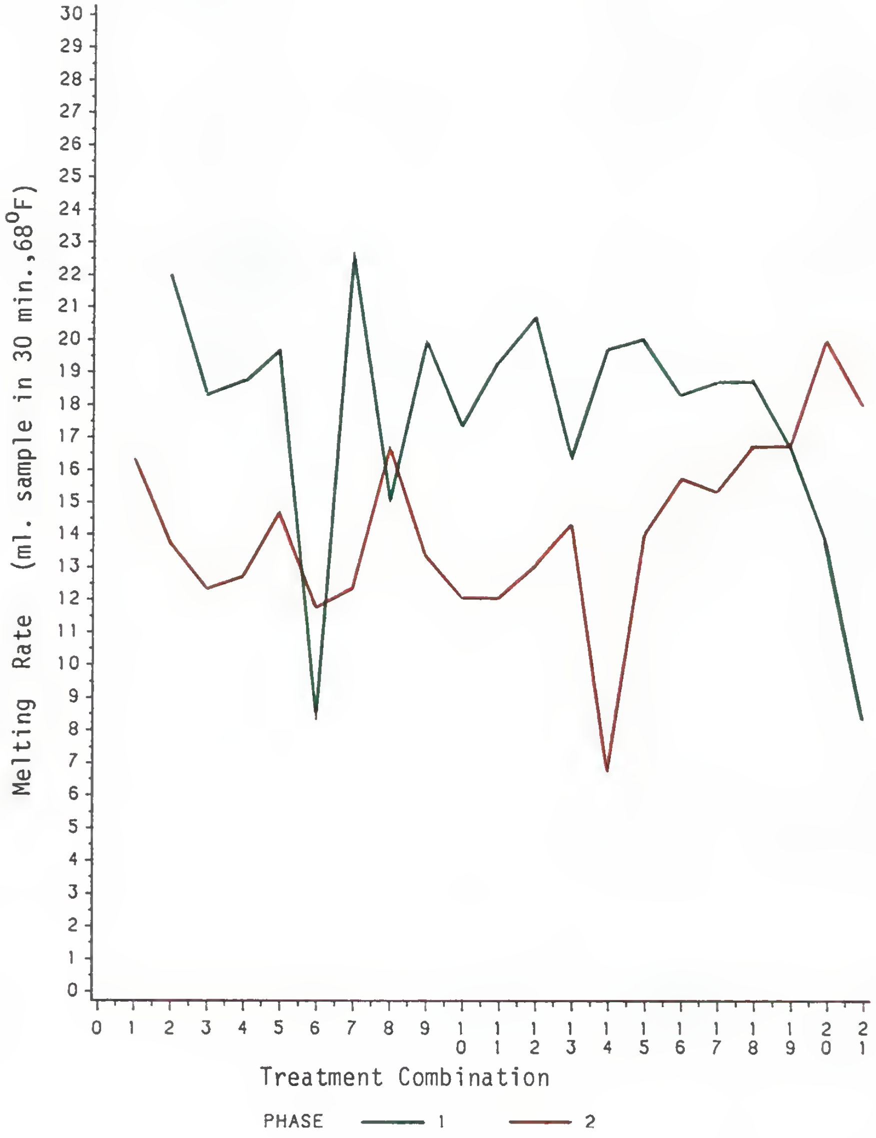
[1] Mean values based on scores from five panelists and three replications.

[2] Horizontal axis refers to treatment combination numbers given in Table 6.


Melting Rate (ml. sample in 30 min.,68^{o}F)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
Treatment Combination
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
PHASE
1
2

Correlation of instrumental data and sensory response

Spearman correlation coefficients calculated between viscosity and each of the eight textural attributes appear in Table 13. Moderate correlation coefficients (r = 0.40-0.80) were found for viscosity and phase I values for coarseness and wateriness. In general, ranked scores for coarseness and wateriness show an inverse relationship with viscosity (Figures 3a and 3b). The trends are somewhat inconsistent, however, which makes sense, given the low to moderate correlation coefficients. Low correlation values (r = 0-0.40) were observed for the remaining textural attributes.

Correlation coefficients calculated between cone penetrometer and plunger readings and sensory scores for coarseness and softness, respectively, are listed in Table 13. These values were disappointingly low and not considered significant. None of the instrumental measurements collected in this study appear to be reliable predictors of the sensory textural attributes evaluated.

Figure 4 - Comparison of ranked values for viscosity and sensory response for coarseness[1]

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[1] Horizontal axis refers to treatment combination numbers given in Table 6.

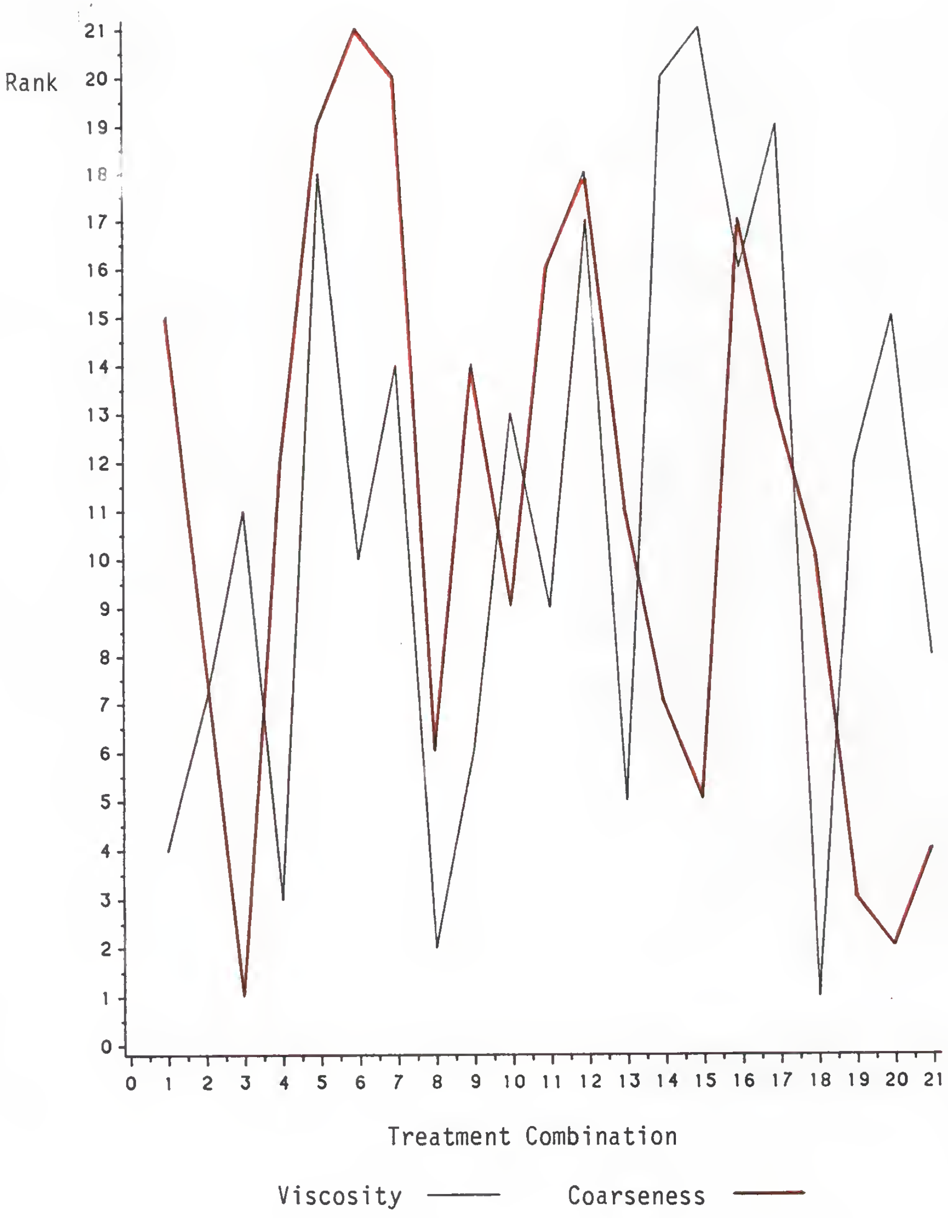
Rank
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
Treatment Combination
Viscosity
Coarseness

Figure 5 - Comparison of ranked values for viscosity and sensory response for wateriness[1]

---

[1] Horizontal axis refers to treatment combination numbers given in Table 6.

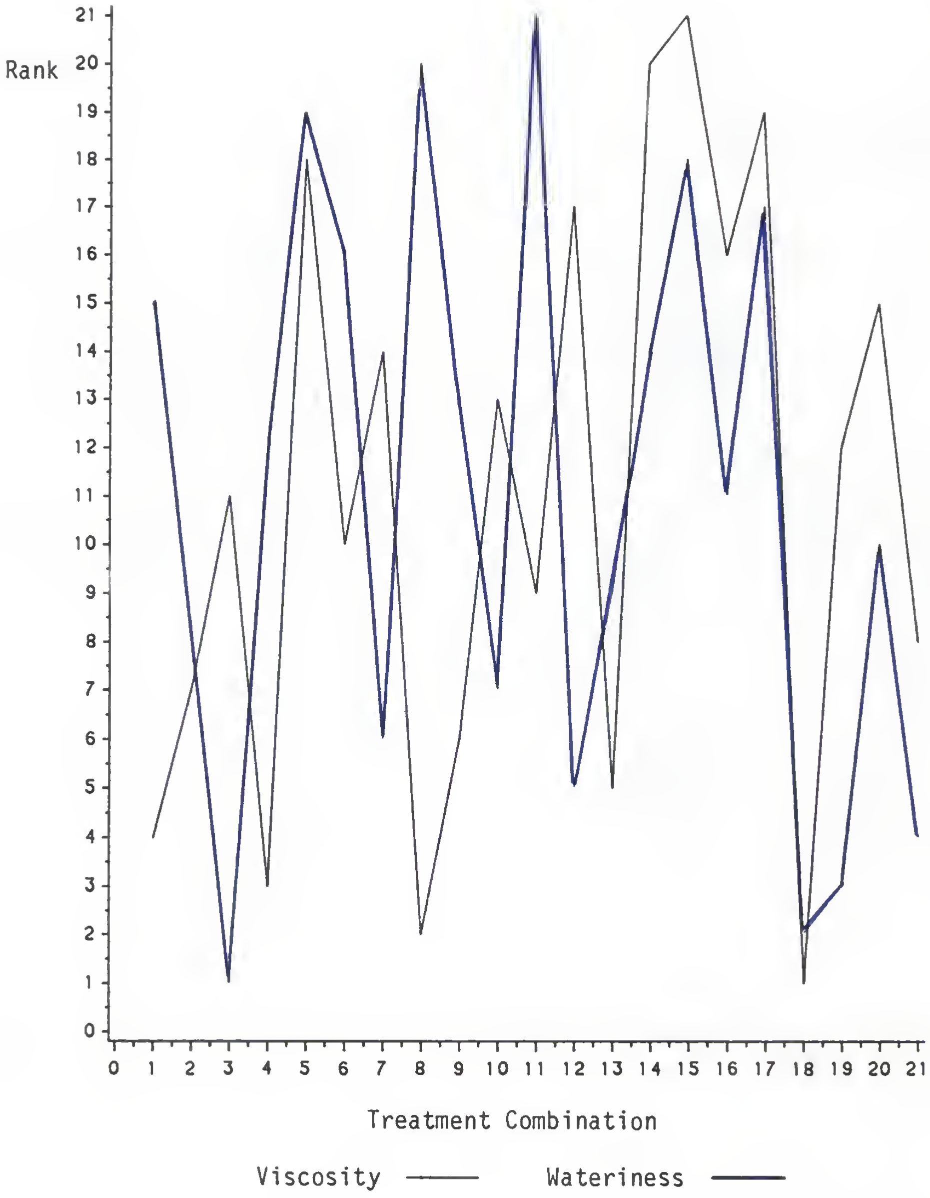
Rank
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
Treatment Combination
Viscosity
Wateriness

Table 13 - Spearman correlation coefficient values for sensory evaluation and instrumental measurements

	Phase I	INSTRON		Phase II	INSTRON	
Sensory Attribute	Viscosity	Cone Penetrometer	Plunger	Viscosity	Cone Penetrometer	Plunger
Coldness	0.29			0.29		
Softness	0.15		-0.11	-0.03		0.10
Coarseness	-0.53	-0.22		-0.21	-0.36	
Wateriness	-0.35			-0.28		
Creaminess	-0.21			-0.10		
Gumminess	0.08			0.10		
Chalkiness	0.25			-0.10		
Mouthcoating	0.12			-0.37		
Sweetness	-			-		

Polydextrose effects

Although significant differences were not found, increasing levels of polydextrose in phase I led to lower scores for coarseness and wateriness and higher scores for creaminess. Thus, polydextrose appears to be at least as effective as sucrose in tying up water and inhibiting formation of the large ice crystals responsible for coarse, watery texture. In phase II, polydextrose samples were less chalky than the control. Polydextrose might also inhibit the development of chalkiness during extended storage.

Proposed mechanisms. Successful substitution of polydextrose for sucrose in frozen desserts has been reported by Torres and Thomas, 1981 and Goff and Jordan, 1984. No report has been made, however, on the mode of polydextrose functionality. The following mechanisms are proposed:

(1) Replacement of solids

Polydextrose was substituted for sucrose on a 1:1 solids basis. Bulking ability of polydextrose should be comparable to that of sucrose,

(2) Control of moisture migration

As a water-soluble bodying agent, polydextrose functions as a humectant, promoting moisture retention and slowing undesirable migration of water molecules within the system, and

(3) Freezing point depression

Baer and Baldwin (1984) demonstrated the capacity of polydextrose to lower the freezing point of the unfrozen mix. The level of water-binding is related to the molecular structure of the bulking agent and the associated level of freezing point depression (Harper and Shoemaker, 1983). Polydextrose compares favorably with sucrose in its ability to tie up water and inhibit formation of the large ice crystals associated with coarse, watery texture.

Fat sparing. For trials with fat replaced by either N-OIL^{R} or PSA2, coarseness and wateriness appear to be held in check or reversed as the level of polydextrose is increased. As more fat is removed from the system, coarseness and waterinesss are expected to increase and creaminess to decrease. This holds true at the 100% sucrose level. As increasing amounts of sucrose are removed from the system, however, negative effects (related to the absence of fat) on textural attributes are actually less apparent.

Polydextrose effectively compensates for sucrose removal and improves textural properties in the absence of fat. This is in accordance with the manufacturer's claim that polydextrose can simultaneously replace 100% of the sugar and part of the fat in a frozen dessert system.

Starch gel effects

Tapioca and potato starch. Gels based on modified tapioca or potato starch are uniquely suited to confer functional properties normally provided by milkfat in a frozen dessert system. Low levels of lipid and protein and a relatively high degree of polymerization promote formation of gels with desirable rheological properties and high resistance to retrogradation and syneresis during storage (Swinkels, 1985). (A supplemental discussion of common cereal starches and starch-based gel systems is presented in Appendix D.)

Differences in gel-forming properties of modified tapioca and potato starch, however, are not easily explained. While the native granules have been extensively investigated, properties of the modified starches are not well known. (The manufacturers would not reveal the nature of the modifications of N-OIL^R or PSA2.)

As indicated in Table 14, many similarities exist between native potato and tapioca starch granules. One difference worth noting, however, is that potato starch granules are larger and exhibit higher water-binding capacity. According to Hood and Siefried (1974), gel properties are directly related to particle size and degree of hydration. The ability of modified potato starch granules to hold more water might explain the lower scores for coarseness and wateriness seen in PSA2 trials.

Table 14 - Composition and properties of native starch granules[1]

Starch Components	Type of Starch				
	Tapioca	Potato	Wheat	Maize	Waxy Maize
Lipid level[2]	0.10	0.05	0.80	0.70	0.15
Protein level[2]	0.10	0.06	0.40	0.35	0.25
% Moisture	13	19	13	13	13
Amylose Content[2]	17	21	28	28	0
Amylopectin Content[2]	83	79	72	72	100
D.P.[3]	3000	3000	800	800	-
Water-binding Capacity[4]	20	24	13	15	22
Rate of retrogradation	slow	slow	med	med	slow
Paste texture	long	long	short	short	long
Relative amount of odor or flavor	low (clean)	med-low (neutral)	med	med	low

---

[1] Adapted from Swinkels, 1985.
[2] On a %dry weight basis.
[3] Degree of polymerization (amylose fraction).
[4] In parts of water /part dry native starch to give equal viscosity after cooking.

Proposed mechanisms. The capacity of starch gels to compensate for textural and physical properties of milkfat might be attributed to the following mechanisms:

(1) Impact on mouthfeel

Hydrated starch particles influence the manner in which the frozen mass feels and liquefies in the mouth, i.e., swelling creates "fluffed up" granules which lubricate ice crystals & amplify the perception of creaminess

(2) Colloidal properties of starch

In addition to influencing the perception of textural attributes, starch polymers act as hydrophillic colloids,

- increasing the viscosity of the continuous phase (in the unfrozen mix) and improving subsequent foam formation and stability
- restricting growth of large ice crystals during freezing and decreasing the proportion of water converted into ice
- inhibiting heat shock during storage
- inhibiting phase separation during meltdown

Change in total solids. Fat contributes nearly one-third of the total solids in conventional ice cream (31.5% for the control used in this study). The substitution ratio, based on solids, starch : fat, was 1 : 4. Mixes with 100% fat replacement contained 29% solids in comparison to 38% solids for the control. The reduced proportion of solids in N-OIL^R and PSA2 trials, in all probability, contributed to differences in textural attributes in fat replacement trials.

Nature of the starch gel. What remains to be identified is the nature of the starch-water associations formed. Are individually swollen particles dispersed throughout the continuous phase like fat droplets in conventional ice cream, or is a gel matrix more or less incorporated into the general structure of the system?

Since the lipid fraction in ice cream is found dispersed both as individual, intact droplets and as a continuous network of agglomerated globules held together by liquid oil from partially de-emulsified and ruptured droplets (Berger, 1976), perhaps corresponding types of gel structures are also present.

As an insoluble constituent in ice cream, the lipid fraction displaces, but does not interact with, water, and therefore has only an indirect influence on the rheology of the aqueous phase. When modified starch granules are dispersed in water, however, they associate with a large number of water molecules, primarily through hydrogen bonding (Nielsen, 1984). The three-dimensional network formed reduces the mobility of the aqueous phase, impedes heat transfer, and slows migration of solutes away from water during storage.

Fat droplets provide a mechanical barrier to the growth of large ice crystals and, in addition, lubricate the crystals already present. Tiny, individual gel particles, less than 5µ in diameter, may also confer a lubricating effect, enhancing creaminess and decreasing the perception of coldness and coarseness (Kaper, 1988). This mechanism has been proposed for Simplesse, the fat substitute based on protein gels developed by Nutrasweet, Inc.: "micro-gel" particles are believed to "fool the tongue" into perceiving a smooth, continuous, fat-like material (McCormick, 1988).

Future studies

Additional investigations might include microscopical examination of possible differences in structure and subsequent swelling behavior between modified potato and modified tapioca starch granules. Examining the nature of the gel matrix formed using simplified model systems (e.g., gels, pastes) might help explain the relative capacity of N-OIL^R and PSA2 to replace the lipid fraction in complex food systems.

Possible ingredient interactions within the system might also be studied. Other components influence gel structure and stabilty, for example, low molecular weight solutes such as sucrose compete for water-binding loci, resulting in the formation of softer, less rigid gels. The nature of certain macromolecular interactions which might influence to gel structure and stability, e.g., associations between starch polymers and milk proteins, might also be explored.

If the study were to be repeated, the following recommendations are offerred:

(1) limit the investigation to assessing the effects of either fat or sucrose replacement, possibly employing polydextrose as a third fat substitute and evaluating its efficacy in relation to N-OIL^{R} and PSA2,

(2) equilibrate the level of solids and percent air incorportaion among treatment combinations, since varying either of these factors might contribute to differences in textural attributes beyond that associated with ingredient variation, and

(3) record the number of freeze-thaw cycles occurring per day and monitor temperature fluctuations within the storage chamber; in addition, limiting storage time to 60 days might allow for assessment of greater number of significant differences between fat and sucrose replacement trials and the control.

CONCLUSIONS

1. Polydextrose proved to be an effective bulking agent maintaining textural properties, relative to the control, in the absence of sucrose. Replacing sucrose with a polydextrose-APM combination did not significantly alter sensory response for textural attributes evaluated in this study.

2. Polydextrose improved textural properties in the absence of fat, relative to the control. The results of this study support the manufacturer's claim that polydextrose functions as a fat-sparing agent.

3. PSA2 was relatively more effective than N-OIL^R in conferring textural properties normally provided by fat. The consistently high rating for chalkiness in N-OIL^R trials indicate that this material is probably not suitable for use in frozen desserts similar to the ones prepared in this study. PSA2, in contrast, inhibited development of chalkiness, particularly after extended storage.

This material can successfully replace physical and textural properties up to the 33% level of fat substitution.

4. None of the instrumentally measured physical properties - viscosity, melting rate, resistance to deformation - appear to be reliable predictors of the sensory textural atributes evaluated in this study.

5. Microscopical examination of the differences in basic structure and swelling behavior between the two modified starches, as well as investigation of the physical nature of the gel system and possible interactions between system components (e.g., starch polymers and milk proteins) might help to explain the mechanisms occurring when starch gels are employed to replace milkfat in a frozen dessert system.

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ACKNOWLEDGEMENT

To Mark, for his love and friendship.

To Cindy, for her love and friendship.

APPENDIX

Table A-1 - F-values and corresponding level of significance[1] from analysis of variance for sensory data
a. Phase 1

Sensory Attribute	Source of Variation				
	trt[2]	rep[2]	pnlst[2]	trt-pnlst	rep-pnlst
Coldness	1.04	0.60	12.96	0.85	3.30
	(n/s)	(n/s)	(.0001)	(n/s)	(.0015)
Softness	9.92	0.89	18.65	1.15	1.83
	(.0001)	(n/s)	(.0001)	(n/s)	(n/s)
Coarseness	7.04	3.14	11.78	0.83	2.22
	(.0001)	(n/s)	(.0001)	(n/s)	(.0274)
Wateriness	10.03	13.25	18.64	1.06	1.92
	(.0001)	(.0001)	(.0001)	(n/s)	(n/s)
Creaminess	9.02	7.26	1.25	0.97	1.83
	(.0001)	(.0009)	(n/s)	(n/s)	(n/s)
Gumminess	1.01	0.52	0.85	1.13	0.91
	(n/s)	(n/s)	(n/s)	(n/s)	(n/s)
Chalkiness	14.97	4.22	12.25	1.53	5.58
	(.0001)	(.0161)	(.0001)	(.0095)	(.0001)
Mouthcoating	2.20	6.01	40.48	1.78	4.80
	(.0033)	(.0029)	(.0001)	(.0007)	(.0001)
Sweetness	2.54	0.81	7.41	0.82	2.09
	(.0006)	(n/s)	(.0001)	(n/s)	(.0383)

---

[1] Probabilities shown in parentheses
n/s - not significant.

[2] Trt - treatment, rep - repetition, pnlst - panelist.

Table A-1 - F-values and corresponding level of significance[1] from analysis of variance for sensory data
b. Phase II

Sensory Attribute	Source of Variation				
	trt[2]	rep[2]	pnlst[2]	trt-pnlst	rep-pnlst
Coldness	1.61	0.25	48.00	1.18	4.87
	(n/s)	(n/s)	(.0001)	(n/s)	(.0001)
Softness	4.41	19.11	16.22	0.56	1.45
	(.0001)	(.0001)	(.0001)	(n/s)	(n/s)
Coarseness	12.66	37.52	3.74	0.32	2.11
	(.0001)	(.0001)	(.0059)	(n/s)	(.0363)
Wateriness	11.60	57.98	3.61	0.40	1.16
	(.0001)	(.0001)	(.0073)	(n/s)	(n/s)
Creaminess	10.95	63.24	2.22	0.45	1.04
	(.0001)	(.0001)	(n/s)	(n/s)	(n/s)
Gumminess	1.09	0.66	8.03	0.94	1.10
	(n/s)	(n/s)	(.0001)	(n/s)	(n/s)
Chalkiness	3.07	80.56	2.49	0.49	1.55
	(.0001)	(.0001)	(.0446)	(n/s)	(n/s)
Mouthcoating	2.14	6.73	35.54	1.05	8.40
	(n/s)	(n/s)	(n/s)	(n/s)	(n/s)
Sweetness	5.18	12.87	32.91	1.05	8.40
	(.0001)	(.0001)	(.0001)	(.0045)	(.0013)

---

[1] Probabilities shown in parentheses
n/s - not significant.

[2] Trt - treatment, rep - repetition, pnlst - panelist.

Table A-2 - F-values and corresponding level of significance[1] from analysis of variance for comparison of sensory scores: phase I vs. phase II

	Source of Variation	
Sensory Attribute	**Time**[2]	**Treatment - Time**
Coldness	0.07 (n/s)	1.06 (n/s)
Softness	570.78 (.0001)	5.84 (.0001)
Coarseness	165.37 (.0001)	1.24 (n/s)
Wateriness	181.20 (.0001)	0.80 (n/s)
Creaminess	119.96 (.0001)	0.75 (n/s)
Gumminess	0.20 (n/s)	0.98 (n/s)
Chalkiness	53.51 (.0001)	0.59 (n/s)
Mouthcoating	11.02 (.0019)	1.45 (n/s)
Sweetness	43.43 (.0001)	1.18 (n/s)

[1] Probabilities shown in parentheses
n/s - not significant.

[2] Interim between phase I and II.

Table A-3 - Comparison of least squares means[1] for sensory attributes: phase I and phase II

Treatment Combination	Phase	Sensory Attributes[2]								
		CLDN	SFTN	CRSE	WATR	CRMN	GUMN	CHLK	MTHC	SWTN
1	I	43.13	21.60	9.20	8.27	40.33	2.00	2.00	39.33	41.33
	II	43.00	14.47a	22.93a	20.87a	32.27	1.93	27.40a	40.60	38.67
2	I	41.13	37.33	33.07	26.80	23.60	2.00	6.07	34.33	40.80
	II	43.67	14.73a	44.20	41.13a	17.60	1.87	26.93a	39.73a	29.87
3	I	43.67	36.80	31.93	29.27	28.33	2.00	11.53	33.87	41.20
	II	43.00	8.93a	50.40a	47.67a	8.53a	1.80	33.20a	39.40a	37.13a
4	I	43.40	35.47	33.40	33.73	20.20	2.00	15.13	32.40	38.13
	II	42.27	8.47a	50.47a	48.73a	7.80a	1.93	30.93	38.27a	35.20
5	I	43.13	36.47	24.87	19.47	35.60	2.00	3.93	34.87	42.87
	II	43.40	13.47a	40.13a	36.13a	19.93a	1.93	31.47a	40.20a	39.00a
6	I	42.20	24.53	18.00	16.07	33.93	2.26	4.87	36.67	41.13
	II	42.73	13.87a	33.00a	33.13a	23.33	1.73	8.67	36.80	40.67
7	I	41.47	32.00	20.93	18.93	31.13	2.00	7.00	36.00	37.93
	II	42.20	10.20a	49.73a	46.60a	10.40a	1.87	19.00	38.07	36.27
8	I	41.80	18.13	8.33	7.67	42.87	2.06	4.20	38.73	41.13
	II	42.67	14.73	22.20a	22.33a	31.53	2.93	28.27a	40.67	40.00
9	I	42.73	29.40	19.87	20.13	32.73	2.00	2.00	35.53	39.73
	II	41.80	9.20a	40.07a	37.60a	18.33a	1.80	21.13	38.07	38.40
10	I	43.33	28.53	30.13	30.53	25.27	2.00	14.20	33.20	38.40
	II	44.60	9.07a	46.67a	45.80a	12.40a	1.87	23.73	37.53	38.20
11	I	42.20	29.07	20.47	23.47	28.40	2.00	20.87	38.07	39.67
	II	42.67	6.53a	48.67a	46.40a	9.73a	1.87	38.07	39.87	35.53a
12	I	40.80	22.93	11.60	9.33	41.93	2.07	2.00	40.20	42.93
	II	43.07	10.67a	23.47	23.93a	27.53a	1.87	17.13	38.80	39.33a
13	I	45.67	30.73	28.00	17.20	35.27	2.00	2.33	36.60	42.47
	II	40.80a	10.00a	46.67a	44.00a	14.73a	2.27	13.73	36.80	37.07a
14	I	44.80	25.80	18.20	20.33	30.60	2.00	6.73	37.40	36.80
	II	43.33	7.73a	47.46a	46.27a	9.27a	2.13	28.53a	37.27	34.13
15	I	41.40	16.20	6.27	4.73	46.27	2.13	2.00	39.40	40.53
	II	40.33	10.00a	18.93a	21.00a	30.27a	1.93	18.73	40.60	38.20
16	I	44.20	20.33	20.40	15.93	34.07	2.00	7.00	38.27	38.93
	II	42.80	13.67a	26.26	28.00	28.33	2.00	21.47	37.60	37.93
17	I	43.00	27.13	27.07	26.40	25.13	2.00	15.93	35.60	36.73
	II	43.07	10.67a	40.07a	38.33	18.07	1.87	21.53	37.27	35.00
18	I	41.53	22.07	20.67	21.07	25.20	2.00	26.73	41.27	37.27
	II	43.26	7.00a	47.27a	46.53a	10.67a	1.87	23.07	36.00a	33.00a
19	I	43.60	17.93	13.07	14.20	34.80	2.00	2.00	35.87	38.87
	II	42.67	12.53	21.00	24.07	27.40	4.93	14.33	39.87	39.47
20	I	42.27	29.93	15.73	16.20	37.27	2.00	4.07	39.27	40.27
	II	42.60	15.00a	32.73a	36.70a	24.13a	1.80	24.47a	36.87	36.27a
21	I	43.73	18.20	14.87	19.47	30.60	2.00	7.40	35.07	33.73
	II	43.33	6.47a	43.47a	41.67a	15.93a	1.80	26.07	37.53	34.20

---

[1] Paired means (phase I and II for each treatment combination) in a column followed by the letter **a** are significantly different ($p \leq 0.05$).

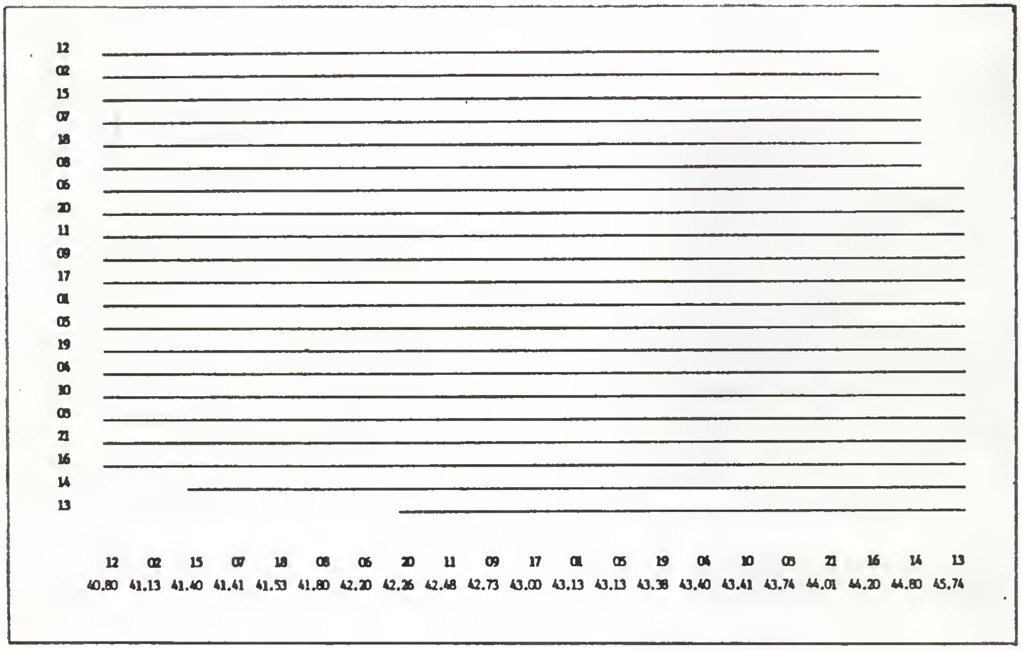
Figure A-1 - Significant differences[1] by treatment combination among least squares means for sensory evaluation of coldness

---

[1] Each treatment combination shown on the Y-axis is significantly different from those shown above ordered means (X-axis) not connected by a solid line

[2] Treatment combinations are given in Table 6.

a. Phase I



b. Phase II

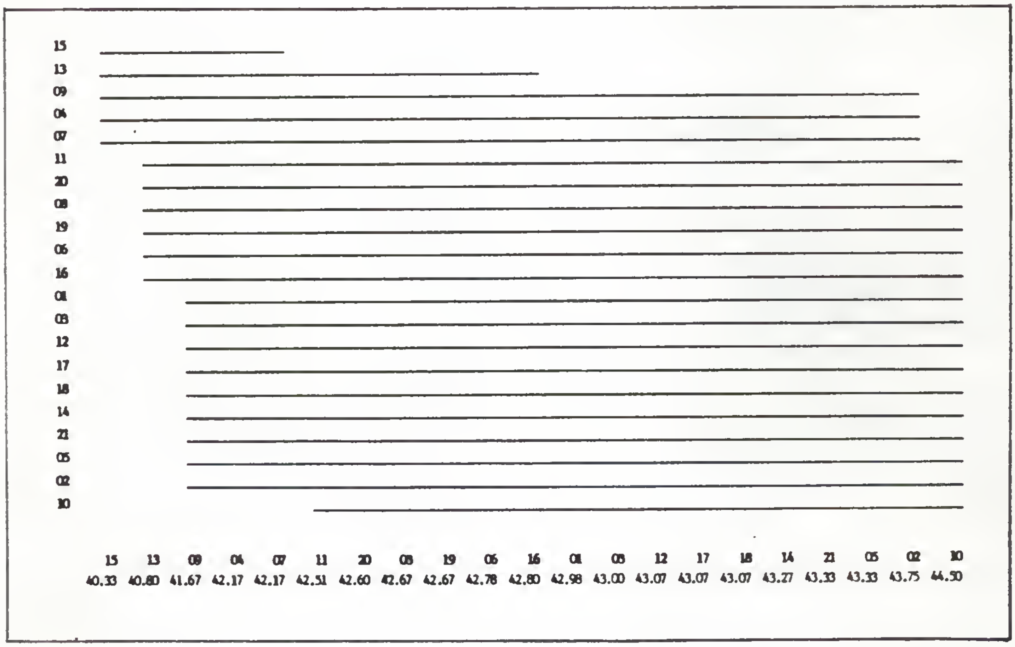
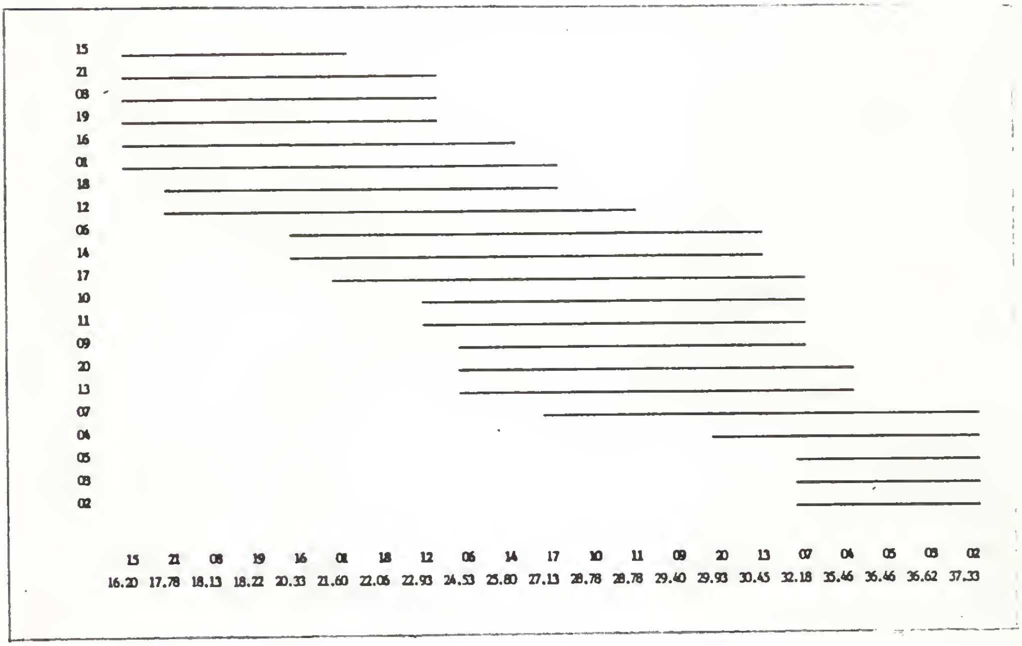


Figure A-2 - Significant differences[1] by treatment combination among least squares means for sensory evaluation of softness

[1] Each treatment combination shown on the Y-axis is significantly different from those shown above ordered means (X-axis) not connected by a solid line

[2] Treatment combinations are given in Table 6.

a. Phase I



b. Phase II

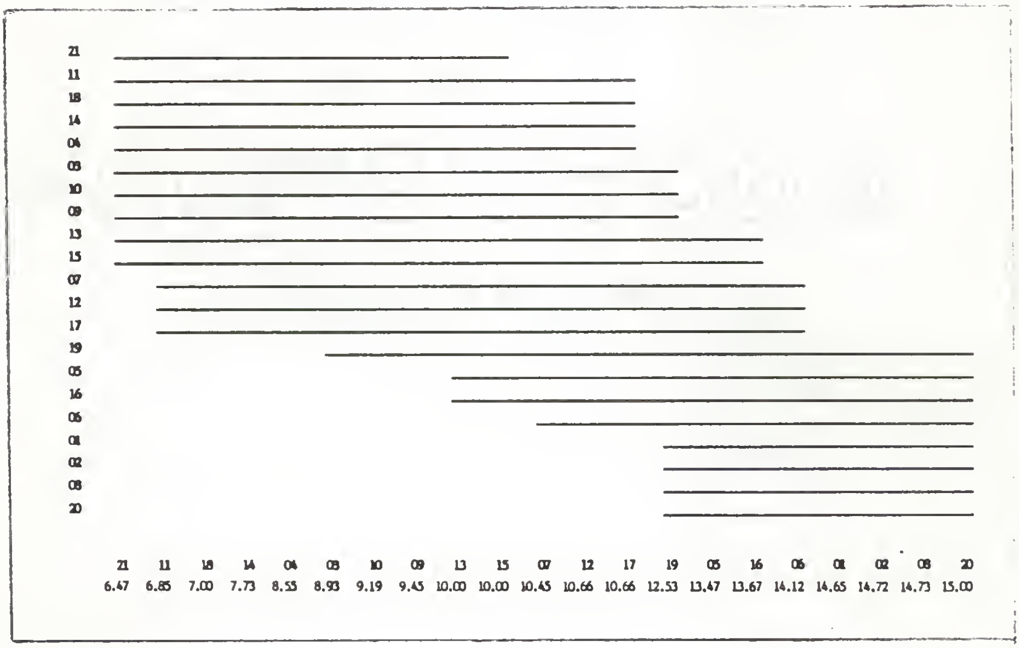
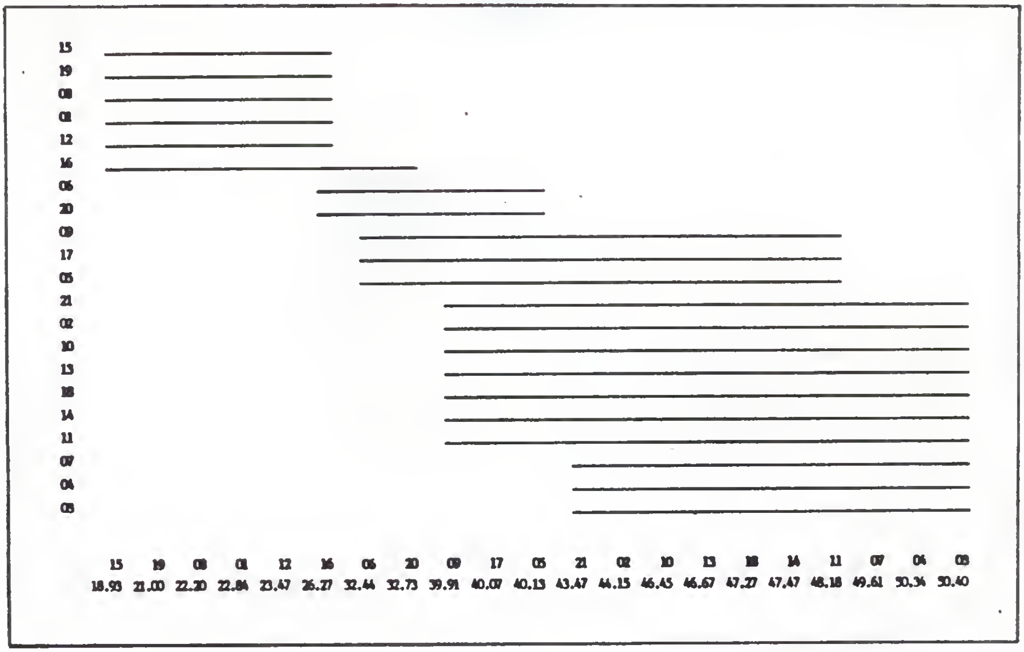


Figure A-3 - Significant differences[1] by treatment combination among least squares means for sensory evaluation of coarseness

[1] Each treatment combination shown on the Y-axis is significantly different from those shown above ordered means (X-axis) not connected by a solid line

[2] Treatment combinations are given in Table 6.

a. Phase I



b. Phase II

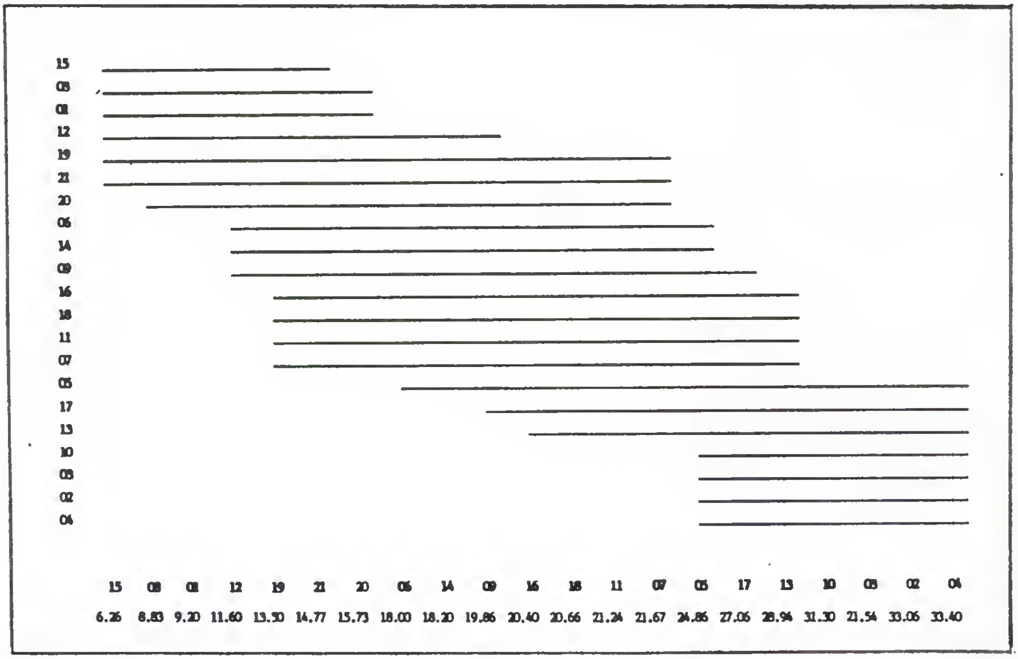


Figure A-4 - Significant differences[1] by treatment combination among least squares means for sensory evaluation of wateriness

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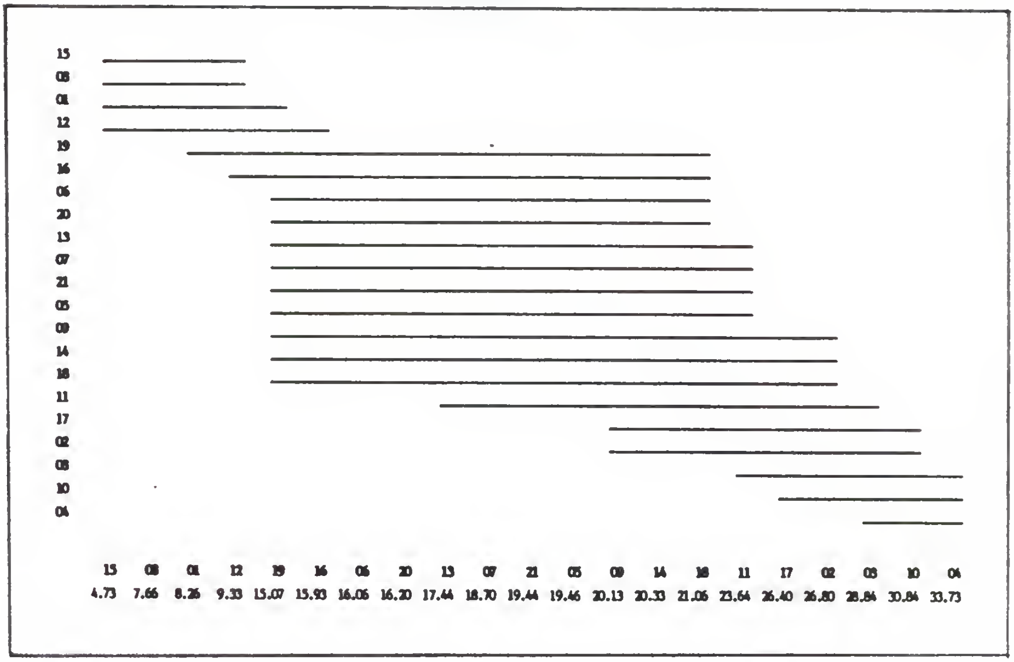
[1] Each treatment combination shown on the Y-axis is significantly different from those shown above ordered means (X-axis) not connected by a solid line

[2] Treatment combinations are given in Table 6.

a. Phase I



b. Phase II

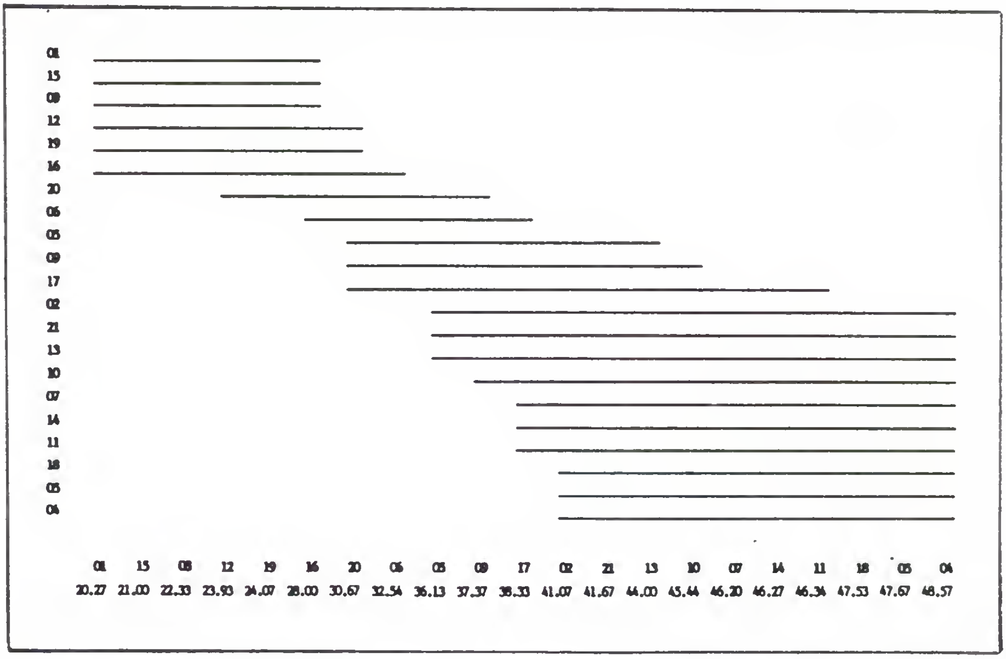


Figure A-5 - Significant differences[1] by treatment combination among least squares means for sensory evaluation of creaminess

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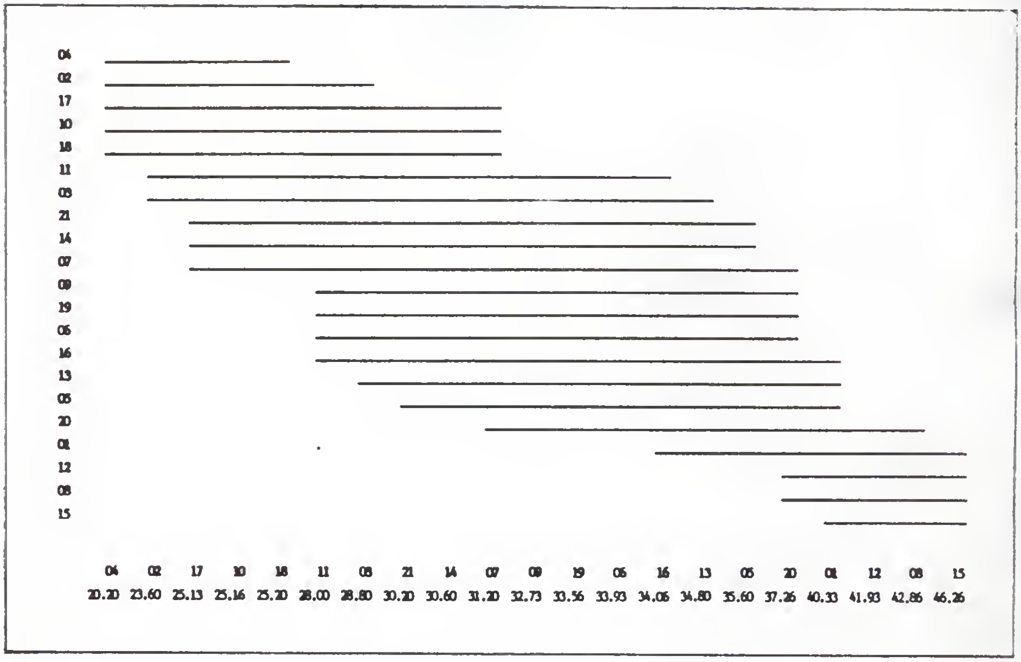
[1] Each treatment combination shown on the Y-axis is significantly different from those shown above ordered means (X-axis) not connected by a solid line

[2] Treatment combinations are given in Table 6.

a. Phase I



b. Phase II

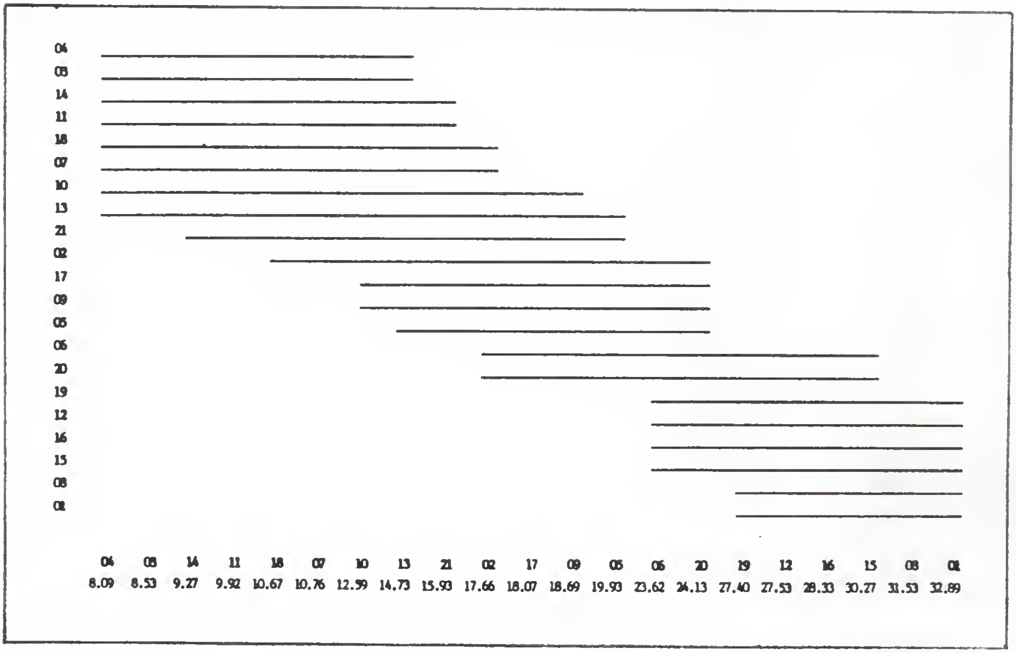
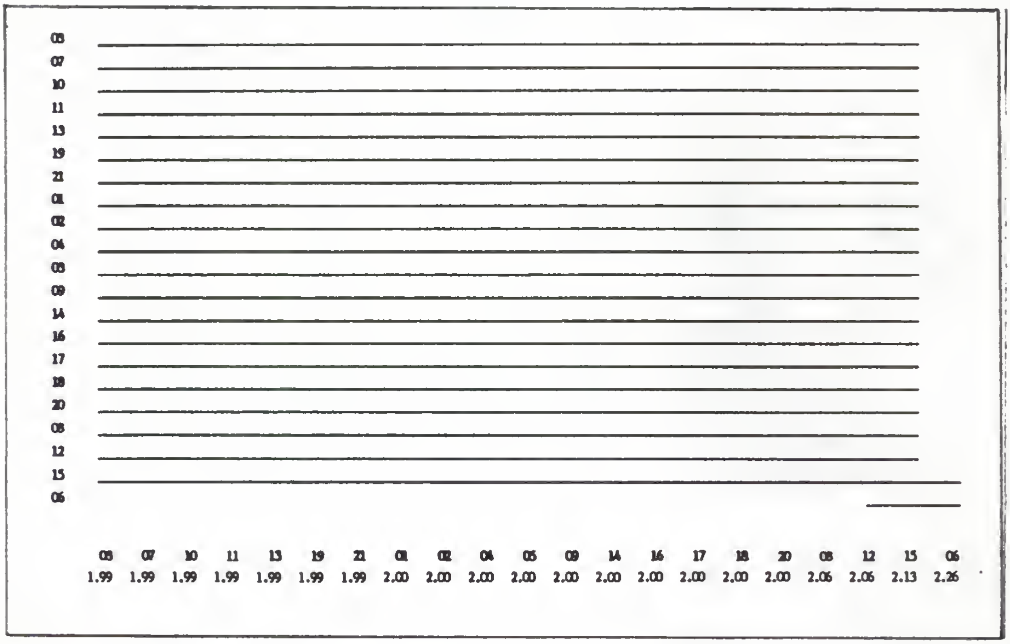


Figure A-6 - Significant differences[1] by treatment combination among least squares means for sensory evaluation of gumminess

[1] Each treatment combination shown on the Y-axis is significantly different from those shown above ordered means (X-axis) not connected by a solid line

[2] Treatment combinations are given in Table 6.

a. Phase I



b. Phase II

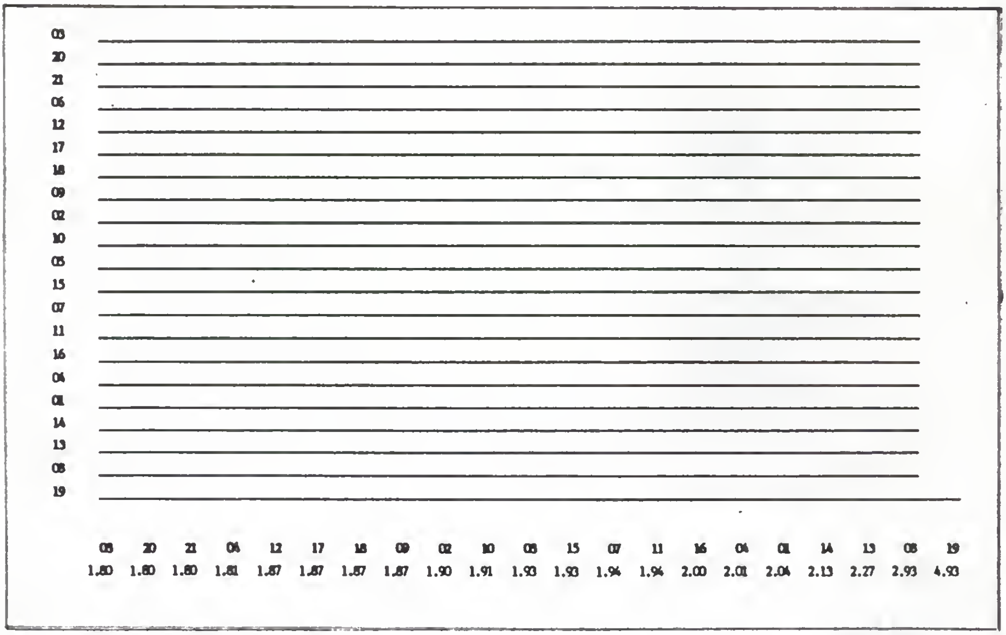
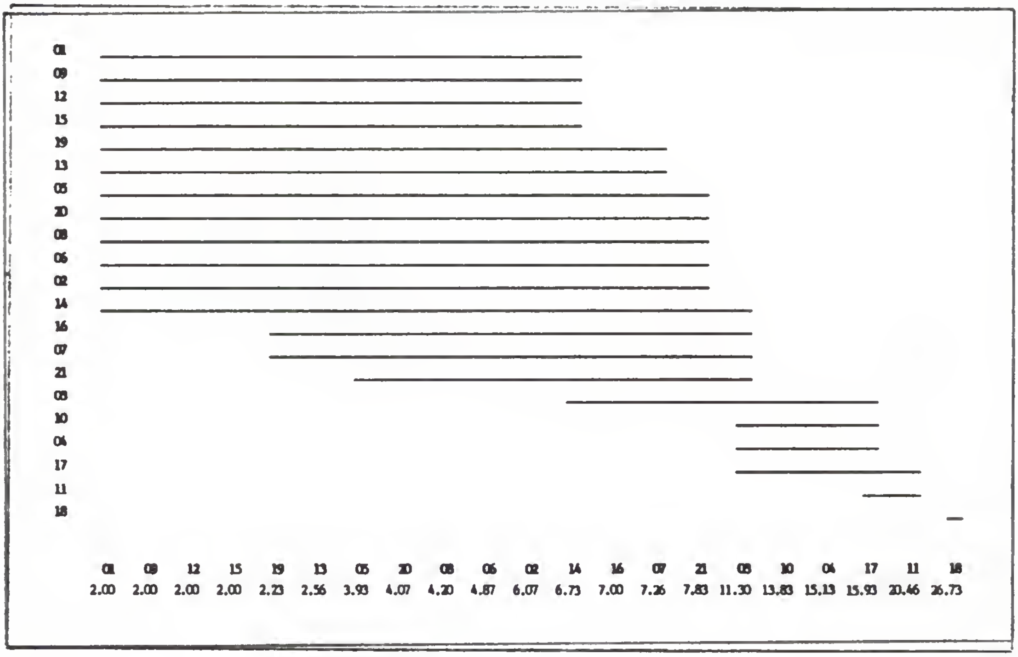


Figure A-7 - Significant differences[1] by treatment combination among least squares means for sensory evaluation of chalkiness

[1]Each treatment combination shown on the Y-axis is significantly different from those shown above ordered means (X-axis) not connected by a solid line

[2]Treatment combinations are given in Table 6.

a. Phase I



b. Phase II

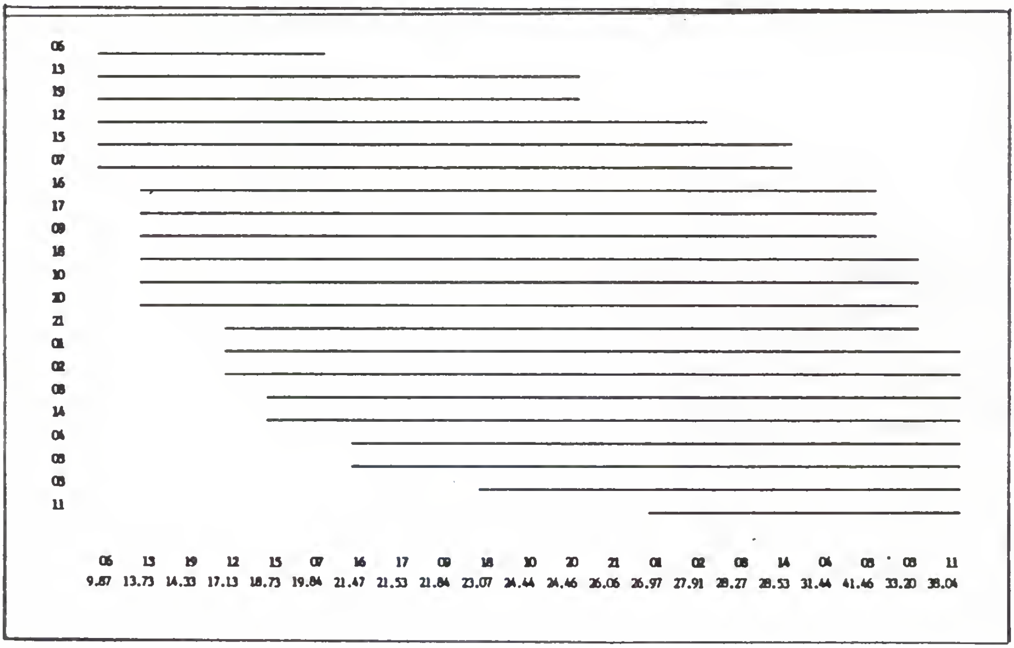
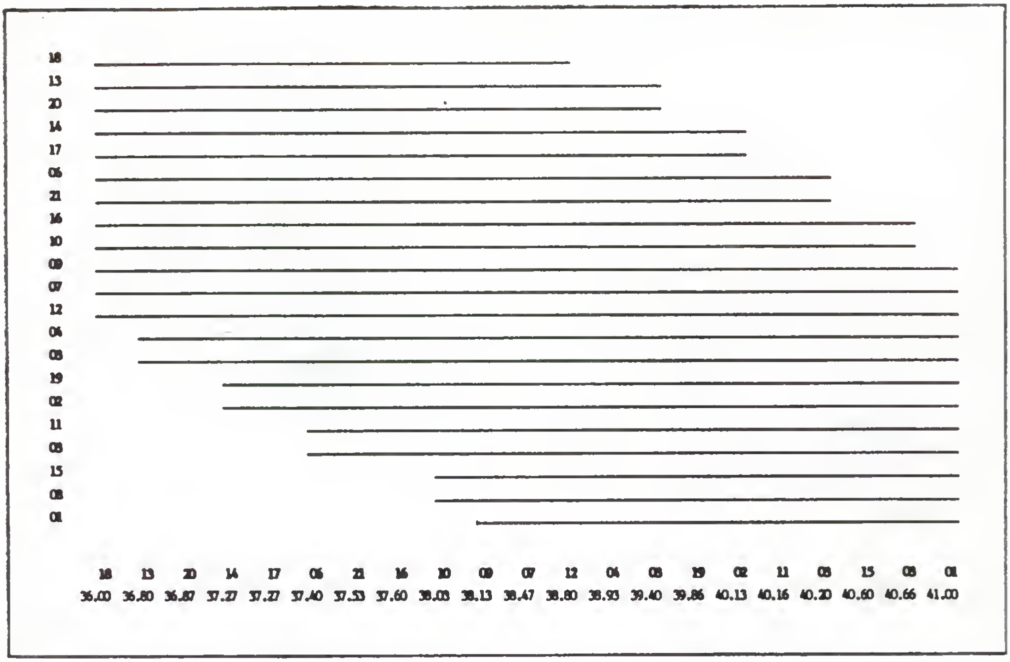


Figure A-8 - Significant differences[1] by treatment combination among least squares means for sensory evaluation of mouthcoating

[1] Each treatment combination shown on the Y-axis is significantly different from those shown above ordered means (X-axis) not connected by a solid line

[2] Treatment combinations are given in Table 6.

a. Phase I



b. Phase II

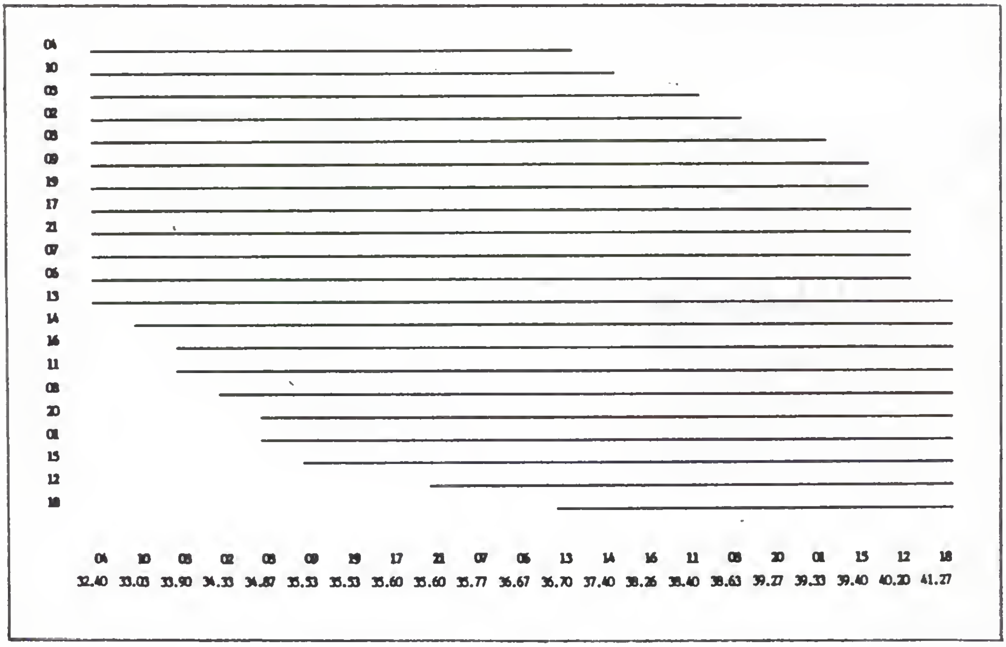


Figure A-9 - Significant differences[1] by treatment combination among least squares means for sensory evaluation of sweetness

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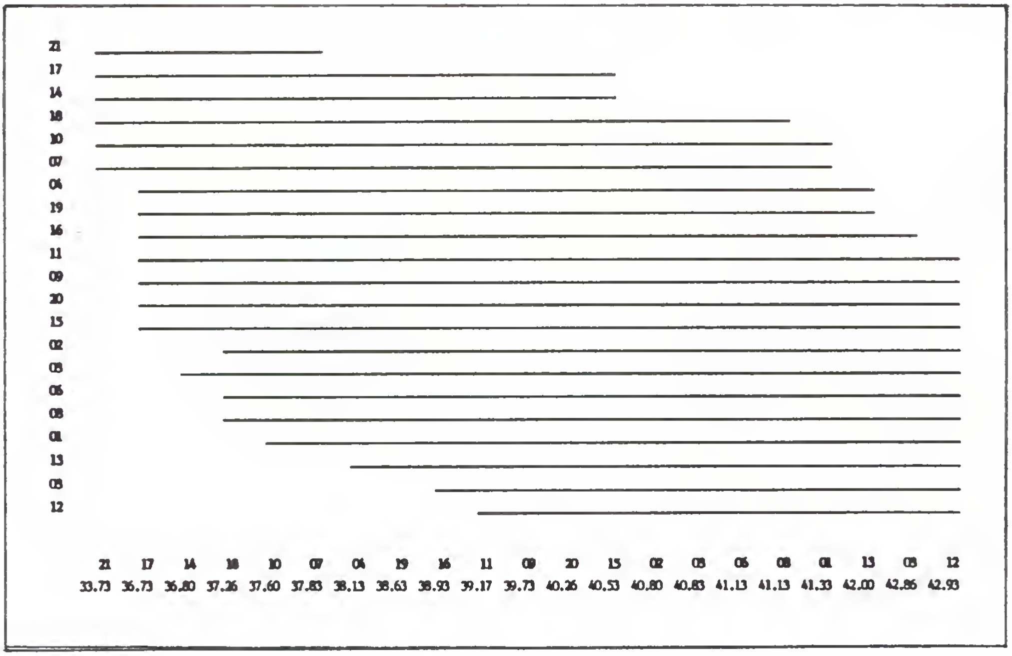
[1] Each treatment combination shown on the Y-axis is significantly different from those shown above ordered means (X-axis) not connected by a solid line

[2] Treatment combinations are given in Table 6.

a. Phase I



b. Phase II

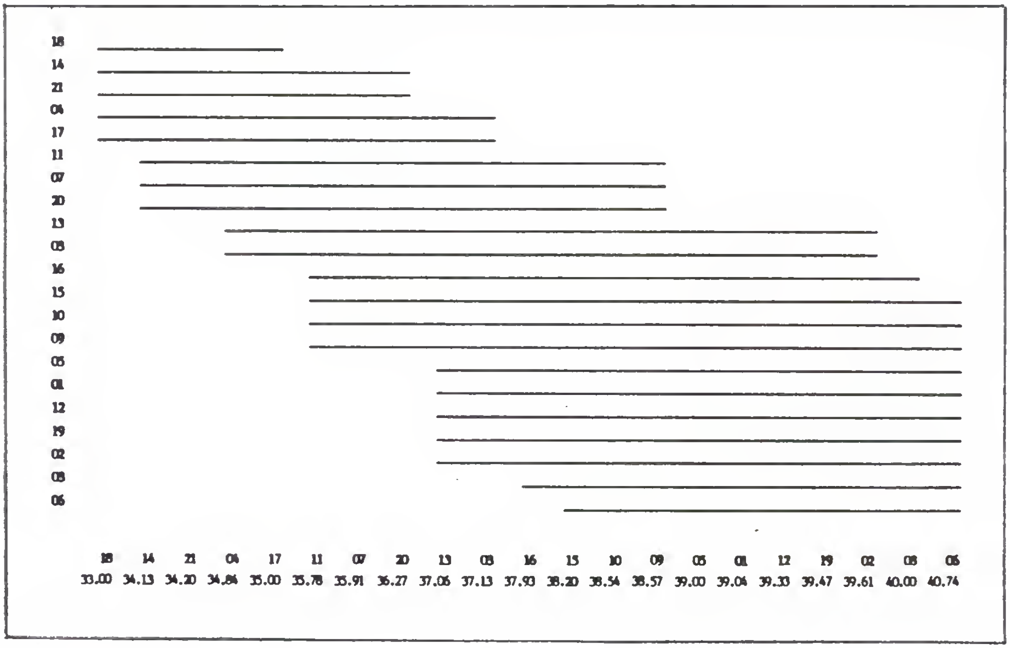


Table B-1

Name________________ Sample#________

Date________________ Code#________

FROZEN DESSERT - TEXTURAL PROFILE

Coldness

not cold very cold

R

Softness

not soft (hard) very soft

R

Coarseness

not coarse (smooth) icy/coarse

R

Wateriness

not watery very watery (thin)

R

Creaminess

not creamy very creamy

R

Gumminess

not gummy very gummy

R

Chalkiness

not chalky very chalky

R

Mouthcoating

low high

R

oily_____ chalky_____ gummy_____

Sweetness

not sweet very sweet

R

Table B-2

FROZEN DESSERT - TEXTURAL PROFILE

Sensory Descriptions

Coldness - an uncomfortable sensation; a chilling of the tongue and palate soon after the sample is placed in the mouth.

Softness - the force necessary to compress sample against the roof of the mouth - or, the ability of the sample to retain its shape. (place sample on tongue and press against roof of mouth)

Coarseness - the perception of ice crystals; extent of coarseness is indicated by the overall level of iciness.

Wateriness - the melting character of the sample; high wateriness is indicated by a sample which melts rapidly, losing viscosity, becoming thin and watery.

Creaminess - the melting character of the sample; high creaminess is indicated by a sample which melts into a creamy (fat-like), full-bodied liquid.

Gumminess - strictly a negative parameter; a sticky, gluey mouthfeel, interfering with desirable melting properties.

Chalkiness - strictly a negative parameter; associated with a dry, powdery mouthcoating, interfering with desirable melting properties.

Mouthcoating - to be judged immediately after last swallow; defined as the degree to which the sample leaves a coating inside the mouth, i.e., difficulty of rinse.

Sweetness -

Appendix C

Table C-1 - Listing of ingredients and manufacturers[1]

1. Heavy Cream[2] (37.5% fat)	Department of Dairy Science Kansas State University Manhattan, KS
2. Nonfat Dry Milk	Land O Lakes, Inc. Minneapolis, MN
3. Sucrose	Food Club brand Topeka Associates Skokie, IL
4. Polydextrose type N	Pfizer Chemical Co. New York, NY
5. N-OIL^{R} (tapioca dextrin)	National Starch and Chemical Co. Bridgewater, NJ
6. Paselli SA2 (maltodextrin)	AVEBE, Inc. Hopelawn, NJ
7. Aspartame	Nutrasweet Co. Skokie, IL

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[1] All ingredients were obtained at the beginning of the study in quantities sufficient for the entire investigation.

[2] Obtained fresh, stored at 4°C.

APPENDIX D

Starch-based gel systems

A gel consists of polymeric molecules cross-linked to form a 3-dimensional network immersed in a liquid medium. The structure is maintained by a combination of weak intermolecular associations, e.g., hydrogen bonds, hydrophobic interactions, Van der Waals and electrostatic forces (Oakenful, 1987). Physical characteristics of a particular starch gel (e.g., softness, rigidity, stability) depend on the source of the starch, processing conditions, and potential interactions with other ingredients.

The starch granule is a water-binding agent capable of forming stable gels. The structure and rheological behavior of starch gels vary according to the type of starch (Lelievre, 1984). Starch occurs in cereal grains, roots, and tubers. Chemical composition and physical characteristics vary according to the biological origin of the starch (Swinkels, 1985). Primary sources of commercial starch include maize, wheat, potato, cassave, and waxy maize.

Gel-forming properties of starch are primarily a function of the composition of the native granule. Most cereal starches, e.g., maize, wheat, rice, sorghum, contain a high percentage of fatty substances (0.6 - 1.0%) as well as a considerable amount of protein (0.25 - 0.50%). Potato and tapioca starch, however, contain less than 0.1% of either lipid or proteinacious materials. (A comparison of the composition and properties of common starch varieties appears in Table 13).

Lipid is often found associated with the amylose fraction of starch, forming relatively inert complexes which interfere with starch hydration and solubilization and reduce overall water-binding capacity and swelling power (Swinkels, 1985). A high protein content is associated with development of mealy flavors, unwanted foam formation and generally inferior gel-forming properties.

Amylose content. The actual gel-forming polymer in starch in amylose. The degree of polymerization (DP) of the amylose fraction determines the ability of starch granules to undergo gelation. The DP associated with optimum gelation properties is approximately 500 (Kaper, 1988). With a DP < 500, the number of short-chain molecules will be too great and gel strength will be inferior, because not enough stable intermolecular associations can be formed. With a DP > 500, the gel is likely to be too rigid.

Native starch granules are usually modified in order to improve funtional properties. The physical properties of native starches tend to limit their usefulness in commercial application. Shortcomings include (1) lack of free-flowing properties, (2) insolubility or failure of granules to swell and develop viscosity in cold water, (3) excess or uncontrollable viscosity after gelatinization, and (4) overly cohesive, rubbery texture of the resultant colloidal sol or gel after cooking.

Enzymical modification, used to prepare both N-OIL^R and PSA2, decreases the degree of polymerization. Starting with a DP slightly higher than 3000, potato and tapioca starch end up with a DP of approximately 500.

Because of their relatively low amylose contents, potato and tapioca starch do not readily undergo syneresis and are relatively less susceptible to the negative effects of retrogradation. Poor freeze-thaw stability in starch-thickened foods is attributed to retrogradation of the amylose fraction (Fennema, 1985). Potato and tapioca are not found to exhibit the undesirable "starchy" flavors typically associated with the cereal varieties. As such, potato and tapioca starch are thought to be well-suited to form soft, yet stable gels which confer fat-like textural properties in a variety of food systems, including frozen desserts.

THE EFFECT OF SUCROSE AND MILKFAT SUBSTITUTION ON SENSORY TEXTURAL AND PHYSICAL PROPERTIES IN A FROZEN DESSERT SYSTEM

by

STEPHEN E. SPECTER

B.A., University of Pennsylvania, 1982

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Foods and Nutrition

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1988

The objective of this study was to evaluate the effect of sucrose and milkfat replacement on sensory textural and physical properties in a frozen dessert system. Three ingredient substitutes were evaluated for their capacity to impart textural properties normally conferred by sugar and fat. Polydextrose replaced sucrose at three levels: 0, 50, and 100%. (Aspartame was addded to furnish sweetness in the absence of sucrose.) A tapioca dextrin (N-OIL^{R}) and a potato starch (Paselli SA2) each replaced fat at four levels: 0, 33, 66, and 100%. Treatment effects were studied using a randomized complete block statistical design.

Twenty-one treatment combinations were evaluated by a trained sensory panel for eight textural attributes - coldness, softness, coarseness, wateriness, creaminess, gumminess, chalkiness, mouthcoating - and sweetness. Physical measurements included unfrozen mix viscosity, percent air incorporation, melting rate, and resistance to deformation of the frozen sample, measured on the Instron. The study was divided into two time periods: samples were evaluated two days after preparation (phase I) and following 140 days storage (phase II).

Analysis of variance for sensory data revealed no significant differences in textural attributes ($p \leq 0.05$) between polydextrose trials for fresh or stored samples. The polydextrose-APM combination effectively compensated for functional properties normally conferred by sucrose and

also some textural properties in the absence of fat.

Replacement of fat with N-OIL^R or Paselli SA2 increased coarseness and wateriness, while decreasing creaminess relative to the control. N-OIL^R was less generally less effective than Paselli SA2 in maintaining the basic textural attributes of the control, particularly with regard to perception of chalkiness. Both starch-based fat substitutes exhibited limited ability to inhibit negative effects associated with extended storage. Few significant differences were noted at any point in the study for four sensory attributes: coldness, gumminess, mouthcoating, and sweetness. Spearman correlation coefficients calculated between sensory and instrumental data were low to moderate, indicating that the physical measurements were not useful predictors of sensory response for the nine attributes evaluated in this study.