Sensory and Physical Properties of a Reduced-Calorie Frozen Dessert System Made with Milk Fat and Sucrose Substitutes[1]

S. E. SPECTER[2] and C. S. SETSER[3]
Kansas State University
Manhattan 66506

ABSTRACT

Effects of milk fat and sucrose substitutes on selected physical and sensory properties of a frozen dessert system were evaluated by sensory and instrumental methods. Analysis of variance revealed no significant differences in textural attributes between sucrose and polydextrose-aspartame in freshly prepared frozen desserts and few differences after storage (140 d). Polydextrose-aspartame effectively compensated for functional properties that normally are conferred by sucrose and some that are conferred by milk fat. Replacement of milk fat with tapioca dextrin or potato maltodextrin increased coarseness and wateriness and decreased creaminess relative to the control. Perception of chalkiness increased more with increased tapioca dextrin than with increased potato maltodextrin. Few or no significant differences among the frozen desserts were noted for the sensory attributes of coldness, gumminess, and mouth coating. Physical measurements did not relate highly to the sensory responses.
(**Key words**: frozen dessert, sensory properties, sucrose substitutes, fat substitutes)

Abbreviation key: **APM** = aspartame, **IUTM** = Instron Universal Testing Machine, **PM** = potato maltodextrin, **TCN** = treatment combination number, **TD** = tapioca dextrin.

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[1]Contribution Number 90-178-J from the Kansas Agricultural Experiment Station.
[2]Present address: University of California, Davis.
[3]Department of Foods and Nutrition.

INTRODUCTION

Dietary factors are implicated in the etiology of a number of chronic degenerative diseases. Health-conscious consumers continue to look for ways to improve nutritional habits without sacrificing psychological satisfaction. Sales of low fat frozen desserts continue to climb, although some reports indicate slowing sales in the reduced-calorie market segment because consumers have perceived that the products have poor quality (12, 13). Mouthfeel is the sensory property that has captured the attention of the producers of fat- and calorie-reduced foods (5), and use of fat mimetics especially affects mouthfeel (12). Drewnowski (8) found that high fat, high sugar combinations in food products were highly appealing and the potential market for the reduced-calorie counterparts to be sizable. Understanding the effects of the replacement ingredients for fat and sugars on sensory properties is essential to achieve high quality, profitable products.

Reduced sucrose in frozen desserts negatively influences physical and sensory properties because sucrose helps control freezing point and crystal size (1, 4, 14, 15, 21, 27, 28). McPherson et al. (18) found that substituting dextrose and aspartame (**APM**) combinations for sucrose in orange sherbet did not provide sufficient solids to maintain optimal textural attributes, particularly after a 4-wk storage period. Corn syrup solids and combinations of corn syrup solids and APM have been used effectively (10), depending on the dextrose equivalency of the corn syrup (23). Goff and Jordan (9) also used polydextrose, a nonsweet, randomly bonded glucan (31), and APM at .06 to .1% as sugar substitutes in a frozen dessert system. Smoothness and acceptability, as evaluated by sensory methods, indicated that substitution of polydextrose for no more than 12% of the 14% total carbohydrates in the mix produced acceptable products (9).

Several carbohydrate- and protein-based substitutes for fat have been suggested in reduced-calorie frozen dessert systems (16, 17). However, few research studies were found on effects, particularly on sensory properties, of removing or replacing fat, alone or with sugar, in frozen desserts. Tharp and Gottemoller (30) indicated that maltodextrin was moderately functional for fat substitution in light frozen desserts, but those workers did not specify any of the sensory effects. Schmidt et al. (26) compared rheological, freezing, and melting properties of ice milks prepared with a carbohydrate- or protein-based fat replacer. Less air was incorporated using the carbohydrate-based replacer than using milk fat (control) or the protein-based replacer.

The objective of this study was to determine effects on sensory texture and physical properties of frozen desserts with reduced fat and sugar shortly after production (fresh) and after prolonged (140 d) storage to evaluate shelf-life potential of the system. Two complex carbohydrate fat replacers, tapioca dextrin (**TD**) and potato maltodextrin (**PM**), and a polydextrose-APM sweetening system were evaluated.

MATERIALS AND METHODS

Product Formulation

Four ingredients—heavy cream, NDM, sugar, and water—were combined in a basic ice cream formulation with 12% milk fat, 10% SNF, and 16% sucrose for a 38% total solids content in the mix. Heavy cream (37.5% fat) was obtained fresh from the Department of Dairy Science, Kansas State University. Other ingredients supplied at the start for the complete investigation were NDM (Land O'Lakes, Minneapolis, MN); polydextrose-N (Pfizer, Inc., New York, NY); TD (N-Oil®; National Starch, Bridgewater, NJ); PM (Paselli SA2; Avebe, Inc., Hopelawn, NJ), and APM (NutraSweet®; NutraSweet Co., Skokie, IL). The APM was included to provide sweetness approximately equivalent to the 16% sucrose control as determined in preliminary difference testing.

Twenty-one treatment combinations were prepared with varying milk fat, sucrose, and ingredient substitutes. Fat percentages were 100, 66, 33, and 0% of the 12% milk fat solids; sucrose percentages were 100, 50, and 0% of the 16% sucrose solids in the formulations. Water for treatment combinations was adjusted to compensate for ingredient changes. The aqueous type of polydextrose necessitated a 1:1.43 (sucrose:polydextrose-APM, wt/wt) substitution ratio to obtain a 1:1 solids exchange with sucrose. One part TD or PM and three parts of water (i.e., 25% substitution) replaced four parts of fat. The level of NDM was adjusted for each treatment combination to maintain a constant 10% SNF; this adjustment accounted for the contribution of SNF from the cream. Formulations for each treatment combination (**TCN**) and the numbers for each appear in Table 1.

Frozen Dessert Preparation

Dry ingredients were combined and agitated for 20 s in a closed container. Distilled water and dry ingredients were whipped using a wire whip in a stainless steel bowl for 30 s to disperse. Heavy cream and polydextrose were added and were agitated for 20 s. The mixture was transferred into a 1.9-L (2-qt) ice cream canister, placed in a water bath (Braun Thermomix, model 1480; B. Braun, Frankfurt, Germany), and pasteurized at 71°C for 30 min. Homogenization was in two stages at 10.3 and 3.4 MPa (Microfluidics laboratory homogenizer; Microfluidics Corp., Newton, MA). The mixture was aged 18 ± 2 h at 4°C. The mix (7°C) was frozen using a 1.9-L (2-qt) electric ice cream freezer (White Mountain model 69-202; Winchendon, MA) with an 8:1 ice:salt mixture (–10 to –11°C) to 40 ± 5% overrun. The frozen (–6 to –7°C) mix was transferred into 60-ml (2-oz) cups with lids and held at –17°C for hardening and storage in a reach-in freezer (model UFD-18L; Frigidaire, Dayton, OH). The 21 formulations were replicated three times.

Sample Evaluation

Sample evaluation was divided into two phases. Initially, samples were evaluated 48 ± 2 h after preparation. The second phase was conducted after the samples were stored for 140 d. Treatment combinations were presented to panelists in a random order for each of the three replications over a 27-d evaluation period for each of the phases. Textural properties of all samples were evaluated by sensory and instrumental methods.

Sensory Analyses. Descriptive analyses of selected textural attributes were conducted using five panelists with 1 to 3 yr of experience in food product evaluation; all were associated with the Sensory Analysis Center at Kansas State University. Six hours of specialized orientation were devoted to familiarizing the panelists with ice cream evaluation techniques, selecting appropriate and meaningful textural parameters, and developing a scoring instrument. Three hours were spent retraining prior to beginning phase 2. A 60-digit linear scale on a computer screen, a computerized version of the standard quantitative descriptive analysis 6-in scale divided in .1 units (29), was used. The sensory attributes evaluated were coldness, softness, wateriness, creaminess, gumminess, chalkiness, and mouthcoating. Sensory descriptors for each attribute and the position on the intensity scale for the reference sample are given in Table 2. The control (100% milk fat, 100% sucrose) served as the reference sample, and the consensus position of the control for each descriptor was marked on a supplementary score sheet and used by panelists as a reference during all evaluations to increase consistency and to decrease variance among panelists. Each sensory attribute of the experimental products and a blind control was scored by placing a mark at the point on the scale that reflected the magnitude of the panelists' perceived intensity for that attribute.

Reference Sample. A "warm-up" sample was provided at each session to establish a frame of reference for evaluating subsequent samples. "Warm-up" reference samples were mixed and frozen 48 h preceding the first session of each phase of the study and held for use during that phase. The formulation of the reference sample was identical to the blind control evaluated in the study.

Sample Presentation. Temperature of all samples was monitored (Minitrend 205 Thermocoupler; Doric Scientific, San Diego, CA). Each sample was equilibrated to −12 ± 1°C prior to presentation. Unsalted crackers, apples, and tasteless water (treated by reverse osmosis, deionization, and a carbon filter) were used by panelists to clear their palates between samples.

TABLE 1. Formulations of frozen desserts for 21 treatment combinations.[1]

TCN[2]	Heavy cream	NDM	Sucrose	Water	Polydextrose	Tapioca dextrin	Potato maltodextrin	Aspartame
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	...	...	.4
9	181	77	68	418	97	8.5	...	.4
10	91	82	68	495	97	17.0	...	.4
11	0	88	68	575	97	25.5	...	.4
12	181	77	68	418	97	...	8.5	.4
13	91	82	68	495	97	...	17.0	.4
14	0	88	68	575	97	...	25.5	.4
15	272	72	...	311	194	...	...	.8
16	181	77	...	388	194	8.5	...	.8
17	91	82	...	465	194	17.0	...	.8
18	0	88	...	545	194	25.5	...	.8
19	181	77	...	388	194	...	8.5	.8
20	91	82	...	465	194	...	17.0	.8
21	0	88	...	545	194	...	25.5	.8

[1]Weight in grams for ingredients in mixes for each of the treatment combinations.

[2]Treatment combination number.

Instrumental Measurements

Viscosity. Mix viscosity (model RV8, spindle #2; UK Viscometers, Ltd., Brookfield Engineering Laboratories, Stoughton, MA, distributor) was measured for each treatment combination at 4 ± 1°C after aging and immediately before freezing.

Resistance to Deformation. According to Bourne et al. (6), softness can be estimated by measuring the degree of deformation under a known compression force. The plunger attachment of the Instron Universal Testing Machine (IUTM, model 1122; Instron, Canton, MA) was used to obtain an instrumental value for softness of the frozen sample using scale loads of 20 and 400 kg for phases 1 and 2, respectively. Settings for the IUTM had to be adjusted for phase 2 because storage increased resistance to deformation. A cone penetrometer method (8, 20) was modified for the IUTM to measure the force required for the cone to achieve a specified depth. Scale loads of 2 and 20 kg, depths of penetration of 15 and 5 mm, and temperatures of −15 and −12°C were used for phases 1 and 2, respectively.

Melting Characteristics. The method of Nickerson and Pangborn (20) and Moore and Shoemaker (19) was used to evaluate melting characteristics. Melting rate was based upon the volume of drip collected after 30 min at 21 ± 1°C from a 60-cc sample placed on a wire mesh over a funnel inserted into a graduated cylinder. Each sample was equilibrated to −15°C immediately prior to measurement.

Statistical Design and Data Analysis

The randomized complete block experimental design included 21 treatment combinations. Mean separations were calculated using PROC GLM of SAS (25) at a level of significance of $P = .05$ unless stated otherwise. For the sensory data, the treatments that were significantly different were partitioned to determine the significance for each of the main effects and interaction contrasts. Mean values collected during phase 1 for the 21 treatment combinations were evaluated for significant differences within each sensory parameter and separated using a protected least significant difference method for each of the attributes for which the treatment effect was significant. A separate similar analysis was carried out for the sensory data from phase 2. Significance of relationships between the rankings of the instrumental and sensory data was tested using the Spearman correlation coefficient (25).

TABLE 2. Sensory texture attributes and definitions used to describe frozen desserts.

Attribute	Definition	Reference position[1]
Coldness	An uncomfortable sensation: a chilling of the tongue and palate soon after the sample is placed in the mouth; high value = very cold.	40
Softness	The force necessary to compress sample against the roof of the mouth or the ability of the sample to retain its shape; minimal force = high value = very soft.	25
Coarseness	The perception of ice crystals; extent of coarseness is indicated by the overall iciness; high value = very coarse.	5
Wateriness	The melting character of the sample; high wateriness is indicated by a sample that melts rapidly, loses viscosity, and becomes thin and watery.	5
Creaminess	The melting character of the sample; high creaminess is indicated by a sample that melts into a creamy (fat-like), full-bodied liquid.	45
Gumminess	Strictly a negative parameter; a sticky, gluey mouthfeel, interfering with desirable melting properties; high value = very gummy.	2
Chalkiness	Strictly a negative parameter; associated with a dry, powdery mouthcoating, interfering with desirable melting properties; high value = very chalky.	2
Mouthcoating	To be judged immediately after last swallow; the degree to which the sample leaves a coating inside the mouth, i.e., difficulty of rinse. Indicate if type is chalky, oily, or grainy.	40

[1]Reference sample was made with 12% milk fat, 16% sucrose, 10% NDM solids for 38% total solids content; scale indicated is 60-digit computerized scale, a 6.0 linear scale divided into tenths.

RESULTS

Sensory Evaluation

The control frozen dessert in this study did not differ significantly from the reduced-calorie product that had one-third or two-thirds of the fat substituted with the PM gel using polydextrose-APM to replace all of the sucrose in the product. This lack of significant difference was true for all attributes for both the freshly prepared frozen desserts and those stored 140 d. Products with other percentages of fat or sucrose substitution or with TD as the fat replacer varied for one or more sensory textural attributes, although gumminess and coldness did not differ for any of the products.

The probability values for the contrasts for attributes with significant treatment effects are shown in Table 3. Mean values for each of the 21 treatments of the sensory attributes with significant differences are given in Table 4. All attributes except softness and mouthcoating of the stored frozen desserts were involved in interactions; however, all probabilities and treatment means are presented in Tables 3 and 4 for completeness and for comparisons with the freshly frozen desserts. Main effect contrasts in Table 3 should be examined carefully when an interaction is present. For example, the sucrose by PM interaction was statistically significant for softness of the fresh product, so the contrasts for the levels of PM and for sucrose within PM levels should be ignored or interpreted carefully. In the case of the stored product, the comparisons of frozen dessert softness can be made for levels of PM because no interactions were found. Highlights of the effects of sucrose substitution and the effects of fat substitution in the frozen desserts are summarized subsequently.

Sucrose Substitution. All freshly prepared or stored frozen desserts with 100% fat and varied levels of polydextrose-APM substituted for sucrose were the same for all sensory attributes (see Table 4, TCN 1, 8, 15). The TD versus PM contrast was significant for fresh and stored frozen desserts for several attributes (Table 3). Thus, sucrose with TD in the freshly frozen dessert resulted in more significant differences from the control product for coarseness, wateriness, creaminess, chalkiness, and mouthcoating than occurred with PM as the fat substitute (Table 4). However, polydextrose-APM substituted for sucrose resulted in fewer differences between PM and TD for those attributes. The same trend was noted for the stored products for coarseness, wateriness, and creaminess.

Fat Substitution. Significant differences were found between the control frozen dessert and those with TD substituted for fat at all sucrose substitutions for both fresh and stored products for several sensory attributes (Tables 3 and 4). Coarseness and wateriness increased, and creaminess decreased, when fat was replaced with TD (Table 4; compare TCN 1 with TCN 2, 3, and 4; TCN 8 with TCN 9, 10, and 11; or TCN 15 with TCN 16, 17, and 18). Several freshly prepared, TD fat-substituted frozen desserts (TCN 3, 4, 10, 11, 16, 17, and 18) were rated consistently chalkier than the control (TCN 1). However, after 140 d of storage, the control also became chalky and was not different from any of the TD products. Mouthcoating was lowest in fresh products if sucrose was used in conjunction with the TD (Table 4; TCN 2, 3, 4, and 10). The frozen dessert with the highest polydextrose-APM and the highest TD (TCN 18) was the only stored product that differed significantly from the control.

Generally, fewer differences were found between the control and any of the frozen desserts using PM than for those with the corresponding percentages of TD. About one-third of the mean scores for sensory attributes (Table 4) with PM substituted for milk fat was significantly different from the control frozen dessert in the freshly prepared product. The freshly prepared TD frozen desserts differed from the PM products for softness, coarseness, wateriness, creaminess, and chalkiness (Table 3). After extended storage, the differences between the control and the frozen desserts with fat or sucrose substitutes were significant for about one-half of the attributes (Table 4). The number of attributes that were different from the control for the reduced fat samples was fewer at the 50 and 100% polydextrose-APM substitution for sucrose than if no polydextrose-APM were used, particularly after storage for 140 d.

Stored TD frozen desserts were significantly different from the PM frozen desserts in coarseness, wateriness, and creaminess (Table 3). Storage resulted in no differences for cold-

TABLE 3. Significance of effects of varied levels of tapioca dextrin (TD) or potato maltodextrin (PM) as a fat replacer and varied levels of sucrose on sensory attributes of freshly prepared and stored (140 d) frozen desserts.[1]

	Probability											
	Softness		Coarseness		Wateriness		Creaminess		Chalkiness		Mouthcoating	
Contrast[2]	Fresh	Stored	Fresh	Stored	Fresh	Stored	Fresh	Stored	Fresh	Stored	Fresh	Stored
Sucrose w/i TD	.0001	.48	.02	.09	.009	.27	.11	.19	.004	.22	.02	.22
Sucrose w/i PM	.0004	.28	.18	.15	.59	.34	.56	.43	.84	.98	.47	.85
Sucrose w/i TD w/o control	.0001	.32	.01	.08	.007	.19	.18	.07	.0006	.35	.005	.14
Sucrose w/i PM w/o control	.0007	.22	.17	.16	.63	.26	.67	.25	.53	.93	.29	.78
TD	.0001	.006	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.61	.01	.07
PM	.0004	.02	.007	.0001	.0002	.0001	.0006	.0001	.009	.37	.20	.004
TD w/o control	.60	.02	.27	.04	.02	.02	.13	.003	.0001	.44	.11	.91
PM w/o control	.31	.02	.52	.0001	.15	.002	.05	.002	.008	.31	.63	.04
Sucrose × TD	.59	.31	.80	.82	.55	.86	.29	.76	.006	.83	.33	.65
Sucrose × PM	.0007	.33	.22	.20	.46	.40	.65	.45	.84	.20	.34	.99
Sucrose × TD w/o control	.36	.90	.25	.63	.06	.76	.27	.69	.10	.64	.15	.61
Sucrose × PM w/o control	.02	.52	.13	.41	.81	.51	.49	.60	.81	.72	.25	.39
TD vs. PM	.02	.20	.0004	.02	.0001	.02	.0001	.02	.0001	.07	.21	.79
Replacer × sucrose	.66	.90	.44	.94	.23	.91	.79	.96	.09	.37	.05	.21

[1]No significant ($P > .05$) differences were found for contrasts with the attributes coldness or gumminess.

[2]w/i = Within, w/o = without.

TABLE 4. Comparisons of least square means of sensory texture attributes[1] of freshly prepared and stored (140 d) frozen desserts with varied percentages of tapioca dextrin (TD) or potato maltodextrin (PM) as a fat replacer at three sucrose percentages.[2]

TCN[3]	Treatment combination	Softness		Coarseness		Wateriness		Creaminess		Chalkiness		Mouthcoating	
		Fresh	Stored	Fresh	Stored	Fresh	Stored	Fresh	Stored	Fresh	Stored	Fresh	Stored
1	Control: 16% sucrose, 12% Milk fat	21.6^{hijk}	*14.5^{ab}	9.2^{hij}	*22.9^{d}	8.3^{hij}	*20.9^{g}	40.3^{abcd}	32.3^{a}	2.0^{g}	*27.4^{abc}	39.3^{abc}	40.6^{ab}
	16% Sucrose variations												
2	4% TD, 8% Milk fat	37.3^{a}	*14.7^{a}	33.1^{ab}	*44.2^{ab}	26.8^{abcd}	*41.1^{abcd}	23.6^{hi}	17.6^{cdefg}	6.1^{efg}	*26.9^{abc}	34.3^{def}	*39.7^{abc}
3	8% TD, 4% Milk fat	36.8^{ab}	*8.9^{abcd}	31.9^{abc}	*50.4^{a}	29.3^{abc}	*47.7^{ab}	28.3^{efghi}	*8.5^{fg}	11.5^{cd}	*33.2^{ab}	33.9^{def}	39.4^{abc}
4	12% TD	35.5^{abcd}	*8.5^{bcd}	33.4^{a}	*50.5^{a}	33.7^{a}	*48.7^{a}	20.2^{i}	*7.8^{g}	15.1^{c}	30.9^{ab}	32.4^{f}	*38.3^{abc}
5	4% PM, 8% Milk fat	36.5^{abc}	*13.5^{abc}	24.9^{abcdefg}	*40.1^{abc}	19.5^{defg}	*36.1^{abcdef}	35.6^{bcde}	*19.9^{bcdef}	3.9^{efg}	31.5^{ab}	34.9^{cdef}	*40.2^{ab}
6	8% PM, 4% Milk fat	24.5^{efghij}	*13.9^{ab}	18.0^{defghij}	*33.0^{bcd}	16.1^{fghi}	*33.1^{bcdefg}	33.9^{bcdefg}	23.3^{abcde}	4.9^{efg}	8.7^{c}	36.7^{abcdef}	36.8^{bc}
7	12% PM	32.0^{abcde}	*10.2^{abcd}	20.9^{abcdefgh}	*49.7^{a}	18.9^{defg}	*46.6^{ab}	31.1^{defgh}	*10.4^{fg}	7.0^{def}	19.0^{abc}	36.0^{bcdef}	38.1^{abc}
	8% Sucrose + 8% polydextrose-APM variations												
8	12% Milk fat	18.1^{jk}	14.7^{a}	8.3^{ij}	*22.2^{d}	7.7^{ij}	*22.3^{fg}	42.9^{ab}	31.5^{ab}	4.2^{efg}	28.3^{abc}	38.7^{abcd}	40.7^{a}
9	4% TD, 8% Milk fat	29.4^{bcdef}	*9.2^{abcd}	19.9^{cdefghi}	*40.1^{abc}	20.1^{cdefg}	*37.6^{abcde}	32.7^{cdefgh}	*18.3^{cdefg}	2.0^{g}	21.1^{abc}	35.5^{bcdef}	38.1^{abc}
10	8% TD, 4% Milk fat	28.5^{defgh}	*9.1^{abcd}	30.1^{abcd}	*46.7^{ab}	30.5^{ab}	*45.8^{ab}	25.3^{fghi}	*12.4^{efg}	14.2^{c}	23.7^{abc}	33.2^{ef}	37.5^{abc}
11	12% TD	29.1^{cdefgh}	*6.5^{d}	20.5^{cdefghi}	*48.7^{ab}	23.5^{bcdef}	*46.4^{ab}	28.4^{efghi}	*9.7^{fg}	20.9^{b}	38.1^{a}	38.1^{abcde}	39.9^{ab}
12	4% PM, 8% Milk fat	22.9^{fghijk}	*10.7^{abcd}	11.6^{hij}	23.5^{d}	9.3^{hij}	*23.9^{fg}	41.9^{abc}	*27.5^{abcd}	2.0^{g}	17.1^{bc}	40.2^{ab}	38.8^{abc}
13	8% PM, 4% Milk fat	30.7^{abcde}	*10.0^{abcd}	28.0^{abcde}	*46.7^{ab}	17.2^{efgh}	*44.0^{abc}	35.3^{bcde}	*14.7^{efg}	2.3^{fg}	13.7^{bc}	36.6^{abcdef}	36.8^{bc}
14	12% PM	25.8^{efghi}	*7.7^{cd}	18.2^{efghij}	*47.5^{ab}	20.3^{cdefg}	*46.3^{ab}	30.6^{efgh}	*9.3^{fg}	6.7^{defg}	28.5^{abc}	37.4^{abcde}	37.3^{abc}
	16% Polydextrose-APM variations												
15	12% Milk fat	16.2^{k}	*10.0^{abcd}	6.3^{j}	*18.9^{d}	4.7^{j}	21.0^{g}	46.3^{a}	30.3^{ab}	2.0^{g}	18.7^{abc}	39.4^{abc}	40.6^{ab}
16	4% TD, 8% Milk fat	20.3^{ijk}	*13.7^{abc}	20.4^{cdefghi}	26.3^{cd}	15.9^{fghi}	28.0^{defg}	34.1^{bcdefg}	28.3^{abc}	7.0^{def}	21.5^{abc}	38.3^{abcd}	37.6^{abc}
17	8% TD, 4% Milk fat	27.1^{efghi}	*10.7^{abcd}	27.1^{abcdef}	*40.1^{abc}	26.4^{abcde}	*38.3^{abcde}	25.1^{ghi}	18.1^{cdefg}	15.9^{c}	21.5^{abc}	35.6^{bcdef}	37.3^{abc}
18	12% TD	22.1^{ghijk}	*7.0^{d}	20.7^{bcdefghi}	*47.3^{ab}	21.1^{cdefg}	*47.5^{ab}	25.2^{ghi}	*10.7^{fg}	26.7^{a}	23.1^{abc}	41.3^{a}	*36.0^{c}
19	4% PM, 8% Milk fat	17.9^{jk}	12.5^{abcd}	13.1^{ghij}	21.0^{d}	14.2^{ghi}	24.1^{efg}	34.8^{bcdef}	27.4^{abcd}	2.0^{g}	14.3^{bc}	35.9^{bcdef}	39.9^{ab}
20	8% PM, 4% Milk fat	29.9^{abcdef}	*15.0^{a}	15.7^{efghij}	*32.7^{bcd}	16.2^{fghi}	*30.7^{cdefg}	37.3^{abcde}	*24.1^{abcde}	4.1^{efg}	24.5^{abc}	39.3^{abc}	36.9^{abc}
21	12% PM	18.2^{jk}	*6.5^{d}	14.9^{fghij}	*43.5^{ab}	19.5^{defg}	*41.7^{abcd}	30.6^{efgh}	*15.9^{defg}	7.4^{de}	26.1^{abc}	35.1^{cdef}	*37.5^{abc}
	LSD, $P = .05$	7.48	6.09	12.55	16.09	9.23	15.04	9.55	11.91	4.85	20.4	4.92	3.85

[a,b,c,d,e,f,g,h,i,j,k]Means followed by the same letter in the same column did not differ ($P > .05$).

[1]Scale used was 60-point computerized version of 6-in intensity scale, divided into tenths; 0 = none and 60 = extremely high level for each attribute.

[2]An asterisk preceding the stored value indicates a significant difference ($P < .05$) from the fresh value for the attribute.

[3]Treatment combination number.

ness or gumminess in any of the frozen desserts, increased chalkiness and mouthcoating in a few products, but decreased softness and creaminess and increased wateriness for several of the products (Table 4). The stored frozen dessert with 33% fat replacement by PM and complete sucrose replacement by polydextrose-APM (TCN 19) did not differ from its freshly frozen counterpart for any textural attribute.

Instrumental Measurements

Viscosity. Mean values for viscosity of the unfrozen mix are given in Table 5. Viscosity ranged from 38.8 to 78.2 CP. In general, treatment combinations with higher fat and 100% sucrose had greater viscosity that those with low percentages of fat. Treatment combinations with varying percentages of sucrose and 100% fat were within a narrow viscosity range and were not different from one another. Cottrell et al. (7) indicated that polysaccharides, such as starch, restricted ice crystal growth during storage and increased mix viscosity. Although none of the physical measurements assessed in this study was a reliable predictor of sensory textural attributes, an inverse relationship was found between mix viscosity and coarseness ($r = -.53$). This result provides moderate support for the findings of Cottrell et al. (7).

Melting Rate. Melting rates were the same for all treatment combinations (Table 5) with a tendency toward greater drip, but not significantly so, in phase 1 than phase 2. Mean values ranged from 16.7 to 22.0 ml/30 min for freshly frozen products and from 10.0 to 17.6 ml/30 min for the stored frozen desserts.

Resistance to Deformation. Data obtained with the IUTM using either the cone or plunger attachments were inconsistent. No clear trends were observed other than decreased resistance for most products with polydextrose-APM without fat replacers (Table 5) and increased resistance to deformation measured with either attachment after storage. Correlation coefficients of IUTM measurements with sensory scores for coarseness and softness were low ($r \leq -.36$ to $+ .1$).

DISCUSSION

Polydextrose-APM Effects

Polydextrose-APM appeared to be similar to sucrose in holding water and inhibiting formation of the large ice crystals responsible for coarse, watery texture in frozen desserts in this study. Polydextrose seemingly inhibited the development of chalkiness during extended storage. Three possible mechanisms for polydextrose's effects are suggested: 1) replacement of solids, 2) control of moisture migration, and 3) freezing point depression. In this study, polydextrose was substituted for sucrose on a 1:1 solids basis, which was not the case in the earlier study using APM and dextrose (18). Bulking ability of polydextrose in frozen desserts should be comparable with that of sucrose. As a water-soluble bodying agent, polydextrose promotes moisture retention and slows the migration of water molecules within the system (3). Baer and Baldwin (2) previously 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 freezing point depression (11).

Coarseness and wateriness increased, and creaminess decreased, as more fat was removed in the frozen desserts with 100% sucrose, as expected. However, frozen desserts with either TD or PM in place of fat did not become as coarse or watery with decreased sucrose as might be expected. The polydextrose-APM in the system compensated for sucrose removal and also improved textural properties in the absence of fat because negative effects related to low fat percentages were less apparent.

Fat Substitution

The capacity of carbohydrate-based gels to compensate for textural and physical properties of milk fat might be attributed to two mechanisms: impact on mouthfeel and colloidal properties of the carbohydrate. Hydrated particles could influence the manner in which the frozen mass liquefies in the mouth; i.e., swollen granules lubricate ice crystals and amplify the perception of creaminess. Hydrophilic colloids, such as the dextrins and maltodextrins, increase the viscosity of the continuous phase in the unfrozen mix. Thus, subsequent foam formation and stability would be improved, large crystal growth during freezing restricted, the proportion of frozen water decreased (22), and heat shock during storage and the resulting phase separation during meltdown inhibited. No significant differences were noted among any of the reduced-calorie and control frozen desserts for meltdown in this study. 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 5 μ in diameter also could confer lubricating effects, enhance creaminess, and decrease the perception of coldness and coarseness. This mechanism is similar to that proposed for the protein-based fat substitutes: micro-gel particles that "fool the tongue" into perceiving a smooth, continuous, fat-like material (17).

TABLE 5. Comparisons of least squares means of physical measurements of mix and frozen desserts with varied percentages of tapioca dextrin (TD) or potato maltodextrin (PM) as a fat replacer at three sucrose percentages.

TCN	Treatment combination	Mix viscosity	Meltdown at 20 ± 1°C[1]		IUTM Cone[2]		IUTM Plunger[3]	
			Fresh	Stored	Fresh	Stored	Fresh	Stored
		(cps)	(ml/30 min)		(kg)			
1	Control: 16% sucrose, 12% Milk fat	66.7^{abc} (5.0[4])	18.3 (1.9[4])	14.3 (1.9[4])	.19^{defgh} (.05[4])	.85^{cd} (.4[4])	1.33^{ab} (.26[4])	30.7^{e} (18.8[4])
2	16% Sucrose variations 4% TD, 8% milk fat	51.2 (6.2)^{def}	20.3	10.7	.05^{i}	.56^{d}	.39^{d} (.32)	34.6^{de}
3	8% TD, 4% milk fat	45.8^{ef}	17.3	13.3	.11^{ghi}	1.19^{cd}	.67^{cd}	49.3^{bcde}
4	12% TD	38.8^{f}	17.0	12.0	.14^{fghi}	1.44^{bcd}	.97^{bcd}	88.0^{bc}
5	4% PM, 8% milk fat	58.2^{cde}	18.7	15.0	.06^{hi}	.58^{d}	.54^{cd}	33.3^{de}
6	8% PM, 4% milk fat	52.7^{def}	19.3	15.3	.15^{fghi}	.95^{cd}	.90^{bcd}	51.6^{bcde} (23.2)
7	12% PM	45.5^{ef}	19.7	17.3	.09^{ghi}	1.08^{cd}	.82^{bcd}	34.1^{de} (23.2)
	8% Sucrose + 8% polydextrose-APM variations							
8	12% Milk fat	78.2^{a}	20.3	14.3	.26^{bcdef}	.53^{d}	1.13^{bcd}	28.5^{e}
9	4% TD, 8% milk fat	53.0^{bcde}	22.0	12.0	.15^{fghi}	1.36^{bcd}	.86^{bcd}	63.7^{bcde}
10	8% TD, 4% milk fat	49.8^{def}	17.0	11.0	.18^{efghij}	1.97^{ab}	.78^{bcd}	78.3^{bcde}
11	12% TD	45.5^{ef}	21.3	15.3	.11^{ghi}	1.63^{abcd}	.77^{bcd}	69.0^{bcde}
12	4% PM, 8% milk fat	74.2^{ab}	19.0	13.3	.35^{ab}	1.35^{bcd}	1.27^{abc}	76.7^{bcde}
13	8% PM, 4% milk fat	52.8^{cdef}	17.7	10.0	.11^{ghi}	1.35^{bcd}	.70^{bcd}	79.0^{bcde}
14	12% PM	51.0^{def}	21.3	14.0	.17^{fghi}	1.83^{abc}	1.14^{bcd}	81.3^{bcde}
	16% Polydextrose-APM variations							
15	12% Milk fat	77.7^{a}	16.7	15.3	.34^{abc}	1.64^{abcd}	1.55^{a}	90.0^{abc}
16	4% TD, 8% milk fat	60.2^{bcde}	18.0	13.0	.27^{bcdef}	.74^{cd}	1.01^{bcd}	39.0^{cde}
17	8% TD, 4% milk fat	53.2^{cde}	21.3	10.3	.27^{bcdef}	1.20^{cd}	.92^{bcd}	60.1^{bcde}
18	12% TD	49.2^{def}	19.0	11.7	.30^{bcde}	2.46^{ab}	1.23^{bcd}	100.3^{ab}
19	4% PM, 8% milk fat	61.7^{bcd}	21.3	10.7	.45^{a}	1.23^{cd}	1.53^{a}	61.3^{bcde}
20	8% PM, 4% milk fat	58.7^{cde}	18.3	12.7	.20^{cdefg}	.78^{cd}	.84^{bcd}	53.0^{bcde}
21	12% PM	59.5^{cde}	17.0	17.7	.32^{abcd}	2.90^{a} (.5)	1.95^{a}	134.8^{a}

^{a,b,c,d,e,f,g,h,i,j}Means followed by the same letter in the same column do not differ ($P > .05$).

[1]Measured by methods of Nickerson and Pangborn (20) and Moore and Shoemaker (19) using 60-cc sample at 21 ± 1°C; differences were not significant for any variables ($P > .05$).

[2]Instron Universal Testing Machine (model 1122; Instron, Canton, MA) to measure force to achieve penetration of 15- or 5 mm at 2- or 20-kg scale load at −15 or −12°C for fresh and stored products, respectively.

[3]Instron Universal Testing Machine (model 1122) to measure force at 20- or 400-kg scale load for fresh and stored products, respectively.

[4]Standard error is the same as this value for all treatment combinations for the variable except where another value is indicated in parentheses.

Microscopic examination of the differences in basic structure and swelling behavior of these and other fat substitutes might help to explain the mechanisms occurring if they are employed to replace milk fat in a frozen dessert system. Investigation of the unfrozen and frozen system using a gel-type fat substitute compared with the ungelled hydrocolloids could verify the relative importance of the gel particles or of moisture control alone in creating the texture of low fat frozen desserts. Flavor binding of the carbohydrate substitutes also needs further investigation (24) to achieve fat-free, low calorie, frozen desserts that will remain in the marketplace as successful alternatives to the full-fat counterparts.

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