Sensory and Physical Properties of Ice Creams Containing Milk Fat or Fat Replacers[1]

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ABSTRACT

The purpose of this research was to determine the relative effects of milk fat, nonfat milk solids, or each of three whey protein type fat replacers on the flavor and texture attributes of vanillin-flavored ice cream. Descriptive sensory analyses disclosed that ice creams containing 4.8% of any of the fat replacers in place of milk fat had no demonstrable effect on vanillin flavor but increased the intensities of whey flavor, syrup flavor, and cooked milk flavor. Compared with each substitute, milk fat significantly reduced the syrup, whey, and cooked milk flavors and increased the fresh milk and cream flavors of the ice cream. Results emphasized the importance of fat as a flavor modifier and the importance of certain fat replacers as aids in improving texture.
(**Key words**: ice cream, flavor, fat replacer, milk fat)

Abbreviation key: **DE** = dextrose equivalent.

INTRODUCTION

Compared with traditional ice creams, the new light, lowfat, and nonfat ice creams suffer from low flavor quality. Because fat is the main carrier of flavor for many compounds, low flavor intensity may not be overcome by addition of more flavoring alone (7). Milk fat affects the flavor of ice cream in three ways: by contributing its own natural richness and creaminess (6); by contributing flavors acquired through hydrolysis, oxidation, or processing; and by modifying the perception of flavorful substances in the product.

If fat is to be effectively replaced in food, the effects of fat on the release of volatile flavor compounds must be equaled by the fat substitute (3). A fat replacer should match the texture, mouthfeel, and functionality of fat in a food product and should convey the desired flavor profile.

Flavors that are largely fat soluble, such as vanilla, are carried by fat into the mouth where the flavors are volatilized prior to sensory reception in the olfactory system. When there is not enough fat to carry these flavors, they are rapidly volatilized in the mouth and then quickly disappear from the perceived flavor profile. Therefore, the synergic action between the fat and flavoring is eliminated (5).

Because milk fat functions as a carrier of important flavor notes, the perception of these flavor notes can be expected to differ when the fat quantity is varied around the concentration of fat that is marginally sufficient to carry the entire amount of flavorant to the olfactory senses of the consumer. The amounts of fat or of other carriers of important flavor notes of ice cream that are necessary to affect this function are unknown. Similarly, the size of fat globules and, consequently, their total surface area per unit of frozen dessert, may be an important variable. These factors can affect all types of fat-soluble flavor notes, both desirable and undesirable. The extent to which fat is demulsified during the freezing of ice cream, thus permitting it to form films, may also affect flavor perceptions.

Milk fat is an important determinant of the texture and body of ice cream (2). Textural creaminess is a highly desirable attribute that is contributed by milk fat but is difficult to obtain with fat replacers.

Fat replacers based on whey protein have distinctive properties that can allow them to perform in food in a manner similar to that of fat globules. Instead of being based on lipid, accepted fat substitutes for ice cream are made of carbohydrates and proteins, which may form lipophilic particles (9). These substitutes withstand interactions between particles (which suggests that their surface structure is similar to that of emulsified fat), and they interact with mouth surfaces to generate a sense of substance (3). Although whey protein concentrate provides good stability and is a good emulsifier, it is reactive toward aliphatic aldehydes and methyl ketones. Because vanillin is an aromatic aldehyde, vanillin flavor may decrease be-

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cause of interactions between vanillin and protein (4).

The objective of this research was to determine the effects of milk fat, nonfat milk solids, or one of three whey-based fat replacers on the flavor and texture of light and nonfat vanillin-flavored ice creams.

MATERIALS AND METHODS

The manufacturers of the fat replacers used in this study suggested using the fat replacers at about 5.00% (4.8% solids) of the total mix. Preliminary experiments involving flavor and mouthfeel were used to determine the sweetener, stabilizer, and vanillin concentrations. Tables 1 and 2 show constituents and selected characteristics of the mixes, respectively. The three fat replacers are made from whey protein by proprietary processes. The manufacturers explain that Dairy Lo™ (Cultor Food Science, Ardsley, NY) and Prolo 11® (3886C) (Kerry Ingredients, Beloit WI) are made from denatured whey proteins, but Simplesse® 100 (The NutraSweet Kelco Co., San Diego, CA) consists of microparticulated whey protein. Prolo 11® contains stabilizer; therefore, only 0.22% stabilizer was used along with 5.22% Prolo 11®. One set of control mixes was formulated with nonfat milk solids, and the other set was formulated with milk fat in place of the fat substitutes. Except for this difference, composition of the control and experimental mixes was the same.

The liquid ingredients, except corn syrup, were placed in the processing vat, and agitation and heating were started. The thoroughly premixed dry ingredients were then added, and the emulsifying agitator was started. When the temperature reached 32°C, the 36 **DE** (dextrose equivalent) corn syrup was added. The mix was then pasteurized at 82°C for 25 s. The mixes were homogenized (APV-Gaulin, Philadelphia, PA) at 13,800 kPa (first stage) and 3500 kPa (second stage). Mixes were cooled to 10°C and collected for aging at 4°C for 12 to 48 h.

Just prior to freezing, a 1% ethyl vanillin solution (5% vanillin in 35% ethanol) was added to each mix. The final concentration of vanillin was 500 mg/L. A continuous freezer (Technogel Model 80; Bergamo, Italy) was used to freeze the mixes to –6°C. Overrun of the ice cream was kept at 85% ± 5%. The frozen ice cream was packaged in 1.892-L paperboard containers (Sealright Co., Inc., Kansas City, KS) and in 176-ml Styrofoam® cups. The surfaces were leveled with a spatula tilted backwards to avoid compacting the ice cream, and the cups were covered with aluminum foil to prevent drying. Ice creams were hardened in circulating air at –30°C. The smaller samples were used for determinations of melting rate, and the larger samples were used for sensory analyses.

To produce heat shock, a set of ice cream samples was stored for 20 d postfreezing at temperatures alternating between –15 and –30°C on a 48-h cycle. The heat-shocked samples were then evaluated for textural characteristics by trained panelists.

Judges for sensory analyses were selected based on their availability and willingness to participate in the study. Descriptive analyses (11) were performed on the fresh ice creams by 11 judges within 5 d of production for flavor, texture, and aftertaste attrib-

TABLE 1. Constituents of ice cream mixes.

				Control	
Ingredient	DairyLo™	Prolo 11®	Simplesse®	NDM	Fat
	(%)				
Skim milk	68.23	68.23	68.23	68.23	61.25
Sugar	10.56	10.56	10.56	10.56	10.56
Corn syrup, 36 DE[1]	8.25	8.25	8.25	8.25	8.25
NDM	4.30	4.30	4.30	9.35	4.30
Litesse® [2]	1.30	1.30	1.30	1.30	1.30
Maltodextrin, 15 DE	1.94	1.94	1.94	1.94	1.94
Stabilizer	0.44	0.22	0.44	0.44	0.44
DairyLo™	5.00	...	...	...	...
Prolo 11®	...	5.22	...	...	...
Simplesse®, Dry 100	...	...	5.00	...	...
Cream	...	...	...	...	12.00
	100.02	100.02	100.02	100.07	100.04

[1]Dextrose equivalent.

[2]Litesse® (polydextrose) and DairyLo™ (Cultor Food Science, Ardsley, NY), Prolo 11® (Kerry Ingredients, Beloit, WI), Simplesse® (The NutraSweet Kelco Co., San Diego, CA), and maltodextrin (15 DE; Grain Processing Corp., Muscatine, IA).

TABLE 2. Selected characteristics of ice cream mix formulas.

Sample	Fat	Fat replacer	NDM	Sweetness[1]	Stabilizer	Total solids
	(%)					
Treatments						
Dairy Lo™ [2]	. . .	5.00	10.03	14.97	0.44	35.43
Prolo 11®	. . .	5.22	10.03	14.97	0.22	35.44
Simplesse®	. . .	5.00	10.03	14.97	0.44	35.43
NMS Control	. . .	. . .	14.88	14.97	0.44	35.48
Fat Control	4.80	. . .	10.03	14.97	0.44	35.42

[1]Estimated sucrose equivalency.

[2]DairyLo™ (Cultor Food Science, Ardsley, NY), Prolo 11® (Kerry Ingredients, Beloit, WI), and Simplesse® (The NutraSweet Kelco Co., San Diego, CA).

utes and again for texture after heat shock treatments by 10 of the same judges. Attributes evaluated included vanillin flavor, sweet taste, syrup flavor, whey flavor, cooked milk flavor, fresh milk flavor, cream flavor, coarse-icy texture, gummy texture, smooth texture, rate of melt in the mouth, mouth coating, astringency, syrup flavor aftertaste, and vanillin aftertaste. Panelists marked responses on 15-cm lines anchored on the left with “not” and on the right with “very”. Fresh and heat-shocked ice creams were evaluated in separate sessions. Panelists were trained during three 1-h sessions during which they developed and defined the descriptors. Panelists expectorated all samples as well as the cracker and water that were used to cleanse the mouth between samples. Each ice cream mix was made and evaluated in three replications, and samples from each replication were evaluated by each panelist in three subreplications.

Samples used to determine melting rate were hardened for at least 24 h at –30°C and then were tempered at –20°C overnight. The Styrofoam cup was cut away carefully, and the samples were placed randomly in a 25°C incubator on top of wire mesh over a funnel, which was supported by a ring stand. Each funnel emptied into a 118-ml Styrofoam cup that had been previously weighed. Every 10 min, the cup under each sample was replaced, the melted ice cream was weighed, and the weight was recorded. The experiment was replicated three times in duplicate.

Freezing points of the ice cream mixes were determined [method 15.13 (1)] using a thermistor cryoscope (model J; Fiske Assoc., Bethel, CT). The cryoscope was calibrated using 7 and 10% NaCl solutions [method 15.13; (1)]. Unfrozen mixes were diluted with three parts of water to one part of mix. Freezing points were converted from Hortvet degrees to Celsius degrees by the following formula: °C = 0.9(°H – 0.0024)(dilution factor).

The forced-draft oven method [method 15.10; (1)] for ice cream mixes was used to determine total solids. Fat content was determined by the Mojonnier ether extraction method (method 15.8F; (1)). Viscosity of each mix was measured using a digital viscometer (model DV-II; Brookfield Stoughton, MA). Samples were tested at 4°C. Prolo 11® samples required a number 2 spindle. All of the other samples required a number 1 spindle.

Analysis of variance was used for data from the sensory analyses of the fresh and stored ice cream and for the compositional analyses. Proc GLM (8) was used for all analyses of variance. Means were separated by the LSD procedures (8). Differences in melting rates were determined using the LQC program (8) for goodness of fit of linear, quadratic, or cubic regression equations (10). Probability levels were set at 5%.

RESULTS AND DISCUSSION

Industry has developed several ingredients to act as replacers of milk fat in nonfat and low fat ice creams. Among them are the three whey-based fat replacers used in this experiment. We chose to add two bulking agents in equal quantities to each of the mixes: 1) polydextrose, a randomly bonded dextrose polymer that functions as a bulking agent and provides only one calorie per gram, and 2) 15 DE maltodextrin, partially hydrolyzed corn starch with about 50% of the molecules having more than 10 carbons and with an average degree of polymerization of 7.4. These ingredients may interact with the other fat replacers and with the added flavoring. However, the ingredients were added in the same amounts in each mix and have been considered to have exerted the same general effects in each product.

Descriptive Analysis: Fresh Ice Creams

Table 3 contains scores from sensory tests. Although this research focused on the flavor imparted

TABLE 3. Mean sensory scores[1] for flavor in fresh[2] ice cream.

Attribute	Dairy Lo™ [3]	Prolo 11®	Simplesse®	Control NDM	Control Fat	Duncan's critical range
Vanillin	7.86	7.65	8.22	8.54	9.16	. . .
Sweet	7.32	6.69	6.97	7.04	7.62	. . .
Syrup	6.81[a]	7.44[a]	6.94[a]	7.07[a]	5.96[b]	0.750
Whey	5.48[a]	4.96[a]	4.00[b]	3.81[b]	2.97[c]	0.745
Cooked milk	6.74[ab]	7.08[a]	6.68[ab]	6.19[b]	5.16[c]	0.769
Fresh milk	3.63[bc]	3.18[c]	3.68[bc]	4.10[b]	5.80[a]	0.689
Cream	5.23[b]	5.76[b]	5.11[b]	5.45[b]	6.99[a]	0.626

[a,b,c]Means within the same attribute with no common superscript differ ($P < 0.05$).

[1]Sensory scores: 1 = not to 15 = very.

[2]Subjected to sensory tests within 5 d of manufacture.

[3]DairyLo™ (Cultor Food Science, Ardsley, NY), Prolo 11® (Kerry Ingredients, Beloit, WI), and Simplesse® (The NutraSweet Kelco Co., San Diego, CA).

by vanillin, there was no significant effect of the variables on this flavor. However, the differences approached significance, and the milk fat control showed more than a 1-point (15-cm scale) higher score than the samples containing Dairy Lo™ or Prolo 11®. Scores for sweet taste were quite similar among the treatments.

Samples containing milk fat were scored significantly lower in syrup, whey, and cooked milk flavors and higher in fresh milk and cream flavors than were samples from the other treatments. Among the four other treatments, whey flavor was higher in samples containing Dairy Lo™ and Prolo 11®. Nonfat milk imparted less whey and cooked milk flavor and more fresh milk flavor than Prolo 11® but did not differ significantly in these attributes from Simplesse® or Dairy Lo™. In general, the three whey-based fat replacers imparted more of the flavors considered undesirable than did nonfat milk solids, and nonfat milk solids did so more than milk fat.

Scores from sensory tests of texture are shown in Table 4. The major finding was that Prolo 11® produced a much smoother, gummier, and slower melting (in the mouth) product than did the other additives. Gumminess was greater in ice cream containing Dairy Lo™ than in ice cream containing milk fat, NDM, or Simplesse®. Ice cream made with Dairy Lo™ melted more slowly than did ice cream made with milk fat, but no difference in melting was noted compared with NDM or Simplesse®. The product containing Simplesse® was more coarse-icy than that containing Dairy Lo™; however, the scores for smoothness did not differ significantly between these two treatments. Normally these attributes, coarse-icy versus smooth, are considered opposites. They were scored separately in this experiment and appear to have been considered differently by the panelists. Generally, however, there was an obvious inverse relationship between these two attributes among the treatments. Astringency was higher when DairyLo™

TABLE 4. Mean sensory scores[1] for texture in fresh[2] ice cream.

Attribute	Dairy Lo™ [3]	Prolo 11®	Simplesse®	Control NDM	Control Fat	Duncan's critical range
Coarse-icy	6.04[b]	3.35[c]	7.07[a]	6.33[ab]	6.38[ab]	0.993
Gummy	4.56[b]	9.61[a]	3.24[c]	3.59[c]	3.04[c]	0.826
Smooth	8.39[b]	12.21[a]	8.68[b]	8.96[b]	8.87[b]	0.889
Rate of melt in mouth	9.05[b]	5.92[c]	9.71[ab]	9.63[ab]	9.93[a]	0.831
Mouth coating	6.19[b]	8.77[a]	5.83[b]	6.00[b]	5.92[b]	0.843
Astringent	4.17[a]	3.02[bc]	4.10[a]	3.57[abc]	3.41[abc]	0.735

[a,b,c]Means within the same attribute with no common superscript differ ($P < 0.05$).

[1]Sensory scores: 1 = not to 15 = very.

[2]Subjected to sensory tests within 5 d of manufacture.

[3]DairyLo™ (Cultor Food Science, Ardsley, NY), Prolo 11® (Kerry Ingredients, Beloit, WI), and Simplesse® (The NutraSweet Kelco Co., San Diego, CA).

or Simplesse® was added in place of Prolo 11®. Astringency scores of samples containing NDM or milk fat lay between those discussed and did not differ from either end of the range. Astringency was the degree to which samples imparted dryness in the mouth after expectoration and before rinsing the mouth. The slow melting rate, extreme smoothness, and high mouth coating obtained by adding Prolo 11® may have offset tendencies for denatured whey proteins to cause dryness in the mouth. Although the processes for producing the three whey-based fat replacers used in these experiments are proprietary, Simplesse® is known to be microparticulated, producing particles ranging from 0.1 to 3 μm in diameter. Heat denaturation appears to provide much of the functionality of DairyLo™ and Prolo 11®. Heat denaturation of whey protein molecules causes unfolding and increases tendencies of the proteins to bind to other substances. The size of these particles is an important determinant of mouthfeel. Bringe and Clark (3) reported that particle sizes of 0.1 to 2 μm cause a creamy sensation, but particles larger than 3 μm impart gritty or powdery mouthfeel.

Descriptive Analysis: Heat-Shocked Ice Creams

Because fat replacers may produce different effects in stored ice cream than in fresh ice cream, descriptive analysis was conducted. Among the heat-shocked samples, only Prolo 11® produced significant effects on textural characteristics compared with samples containing milk fat (Table 5). As with the fresh samples, Prolo 11® had greater gumminess and smoothness, lower course-icy, and slower melting in the mouth. Differences because of the use of Dairy Lo™ that were apparent in fresh samples were not seen in heat-shocked samples.

Comparisons of data in Tables 4 and 5 suggest that scores for course-icy texture and rate of melting in the mouth increased but gumminess and smoothness decreased during heat-shock treatment. However, heat shock had essentially no effect on statistically significant differences among treatment effects.

Physical Characteristics

Concentrations of milk fat in the ice creams were close to the target values of 4.8 and 0.5% for the control and the nonfat types, respectively (Table 6). DairyLo™ (Cultor Food Science, Ardsley, NY), Prolo 11® (Kerry Ingredients, Beloit, WI), and Simplesse® (The NutraSweet Kelco Co., San Diego, CA). Amounts of fat differed significantly among the whey-based fat replacers and NDM, but differences were relatively small and should have had no effect on the sensory properties of the ice creams. There was no significant difference in total solids among the samples, and means ranged from 35 to 35.4% (data not shown). The control ice cream, made with milk fat, melted significantly more slowly than the other samples among which there was no significant difference in melting rate (Figure 1).

Freezing points for each treatment differed significantly (Table 6); ice creams containing Dairy Lo™ and milk fat froze at the lowest and highest temperatures, respectively.

When fat is removed from ice cream and is replaced with nonfat milk solids or other dissolved substances, the freezing point is lowered. The small decrease in freezing point from that of the control ice cream caused by Prolo 11® suggests that it contained mostly proteins and stabilizers. The other two fat replacers and the NDM had significantly lower freezing points, suggesting that they contain more lactose and milk salts than does Prolo 11®. Even though the sample

TABLE 5. Mean sensory scores[1] for texture in stored[2] ice cream.

Attribute	Dairy Lo™ [3]	Prolo 11®	Simplesse®	Control NDM	Control Fat	Duncan's critical range
Coarse-icy	7.08[a]	3.79[b]	7.45[a]	6.73[a]	6.98[a]	0.758
Gummy	3.98[b]	9.33[a]	3.24[b]	3.53[b]	2.92[b]	0.775
Smooth	8.02[b]	11.53[a]	8.18[b]	8.60[b]	8.37[b]	0.783
Rate of melt in mouth	10.05[a]	6.31[b]	10.06[a]	10.00[a]	10.25[a]	0.783

[a,b]Means within the same attribute with no common superscript differ ($P < 0.05$).

[1]Sensory scores: 1 = not to 15 = very.

[2]Stored 20 d at temperatures alternating between –15 and –30°C on a 48-h cycle.

[3]DairyLo™ (Cultor Food Science, Ardsley, NY), Prolo 11® (Kerry Ingredients, Beloit, WI), and Simplesse® (The NutraSweet Kelco Co., San Diego, CA).

TABLE 6. Physical characteristics of ice cream mixes.

				Control	
Characteristic	DairyLo™ [1]	Prolo 11®	Simplesse®	NDM	Fat
Fat, %	0.44[cd]	0.46[c]	0.55[b]	0.41[d]	4.77[a]
Freezing point, °C	–1.378[e]	–1.061[b]	–1.343[d]	–1.316[c]	–1.010[a]
Viscosity, mPa·s	38.0[b]	1190.0[a,2]	26.2[c]	24.5[c]	11.9[d]

[a,b,c,d,e]Means within a row with no common superscript differ ($P < 0.05$).

[1]DairyLo™ (Cultor Food Science, Ardsley, NY), Prolo 11® (Kerry Ingredients, Beloit, WI), and Simplesse® (The NutraSweet Kelco Co., San Diego, CA).

[2]Prolo 11® given as apparent viscosity.

containing Prolo 11® had a higher freezing point by 0.25 to 0.32°C, the sample melted at about the same rate as did the other nonfat ice creams (Figure 1).

Because milk fat is suspended rather than dissolved, variations in its content in ice cream do not affect freezing point as long as the concentrations of dissolved substances in the aqueous phase are kept constant. Milk fat also slows the rates of heat transfer through ice creams. Therefore, ice creams that contain fat would be expected to melt more slowly than would nonfat ice creams containing similar amounts of total solids and stabilizer-emulsifier.

There were significant differences in viscosities among treatments (Table 6). Viscosity for ice cream that contained Prolo 11® is reported as apparent viscosity because the mix showed non-Newtonian behavior (i.e., shear thinning). This ingredient is formulated with stabilizer, the type and concentration of which are proprietary. It is interesting that, although fat slowed the rate of melting at 25°C, panelists detected no difference among samples containing fat, NDM, or Simplesse® in the rate of melting in the mouth. Furthermore, the perception of panelists that Prolo 11® caused slow melting in the mouth was not evident in melting tests at 25°C, which suggests that the high viscosity of mix produced by Prolo 11® was responsible for the perceptions of the judges that this product melted relatively slowly in the mouth.

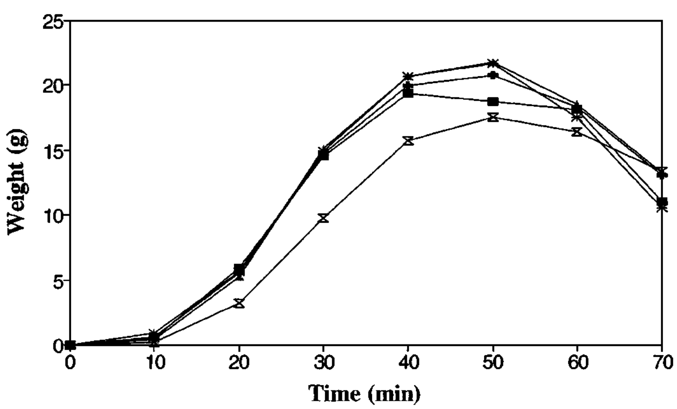

Figure 1. Weights of melted ice creams accumulated every 10 min for 70 min: Dairy Lo™ (■; Cultor Food Science, Ardsley, NY), Prolo 11® (▲; Kerry Ingredients, Beloit, WI), Simplesse® (*; The NutraSweet Kelco Co., San Diego, CA), NDM control (+), and fat control (×).

The samples that gave Newtonian responses were relatively low in viscosity, and the sample containing Dairy Lo™ had the highest of the four samples. There was no difference in viscosity between samples containing Simplesse® and those containing NDM. Milk fat produced the lowest viscosity (Table 6).

CONCLUSIONS

Substitution of selected whey-based fat replacers for milk fat to make nonfat instead of reduced fat ice cream resulted in no change in flavor produced by vanillin. However, intensities of syrup, whey, and cooked milk flavor were increased by the substitution. Effects on texture differed among the three fat replacers tested. The high viscosity of the mix coupled with the gumminess, slow rate of melting, high degree of mouth coating, and extreme smoothness of product made with Prolo 11® indicated that overstabilization occurred even though the amount of stabilizer added was 50% of that added to the other mixes.

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