Effect of Milk Fat Content on Flavor Perception of Vanilla Ice Cream[1]

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ABSTRACT

The effects of milk fat concentration on flavor perception of vanilla ice cream (with 0.5 to 10% fat) were studied by sensory analyses. The percentage of free vanillin in the ice cream was determined by HPLC. The HPLC data showed that the amount of free vanillin decreased when fat content increased. Perceptions of vanilla flavor and sweetness were evaluated by a trained panel using time-intensity methodology. No significant difference was found in sweetness perception. Among 11 time-intensity parameters for vanilla flavor perception, the panel found a significant difference only in the time required to reach maximum vanilla intensity. However, free-choice profiling and a consumer preference panel showed, respectively, that, as fat content was increased, sensory quality improved, and overall preference increased.

(**Key words**: vanilla flavor, fat content, ice cream)

Abbreviation key: **D** = dimension, **FCP** = free-choice profiling, **MPS-1** = micropartition system-1, **TI** = time-intensity, $\mathbf{T_{max}}$ = time required to reach maximum intensity.

INTRODUCTION

Fat is important in foods for sensory qualities such as flavor, color, texture, and mouthfeel. Fat is the precursor, carrier, and modifier of many flavor components (4, 11, 17, 21, 25, 30). Fat is thought to have a unique functionality that enables it to react with flavor compounds and to have a specific pattern of flavor release in the mouth that no fat replacer can provide. Interactions among volatile aroma substances and nonvolatile compounds depend on the physicochemical properties of the compounds and on the binding that may occur among them (28). Although the impact of fat concentration on the appearance and texture of foods is well known, its influence on flavor release and perception is still not well understood (12, 16). Flavor perception is determined by the nature and quantity of the flavor compound and its availability to the sensory system as a function of time (10, 14, 15).

The total amount of lipid in a food influences both its texture and flavor. A reduction in fat content in ice cream from 10 to 3% resulted in the loss of creaminess, an attribute normally associated with ice cream (17). Weit et al. (29) found that fat content affects the sensory profiles and the perceived sweetness intensity of sweeteners. Sensory characteristics of sucralose, sucrose, and aspartame were studied in lipid model systems varying in fat concentrations. The sweetness of sucralose and aspartame decreased as fat contents were increased, especially at lower sweetener concentrations. Fat affects the headspace concentration of flavor compounds by influencing their vapor pressure. Schirle-Keller et al. (25) found that lipophilic volatiles were trapped by the lipid compounds in food, which resulted in low headspace concentration of these volatiles.

Vanilla is the most used flavoring in ice cream, constituting more than 29% of supermarket sales in 1995 (8). Vanillin (4-hydroxy-3-methoxybenzaldehyde) is the predominant component in vanilla extract, occurring in concentrations of 0.5 to 2.5%. Vanillin is often used to represent vanilla content in instrumental analysis and is the major component of artificial vanilla flavorings (7, 23).

Most studies on the perception of vanilla flavor have been focused on perception of vanilla or vanillin in pure solutions and in model systems involving sweeteners (9), dairy proteins (6, 13), bean proteins (18), or fat replacers based on proteins (25). However, not much has been reported on the effect of milk fat on vanilla perception in real food systems, such as ice cream.

The objective of the present study was to determine the effects of fat content on flavor perceptions in ice cream, using sensory analysis, and on amount of free vanillin in the aqueous phase, using HPLC.

Received Febraury 3, 1997.
Accepted July 7, 1997.
[1]Contribution from the Missouri Agricultural Experiment Station. Journal Series Number 12,597.
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MATERIALS AND METHODS

Ice Cream Preparation

The ice cream formulas were calculated by conventional methods (1). Ingredients used were pasteurized skim milk and 40% cream (Prairie Farms, Carlinville, IL), low heat nonfat dry milk, and dry buttermilk solids (Mid-America Dairymen, Sabetha, KS), sugar, 36 DE (dextrose equivalent) corn syrup (Cargill, Eddyville, IA), and nonfat stabilizer (number 19; Stabilized Products, St. Louis, MO). Polydextrose (Litesse®; Pfizer, New York, NY) was used as the fat replacer. Tables 1 and 2 show the characteristics of the ingredients and mixes. Mixes were formulated in two groups, containing 39.2 and 33.2% total solids, respectively, so that no more than 4% polydextrose was used to minimize its effect on flavor.

After ingredients were thoroughly mixed and preheated in mixing vats (66 L), the mixes (23 L each) were HTST pasteurized (Processing Machinery and Supply Co., Philadelphia, PA) at 81.5°C for 25 s and homogenized in a two-stage homogenizer (APV-Gaulin GmbH, Philadelphia, PA). Pressures were 13.8 and 3.5 MPa for the first and second stages, respectively. The mixes were then rapidly cooled to below 10°C and aged at 4°C for 24 to 48 h.

Mixes were frozen in a continuous freezer (Technogel model 80; Bergamo, Italy). Twofold pure Bourbon vanilla extract was added (0.6% vol/vol) according to manufacturer recommendation (Beck Flavors, St. Louis, MO) to the mix before freezing. The mix was frozen to –6°C with 80 to 90% overrun. Ice cream for sensory analyses was packed in 1.89-L paperboard containers (Sealright Co., Kansas City, KS). Samples for melting rate testing were packaged in 120-ml styrofoam cups. Surfaces were leveled, avoiding compaction, and then covered with aluminum foil. Samples were hardened at –30°C for at least 48 h. All mixes were produced with two replications.

Determination of Chemical and Physical Properties

Total solids and fat content for ice cream mixes were determined using the forced-draft oven (method 15.10 C) and Mojonnier ether extraction (method 15.8 F) methods, respectively, as described in *Standard Methods for the Examination of Dairy Products* (2). Viscosities of the mixes were tested using a digital viscometer (model DV-II; Brookfield Engineering Laboratories, Stoughton, MA). Samples were tested at 4°C with a number 1 spindle (spindle factor: SMC = 7.68 and SRC = 0.22). The shear stress of each sample was measured at rotation speeds of 0.3, 0.6, 1.5, 3, 6, 12, 30, and 60 rpm. The measurements were done in two replications; duplicate tests were conducted for total solids and viscosity, and triplicate tests were conducted for fat content.

Before melting rate determination, samples were tempered at –20°C overnight. The styrofoam cup was carefully cut away to expose the sample that was then placed on wire mesh over a funnel that was supported by a ring stand over a preweighed styrofoam cup. All samples were melted at ambient temperature (20 ± 0.5°C). The melted samples were collected in the styrofoam cups and weighed every 10 min. Tests of each replicate were done in triplicate. Data were analyzed using response surface methodology (24). Melting rates were calculated from the linear portion of

TABLE 1. Characteristics of ingredients used in ice cream manufacture.

Ingredient	Fat	Nonfat milk solids	Sweetness[1]	Total solids
	(%)			
Skim milk	. . .	8.6	. . .	8.60
Cream	40	6.24	. . .	46.24
Nonfat dry milk	. . .	97.0	. . .	97.00
Dry buttermilk solids	5	91.0	. . .	96.00
36/43 DE[2] Corn syrup solids	. . .	. . .	52	79.45
Sucrose	. . .	. . .	100	100.00
Stabilizer-emulsifier 19[3]	. . .	. . .	. . .	90.00
Polydextrose (Litesse®)[4]	. . .	. . .	. . .	100.00

[1]Based on sweetness relative to sucrose.

[2]Dextrose equivalent.

[3]Contents: cellulose powder, whey protein concentrate, mono- and diacylglycerides, modified food starch, carrageenan, and polysorbate 80.

[4]Pfizer, Inc. (New York, NY).

TABLE 2. Target composition of ice cream mixes

	Mix						
	1	2	3	4	5	6	7
	(%)						
Fat	10	8	6	4	2	1	0
Litesse®[1]	0	2	4	0	2	3	4
Nonfat dry milk	11	11	11	11	11	11	11
Dry buttermilk	1	1	1	1	1	1	1
36/43 DE[2] Corn syrup	4.8	4.8	4.8	4.8	4.8	4.8	4.8
Sucrose	12	12	12	12	12	12	12
Stabilizer-emulsifier 19	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Total solids	39.2	39.2	39.2	33.2	33.2	33.2	33.2

[1]Pfizer, Inc. (New York, NY).

[2]Dextrose equivalent.

each melting curve. Differences in slopes were analyzed by ANOVA, and least significant differences were calculated using SAS (24).

Reverse-Phase HPLC

The HPLC method was based on the procedure described by Guarino and Brown (5). A C_{18} column was selected because of its suitability for separation of vanillin in pure solutions (5) and in milk protein models (13). A standard curve was generated using solutions of 0, 0.1, 0.2, 0.3, 0.4, and 0.5 mg/L made from vanillin crystals (Fisher Scientific, St. Louis, MO) in 35% ethanol.

The micropartition system-1 (**MPS-1**) of Amicon (Danvers, MA) has been used to separate free vanillin from bound vanillin in protein binding model systems (13, 18). In the present study, the free vanillin in the ice creams was separated by the MPS-1 and then quantified using HPLC. The amount of vanillin in the twofold pure Bourbon extract (Beck Flavors) was also determined. The extract was filtered through a YMT membrane in the MPS-1. The driving force was centrifugation at 1800 × g at 0°C for 40 min (model J2-21 centrifuge; JA-18, r = 132 mm; Beckman Automated Lab Operations, Allendale, NJ). The filtrate was ready for HPLC injection.

The ice cream mixes were diluted 1:1 (vol/vol) with distilled water and were shaken for 20 h in an ice bath at 100 rpm (model G76; gyrotary water bath shaker; New Brunswick Scientific, New Brunswick, NJ) to establish the equilibrium between free and bound vanillin. Each diluted sample was centrifuged at 13,000 × g at 0°C for 20 min to break the emulsion into three layers (fat, aqueous, and protein-based solid). One milliliter of each aqueous layer was transferred into the MPS-1 system and centrifuged as described. The vanillin in the filtrate (free vanillin) was then determined by HPLC. The moisture content of each diluted sample was determined by the oven-drying method (15.10C) (2). A steam bath (Thelco model 83; Precision Scientific Co., Chicago, IL) and a radiant heat oven (Lab-Line Imperial II; Lab-line Instruments, Inc., Melrose Park, IL) were used.

The HPLC analysis was conducted using a 15-cm × 4.6-mm LC-18 column with 5-μm particle size packing (Supelco, Inc., Bellefonte, PA), a Perkin-Elmer HPLC with a 20-μl fixed loop (Rheodyne, Cotati, CA) a series 410 LC pump, and an LC 90 UV spectrophotometric detector (Perkin-Elmer Instrument Division, Norwalk, CT) that was set at 254 nm. The carrier was acidified water and methanol (90:10, vol/vol). The acidic water was made as 10 ml of glacial acetic acid diluted in 800 ml of HPLC grade water (Fisher Scientific). The flow rate was 1.5 ml/min.

Amounts of vanillin in the vanilla extract and amounts of free vanillin in the ice creams were determined. Differences between the concentrations of free vanillin in ice creams and the calculated concentrations of total vanillin from the added vanilla extract were considered as the bound vanillin. The percentage of free vanillin was calculated as the amount of free vanillin detected in the ice creams versus the amount of vanillin added. Tests were done in two replications with triplicate samples. Data were analyzed by ANOVA using SAS® (24).

Sensory Procedures

Ice cream samples were tempered to –12°C at least 24 h before serving. Complete randomized block designs were used for all tests (3). All samples (about 60 ml in a 120-ml cup) were coded with three-digit random numbers, and all orders of serving were completely randomized. To prevent ice cream from melt-

TABLE 3. Parameters used for time-intensity curve analysis.

Parameter	Definition
T_{start}	Time from ingestion until onset of the sensation.
T_{end}	Time from ingestion through extinction of the sensation.
T_{total}	Total time of the sensation from onset through extinction.
I_{max}	Maximum perceived intensity.
T_{max}	Time needed from onset to reach the maximum intensity.
MaxSLL	Maximum rate of increase in intensity perceived (maximum slope of the left half of the time-intensity curve).
T_{maxsll}	Time at the maximum increasing rate of the perception.
AveSLL	Average rate of increasing intensity perception.
MaxSLR	Maximum rate of decrease in intensity perceived (Maximum slope of the right half of the time-intensity curve).
T_{maxslr}	Time at the maximum decreasing rate of the perception.
AveSLR	Average rate of decay of the perceived intensity.

ing, samples were served one at a time. Time-intensity (**TI**) and free-choice profiling (**FCP**) were done in two replications with duplicate samples within each replicate.

The TI evaluation. Ten students (5 males and 5 females, ages 22 to 32 yr, University of Missouri-Columbia) participated in the test.

An IBM-PC compatible server computer monitored five IBM-Personal System 2 computers in five individual tasting booths. The PSA-System V. 1.64 (22) was loaded in the server computer to control the TI evaluations in each booth. Instructions were given on each individual computer screen. Each judge used a mouse to move a slider up and down a vertical unstructured line scale that was 10 cm long and anchored with the descriptor “none” at one end and “extreme” at the other.

Judges were familiarized with the ice cream samples and TI procedures during three training sessions. Sample size, proper swallowing time, and testing time for a sample were decided by judges through discussion.

During testing, judges started to record the intensity of sweetness or vanilla flavor immediately after 2.5 ml (0.5 tsp.) of ice cream was put into the mouth. At 12 s, a message appeared on the screen to tell judges to swallow, and the evaluation continued until the sensation was extinct. Data were collected from each judge by the computer every 0.25 s for 3.5 min.

The intensity of vanilla flavor and sweetness of each sample were rated in separate sessions at least 2 h apart. Three or four samples were evaluated during each session. The TI curves were plotted for vanilla or sweetness ratings for each judge, sample, and replication. Each plot was evaluated for 11 parameters as defined in Table 3. The ANOVA (24) was used to analyze the data. Main effects included judge, ice cream, replication, and all two-way interactions. Averaged curves were calculated.

FCP. The FCP evaluation was conducted using the same panel that had participated in the TI analysis. All seven samples were presented to each judge in a session for term development. Each judge was asked to generate a personal list of all terms needed to evaluate the ice creams. During testing sessions, judges evaluated each sample using nine-point scales (1 = low and 9 = high) identified by each panelist’s own list of terms. Two replications were done with triplicate samples. All seven samples within each replication were served in random sequence on each of 3 d during which samples were presented for a maximum of 25 min followed by a rest period of at least 2 h.

The ANOVA (24), with the main effect being ice cream, was used to analyze each attribute for each judge. Attributes that did not discriminate among samples were eliminated from further analyses. The final data matrices were analyzed by general Procrustes analysis, Version 2.2 (22).

Consumer Preference Test

Sixty-three volunteers (students, faculty, and staff of the University of Missouri-Columbia, including 34 females and 29 males, ages 19 to 59 yr) participated in the study. All seven samples were served to each judge on one tray in random testing order. Judges were asked to taste each sample and indicate the degree of liking of each sample on a nine-point hedonic scale (26). Data were analyzed by ANOVA (24); the main effects were consumer and ice cream.

RESULTS AND DISCUSSION

Chemical and Physical Tests

Actual total solids contents did not differ significantly from the target values ($t = 0.254$; df = 6; $P <$

TABLE 4. Physical and chemical properties of ice creams and percentages of free vanillin in ice creams analyzed by HPLC.

	Mix						
	1	2	3	4	5	6	7
Fat, %	9.65^{a}	7.57^{b}	5.63^{c}	4.18^{d}	2.35^{e}	1.31^{f}	0.53^{g}
Total solids, %	39.50^{a}	39.31^{a}	39.42^{a}	33.73^{b}	33.92^{b}	33.92^{b}	33.88^{b}
Apparent viscosity, Pa·s	0.074^{a}	0.056^{b}	0.046^{c}	0.028^{d}	0.023^{e}	0.022^{ef}	0.020^{f}
Melting rate,[1] %/min	2.44^{a}	2.18^{a}	1.72^{b}	1.20^{d}	1.29^{cd}	1.64^{bd}	1.45^{bcd}
Free vanillin, %	49.52^{a}	52.29^{ab}	52.69^{ab}	60.71^{c}	56.05^{bc}	58.45^{c}	59.65^{c}

[a,b,c,d,e,f]Means within a row with no common superscript letter differ ($P < 0.05$). Least significance differences for fat, total solids, viscosity, melting rate, and percentage of free vanillin were 0.1898, 0.3024, 0.0023, 0.3592, and 5.2253, respectively.

[1]Percentage of weight melted (weight melted divided by sample weight) per minute was calculated using the linear portion of each melting curve. The linear portions occurred between 10 and 40 min for sample 1, 20 and 50 min for sample 2, 30 and 60 min for samples 4 and 7, and 40 and 70 min for samples 3 and 6.

0.05). Total solids contents of the seven samples fell into two groups, the higher fat samples (6 to 10% fat) and the lower fat samples (0.5 to 4% fat); the groups contained 39.31 to 39.50% and 33.73 to 33.92% total solids, respectively. Within each group, total solids values did not differ ($P < 0.0001$) from each other (Table 4).

Although the sample with higher fat averaged less than the target values and the lower fat samples averaged more than the target values, the actual fat contents did not differ significantly from the formulated values ($t = 0.842$; df = 6; $P < 0.05$). The nonfat sample contained 0.53% fat (Table 4) because the dry buttermilk used contained a small amount of fat (5%).

Apparent viscosity values (27) averaged over shear rates increased as fat content increased. The viscosities of mixes that contained 10, 8, 6 and 4% fat differed from each other and were higher than those of the lower fat mixes ($P < 0.001$). However, as fat content increased from 0.5% to 1% and from 1% to 2%, viscosities of the mixes were not significantly ($P > 0.05$) affected (Table 4).

Ice creams melted at different rates ($P < 0.0001$) (Table 4) and in different patterns (Figure 1). Ice creams with high amounts of total solids melted faster ($P < 0.0001$) than did those ice creams containing low amounts of total solids, which was probably due to the effect of dissolved solids on freezing point depression. Water contents were approximately 60.8 and 66.8% in samples containing high (39.2%) and low (33.2%) amounts of solids, respectively. Samples that contained the higher amount of total solids also contained the higher amounts of fat. For example, the ratio of water-soluble ingredients to water in the 10% fat sample (24.06:60.8 = 0.40) was higher than that in the 4% fat sample (24.06:66.8 = 0.36), which was due to the 6% difference in fat content between the two samples. The higher the concentration of the water solute, the lower was the freezing point and the faster was the melting rate. Therefore, the samples that were high in solids and fat melted faster than did the samples that were low in solids and fat.

The response surface methodology provided a significant model ($P < 0.05$) for the melting rates of the ice creams. The coefficient of determination was 0.9802 after five dependent variables were removed by the backward elimination procedure. The response surface plot (Figure 1) was generated by the following third-degree polynomial equation for percentage of weight melted (PWM):

$$\begin{aligned} \text{PWM} = & -0.31 + 0.017F^2 - 0.0017F^2T \\ & - 0.0015F^3 - 0.00015T^2 + 0.00015F^3T \\ & + 0.000023F^2T^2 - 0.0000021F^3T^2 \\ & -0.00000009F^2T^3 = 0.00000001F^3T^3, \end{aligned}$$

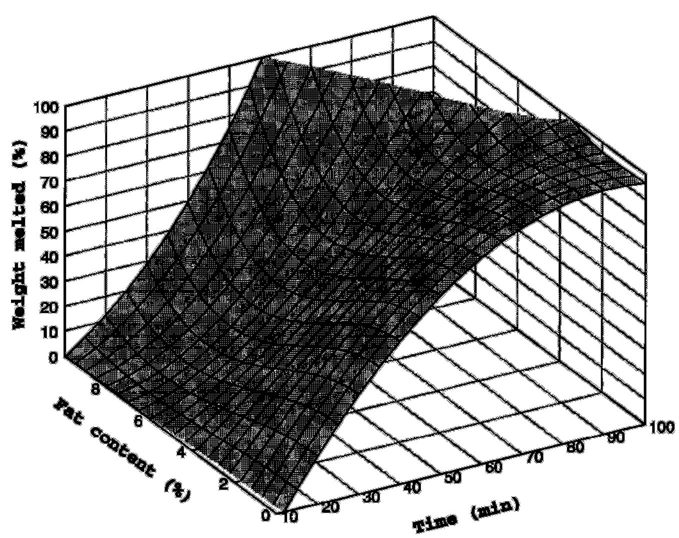

Figure 1. Response surface graph of melting profile of ice creams containing 0.5 to 10% fat.

TABLE 5. Results of time-intensity analysis and consumer testing.

	Mix						
	1	2	3	4	5	6	7
T_{max},[1] s	17.81[a]	17.71[a]	17.74[a]	17.50[b]	17.57[ab]	17.20[c]	16.65[d]
Consumer preference score[2]	2.5[a]	3.1[b]	3.7[c]	4.9[ef]	4.6[e]	4.7[ef]	5.1[f]

[a,b,c,d,e,f]Means within a row with no common superscript letter differ ($P < 0.05$ and 0.001) for T_{max} and consumer preference scores, respectively.

[1]Time required to reach maximum intensity.

[2]Scale: 1 = like extremely to 9 = dislike extremely.

where F = fat content (percentage) and T = time (minutes).

Patterns of melt for ice creams with different fat contents were different. Samples with high percentages of fat (6 to 10%) and solids (39%) melted faster than the others and reached 100% melting around 60 min; the melting rate increased as fat content increased. The samples with low fat (0 to 2%) and solids (33%) needed more than 100 min to melt completely. Ice cream containing 4% fat and 33% solids melted in a more linear pattern and more slowly than all the other samples (Figure 1).

HPLC

Amounts of free vanillin in ice creams containing 0.5 to 4% fat did not differ ($P < 0.01$). Furthermore, an increase in fat content from 6 to 10% had no effect ($P > 0.01$) on the amount of free vanillin in the ice cream. However, the samples with high amounts of fat (6 to 10%) and solids had less ($P < 0.01$) free vanillin than did the samples with a low amount of fat (0.5 to 4%) and solids. Comparisons between treatments matched for content of nonfat (serum) solids show more clearly the effect of fat on free vanillin. These matched samples contained about 10 and 4% fat, 8 and 2% fat, and 6 and 0.5% fat (Table 4). In each comparison, the sample with the higher fat and lower water content had the lower concentrations of free vanillin. Differences were significant for two of the three comparisons 10% vs. 4% and 6% vs. 0.5%. The result also indicated the concentration of polydextrose, which ranged from 0 to 4% in the two groups of mixes, was not a factor affecting free vanillin concentration.

Sensory Analyses

TI Evaluation. No significant effect was found for any sweetness parameter ($P < 0.05$). Because the sweetness levels were formulated to be the same for all seven samples, these results suggest that differences in fat content had no effect on sweetness perception.

For vanilla flavor perception, a difference ($P < 0.05$) was found for the time needed to reach maximum intensity of vanilla flavor (**T_{max}**) only. The other TI parameters did not discriminate among the samples.

The mean T_{max} values differed among samples (Table 5). The typical time between food ingestion and swallowing or expectoration is 5 to 10 s; in this case, ice cream samples were swallowed at 12 s. The normal duration of tasting stimuli is 1.5 to 2.0 s; therefore, the range of 240 ms to 1.1 s shows considerable differences among T_{max} values. An increase in fat content from 6 to 10% at 2% intervals did not significantly increase the T_{max}. The T_{max} values of ice creams containing less than 2% fat significantly decreased as fat content decreased. The maximum vanilla flavor intensities of the 0.5% and 1% ice creams were reached in less time ($P < 0.05$) than those of the other samples.

In a product containing fat, lipophilic flavor compounds are bound to the fat molecules by Van der Waals and hydrophobic interactions (21). In the absence of fat, lipophilic flavor molecules are poorly bound to the food matrix via altered interactions between flavor and ingredients. The resulting headspace concentrations of these molecules in the mouth are relatively high, which is why the low fat ice creams tested in the present study had significantly shorter T_{max} as fat content decreased.

Differences ($P < 0.05$) existed among judges and replications. Differences among judges occurred because results from each judge had unique TI curve patterns because of physiological differences. Significant differences among replications might have been caused by inconsistencies of judges. However, these differences did not have significant effects on evaluations of the treatment effects as indicated by nonsignificant interactions of judge and ice cream and of replication and ice cream ($P > 0.05$).

FCP. Procrustes analysis adjusts individual configurations through geometric transformations and geometrically matches them as closely as possible to generate a consensus configuration (19). According to Peay (20), a high R_c value means the result is close to true consensus.

The R_c value obtained by general Procrustes analysis in the present study was 86.3%, which means that the consensus plot of samples represents true consensus among judges. Variances among judges indicated that judges 3 and 5 disagreed with all of the others. Judge 3 responded differently on both dimension (**D**) 1 and 2. Judge 5 disagreed with other judges on D1 only. Responses of all other judges weighed equally in the matrix.

For the consensus configuration of samples, 81.89, 2.89, and 1.78% were represented by D1, D2, and D3, respectively. Therefore, the result was primarily a one-dimensional solution, which was the expected result because the ice creams were formulated to differ primarily in the fat content.

Individual loadings (attributes) that were highly correlated (r > 0.80) to D1 fell into two categories: those related to flavor and taste or those related to texture. Flavor attributes used to describe the positive (right) side of D1 were mostly milky, whole milk, vanilla, and sweet. Whey, off taste, greasy, bitter syrup and sweet were the main flavor attributes used to describe the negative (left) side of D1. Textural attributes that related to the positive side of D1 were creamy, smooth, soft, sticky, and gummy. The negative side of D1 was described by textural attributes such as weak or fast melt, ice or icy or ice crystal, watery, sherbet, sandy, and powdery. It is logical to conclude that the right side of D1 represents high quality properties, such as rich vanilla flavor, pleasant milky flavor and sweetness, smooth, creamy and soft texture. The left side of D1 represents poor quality properties, such as off-flavors (whey, syrup, bitter, and greasy), weak, fast melting, icy, and sandy, or powdery texture.

Ice creams clearly lined up on D1 from left to right when fat content increased from 0.5 to 10% (Figure 2). High fat ice creams were located at the end of positive side of D1 and close to one another. According to the loading, these samples were rich in vanilla flavor and had a smooth and creamy texture. Samples with 1 and 2% fat content were very similar and located on the negative side of D1; therefore, these samples fell in the low quality category. Ice cream with 0.5% fat was located at the very end of the negative side of D1; it was icy, weak in body, sandy or powdery in mouthfeel, and unpleasant in flavor.

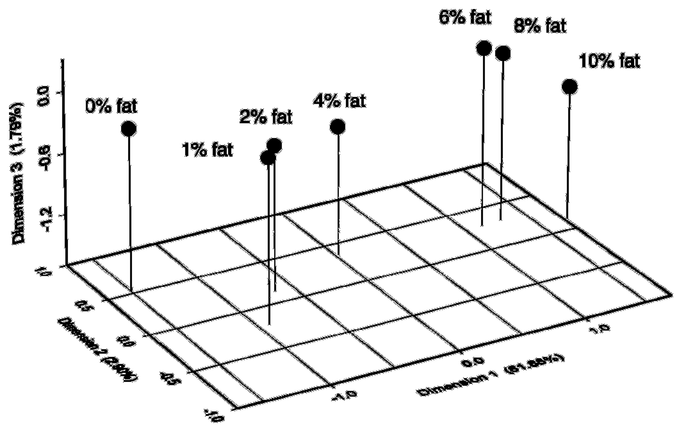

Figure 2. The general Procustes analysis consensus plot of ice creams evaluated by free-choice profiling.

The FCP results indicated that fat content had significant effects on ice cream properties.

Consumer test. Using a nine-point hedonic scale (1 = like extremely to 9 = dislike extremely), the consumer preferences scores differed ($P < 0.001$) among samples (Table 5), and the greatest differences in scores occurred within the high fat mixes. Increased fat content resulted in higher preference scores. Each 2% increase in fat content resulted in a 0.5- to 0.6-unit increase of preference score on a nine-point scale, except around 4% fat content.

Before the preference testing, judges answered questions in a questionnaire, such as what kind of ice cream (regular, low fat, or nonfat) they preferred. Of 63 judges, 48, 10, and 5 said they preferred regular, low fat, and nonfat ice creams, respectively. The result of hedonic ratings of all judges agreed with their individual claims.

Fifty-five of 63 judges (87%) rated the 4% fat sample as the least preferred, including 32 of 48 who said they preferred high fat and 11 of 15 of those who preferred low fat and nonfat ice creams. From the FCP result, D1 represented high fat qualities on the positive side and low fat qualities on the negative side. On this dimension, the 4% fat sample was located close to the zero point and far from both high fat and low fat samples. The zero point represented the lowest values of all attributes. Therefore, 4% fat ice cream had the lowest intensities of most attributes tested, which means that it had neither the characteristics of higher fat ice creams nor those of the lower fat ones, which explained why the 4% fat sample was not preferred either by judges who liked high fat ice creams or by those who liked low fat products.

Interrelationships among physical, chemical, and the significant TI parameters were analyzed by correlation using SAS® (24). Viscosity and melting rate were highly correlated (r = 0.95 and 0.88, respectively; $P < 0.0001$) with fat content. The percentage of free vanillin and T_{max} for vanilla flavor were correlated to fat content (r = –0.60 and 0.81, respectively; $P < 0.0001$). The inverse relationship between free vanillin and fat content was consistent except for the sample containing 4% fat, which had the highest free vanillin content.

The T_{max} was significantly and negatively correlated to the amount of free vanillin in ice creams (r = –0.50; $P < 0.01$). The higher the amount of free vanillin in the ice cream, the shorter was the T_{max}. However, T_{max} was more highly correlated ($P < 0.0001$) to fat content (r = 0.81), total solids (r = 0.67), and viscosity (r = 0.69) than to percentage of free vanillin in the sample.

Ice creams with a higher fat content had a shorter T_{max}. A possible explanation is that the volatility of vanilla flavor components partitioned in the fat was decreased from that of those components in the serum. Therefore, T_{max} were shorter in low fat than high fat samples.

Fat can also physically modify flavor perception. The presence of fat can influence the physical state of the food and the partitioning among the food, saliva, receptors, or headspace in the mouth. Fat can interfere with tastants diffusing to receptors or entering the headspace and can also change the rate of regeneration of interfacial surfaces required for tasting (4, 9, 11, 19).

When foods containing solid fat, such as ice cream or chocolate, melt in the mouth, a layer of non-Newtonian semi-solid fluid is formed between the remaining solid food and the skin. The coating of the tongue with melted fat decreases or prevents the perception of water-soluble flavorants (4). Ice cream with higher fat content melted into a fluid that had higher viscosity than that found in ice cream with lower fat content. The more viscous coating blocked more taste receptors than the less viscous one and also decreased the diffusion rate of vanilla flavor to the taste receptors. Therefore, the T_{max} was increased.

CONCLUSIONS

The FCP result indicated obvious differences among samples. Fat significantly affected overall quality of ice creams, including both flavor and textural properties. High fat samples were preferred by consumers over the low fat ones, even by consumers who said they preferred low fat and nonfat ice creams.

The only significant TI attribute, T_{max}, was highly correlated to fat content and viscosity of the ice cream mix ($P < 0.001$). A possible explanation is that samples with higher fat content formed more viscous coating layers than the low fat samples when melted in the mouth. Therefore, flavorants in the low fat samples diffused to the receptors faster and reached maximum flavor intensities sooner than did flavorants in the high fat samples.

Fat content affected the physical properties and the amount of free vanillin in ice creams. The HPLC result indicated an approximately 7% difference in the amount of free vanillin between the samples that were high in fat and solids (average 51.5%) and the samples that were low in fat and solids (average 58.7%); however, the TI panelists did not perceive differences in vanilla flavor intensity among samples. The FCP result did indicate a difference in the vanilla flavor profile between two groups of samples. A possible explanation for lack of correlation of sensory and instrumental data is that TI and FCP panelists evaluated the overall vanilla flavor intensity, but HPLC only measured vanillin concentration. This result suggested that other flavor compounds in vanilla extract are important for both the intensity and characteristics of vanilla flavor perception. Determinations by instrumental analysis of concentrations of major flavor components in the vanilla extract other than vanillin might give better comparisons with sensory data for overall vanilla flavor analysis.

The data suggest that both blocking of taste receptors by the viscous coating and effect of total solids content on free vanillin were also possible causes of differences in perception of vanilla flavor in the ice creams. Therefore, vanilla flavor perception in ice creams was affected both by physical modification of the perception condition and by chemical solubilization of the flavorant. Fat content and total solids content had different effects on the flavor perception and the free vanillin concentration. Variation of the fat content had a more significant effect on T_{max} within the ice creams with low fat and low solids, but the effect of fat content on T_{max} perception was not enough to produce differences among samples that contained more than 6% fat and 39% total solids. The free vanillin concentration differed significantly between the high solids ice creams and low solids ice creams, but not within each group. The complex matrix interaction for flavor needs further investigation using simpler model systems.

ACKNOWLEDGMENTS

Appreciation is extended to Dairy Marketing, Inc. and the Missouri Agricultural Experiment Station for financial support.

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