Sugar and Fat Effects on Sensory Properties of Ice Cream

J.-X. GUINARD, C. ZOUMAS-MORSE, L. MORI, B. UATONI, D. PANYAM, and A. KILARA

ABSTRACT

Vanilla ice cream with 8, 13 or 18% sucrose and 10, 14 or 18% butterfat was evaluated by descriptive analysis (DA) with 15 judges, instrumental texture measurements (ITM), and hedonic rating with 146 consumers. Increased sugar caused higher vanilla, almond, buttery, custard/eggy, sweetness, fatty, creamy, doughy and mouthcoating characteristics, and lower coolness, ice crystals, melt rate (ITM) and hardness (ITM). Increased fat caused higher buttery, custard/eggy and sweet flavor, fatty, creamy, doughy and mouthcoating texture, and lower color, ice crystals and melting rate (DA). Acceptability was positively related to the vanilla, creamy, fatty and milky characters, and negatively related to color, ice crystals and ITM hardness.

Key Words: ice cream, sugar, fat, sensory properties

INTRODUCTION

BUTTERFAT, SUGAR, OVERRUN AND SPECIFIC FLAVOR are critical determinants of the sensory quality of ice cream, and their effects have been extensively investigated (Specter and Setser, 1994). Wittinger and Smith (1986) showed ice cream with high levels of high-fructose corn syrup as sweetener, or high guar to locust gum ratio as stabilizer became objectionably icy soon after manufacture. Replacing 50% of the sucrose in vanilla ice cream with high-fructose corn syrup, along with increased fat levels, caused a decrease in instrumentally-measured firmness and in perceived sweetness, but resulted in a smooth texture (Conforti, 1994). Response surface methodology was used to optimize sugar blend ratios in ice milk (Fujii, 1993). Stampanoni Koeferli et al. (1996) showed that within the 3 to 12% range, fat increased primarily the buttery, creamy and mouthcoating characteristics of ice cream and reduced its melting rate, coldness and ice crystal perception, whereas sugar increased sweetness, caramel and vanillin notes, and decreased milkiness. Non-fat milk solids caused a decrease in coldness, ice crystal and melting rate perceptions, and an increase in creaminess and mouthcoating. Other descriptive studies of sensory properties of vanilla ice cream have focused on the effects of time-temperature changes during storage (Dolan et al., 1985) and of homogenization (Schmidt and Smith, 1988), on sources of error in sensory texture profiling (King and Arents, 1994) and on vanilla flavor and base interactions (King, 1994).

Most effort has been focused on producing highly palatable reduced-fat ice cream. However, premium ice cream (≥ 14% butterfat and typically high sugar levels) has continued to dominate the packaged ice cream market (The Latest Scoop, 1995). McCandlish et al. (1992) predicted optimum levels of fat for overall, flavor and texture preference were 11.75, 13.51 and 10.2%, respectively (McCandlish et al., 1992). We found optimum levels of sugar and fat in vanilla ice cream were 14.3% and 14.8% for overall liking, 14.1% and 15.4% for flavor liking, and 13.2% and 14.0% for texture/mouthfeel liking (Guinard et al., 1996). No study has been reported of which sensory attributes of ice cream (as affected by sugar and fat content) were determinants (positive or negative) of consumer liking.

The purpose of our study was to investigate the effects of sugar and fat on the sensory properties of vanilla ice cream. Specific objectives were (1) to examine the effects of sugar and fat (and their interaction) on the color, flavor and texture/mouthfeel of vanilla ice cream as measured by descriptive analysis and instrumental measurements, (2) to investigate relationships between descriptive and instrumental measures of textural properties, (3) to examine the effect of sugar and fat (and their interaction) on sensory acceptability, and (4) to investigate which sensory properties (by descriptive analysis and/or instrumental means) are effective predictors of acceptability.

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MATERIALS & METHODS

Ice cream manufacture

Vanilla ice cream was made from mixes containing 10, 14, or 18% fat and 8, 13, or 18% sugar, using milk and cream conventionally supplied to the University Creamery. All mixes contained 6% corn syrup solids (sugar balance made up with sucrose), 11% milk solids non-fat and 0.35% stabilizer-emulsifier (PGX-1; Germantown U.S.A. Co., Germantown, PA). Mixes were heated to 82.2°C, held for 25s, homogenized in two stages (e.g., 6.9 MPa first, and then 3.45 MPa), cooled to 4°C, and aged for 18h. After aging, mixes were flavored with twofold bourbon vanilla pure extract (Virginia Dare Extract Company, Inc., Brooklyn, NY) at 5.47 mL/L. Mixes were frozen to 85% overrun in a 3-barrel freezer (V303; Cherry-Burrell Corp., Cedar Rapids, IA), packaged in 118.3-mL polyfoam cups with cardboard lids, and stored in a hardening room at −34.4°C until sensory tests were conducted. Prior to testing, samples were tempered at −18°C for 16h.

Ice cream sample composition

The targeted experimental design was a 3^2 factorial design with three levels each of sugar (sucrose) and fat chosen to meet requirements for standards of identity and to be representative of commercially available ice cream products (Table 1). Fat was determined by the Mojonnier method, and total solids were estimated by atmospheric oven, as described in Standard Methods for the Examination of Dairy Products (Marshall, 1992). Sugar concentration was determined enzymatically (sucrose/D-glucose/D-fructose kit; Boehringer Mannheim, Mannheim, Germany) and expressed as percentage of sucrose (Barnes et al., 1991).

Instrumental measurements

Hardness and tackiness were measured with a TA-TX2 Texture Analyzer (Texture Technologies Corporation, Scarsdale, NY) equipped with a 2.54-cm cross-head acrylic cylindrical probe, at a speed of 2 mm/sec, to a penetration depth of 15 mm. Hardness was measured as the peak compression force (g) during penetration of the sample, and tackiness as the (negative) peak during withdrawal. Melt rate was measured as the weight of drip at 25°C from a 118.3-mL sample of ice cream placed on a size-4 mesh vs time. Melt rate was the slope of the melt curve. Ice cream samples were tempered to about −10°C before analysis.

Descriptive analysis

The sensory properties of the ice cream samples were measured using a variation of the Quantitative Descriptive Analysis (DA) method (Stone and Sidel, 1993). A panel of 15 judges was recruited among students in an advanced foods course on sensory evaluation and formulation techniques at The Pennsylvania State University. First, judges developed a

Table 1—Composition of ice cream samples (means ± SD; % w/w based on 3 measurements on 3 different samples)

Samples	Sugar (% w/w)	Fat (% w/w)	Total solids (% w/w)
1	8.94 ± 0.03	8.73 ± 0.05	32.49 ± 0.05
2	10.85 ± 0.06	14.28 ± 0.10	39.90 ± 0.04
3	11.61 ± 0.16	17.68 ± 0.48	45.29 ± 0.04
4	13.65 ± 0.30	9.94 ± 0.06	39.32 ± 0.09
5	13.54 ± 0.38	14.99 ± 0.01	43.95 ± 0.13
6	13.29 ± 0.23	18.75 ± 0.02	47.31 ± 0.17
7	17.65 ± 0.09	11.40 ± 0.06	44.15 ± 0.04
8	18.81 ± 0.26	15.08 ± 0.13	49.19 ± 0.17
9	17.91 ± 0.01	19.30 ± 0.23	53.16 ± 0.25

list of terms describing the sensory attributes of vanilla ice cream. This phase of the DA was carried out with commercial ice creams, including Penn State Creamery vanilla ice cream. Judges then developed definitions for each of the terms, and were given standards to demonstrate each attribute. Depending on the attribute, judges were given one standard for the attribute, or a set of standards, some with the attribute and some without (Table 2). Before each training and descriptive analysis session, judges tasted and smelled the available standards. A 16.5-cm line scale, typically anchored with the words ''low'' and ''high'' about 2 cm from each end, was used to rate intensity of the attributes. Color was rated on a scale from white to off-white to pale yellow anchored with colors with the same hue from the Munsell® book of colors (Macbeth, Baltimore, MD), e.g., 5Y 9/1 and 5Y 9/4 (hue, value/chroma), for the off-white and pale yellow chips, respectively. Judges were trained over five 1.5-hr sessions, which consisted of consensus (1h) and individual (30 min) evaluations of 4 commercial vanilla ice creams (first 3 sessions), or 4 samples from the experimental design (last 2 sessions), with one duplicated sample in each of the individual evaluations. Consistency and reproducibility of the judges was assessed by plotting individual ratings of samples and by comparing the two ratings of the duplicate ice creams. Judges whose trends were inconsistent with the rest of the panel or whose reproducibility was questionable were briefed by the experimenter and asked to taste the 'problem' samples again.

Descriptive analysis of the 9 samples was then carried out in duplicate over 4 sessions, with 4 or 5 samples evaluated per session. The order of presentation of samples was randomized across sessions and across judges. A session lasted 20 to 30 min, depending on the judge. All evaluations were conducted in isolated booths maintained at 20°C, under incandescent illumination. Samples, labelled with 3-digit codes, were served at −10°C in the polyfoam cups in which they were frozen. Judges were instructed to rinse with distilled water between samples.

Consumer testing

Consumer testing was advertised by posting flyers on the Penn State campus at University Park. University students (146 total, 73 each men and women, users and likers of ice cream) participated. Testing was held on 3 consecutive days between 11 am and 3 pm. Upon arrival at the Sensory Science Laboratory, subjects read an explanation of the study and gave their informed consent.

Sensory evaluation of the ice cream samples was conducted under the same conditions described for DA, except that subjects tasted all 9 samples in one seating, and indicated their degree of liking of the texture/mouthfeel, flavor (aroma/taste) and overall degree of liking of the samples on a 9-point hedonic scale from 1=dislike extremely to 9=like extremely, with 5=neither like nor dislike (Peryam and Pilgrim, 1957). Subjects were instructed to rinse with distilled water between samples.

Data analysis

Analysis of variance was applied to the descriptive and hedonic ratings. Sources of variation were judges, samples, replications and their two-way interactions in the ANOVAs of the descriptive data, and gender, subjects (nested in the gender effect), and samples in the ANOVAs of the hedonic data. Multiple mean comparisons were by Fisher's least significant difference. The relations between analytical (instrumental and descriptive) measures and sugar and fat concentrations were investigated with the response surface methodology (RSM). RSM was chosen because it is a multiple regression method which explores not only linear effects (of sugar or fat) on the perceived intensity of the attribute but also quadratic effects (of sugar or fat) and cross-product effect (of the interaction between sugar and fat). The following equation ensues:

$$Y = b_0 + b_1X_1 + b_{11}X_1^2 + b_2X_2 + b_{22}X_2^2 + b_{12}X_1X_2,$$

with Y = analytical measure, X_1 = sugar (percentage), and X_2 = fat (percentage).

Principal component analysis was applied first to the descriptive and analytical ratings (based on the correlation matrix) to determine relationships among attributes and differences among samples in the design, and second to the combined analytical and hedonic measures (also based on the correlation matrix) to explore which attributes might be predictors of consumer acceptability. The relation between hedonic ratings and descriptive and instrumental measures was then investigated by stepwise and multiple regression analyses. Because curvilinear relations (inverted-U-shaped) have often been found between hedonic ratings and analytical (descriptive or instrumental) measures (Muñoz et al., 1992), individual polynomial regressions (of the second and third orders) were also used to examine relationships between the 3 hedonic ratings and individual analytical variables. All analyses were performed with SAS software (SAS Institute, Inc., 1991). Significance was defined at $p<0.05$.

RESULTS & DISCUSSION

CHEMICAL ANALYSES of the composition of samples revealed that in most cases, the targeted fat, sugar and total solid levels were achieved (Table 1). Samples were processed in increasing order of fat content in a continuous manner so that some deviation from target levels had been expected.

Descriptive analysis

Results of ANOVAs of attribute ratings across the 9 ice cream samples for 13 judges were summarized (Table 3, data from two judges who used some descriptive terms improperly were removed prior to analysis). Judges were a highly significant source of variation in all cases ($p<0.001$), except for the attribute 'fluffy/aerated' ($p<0.05$). Such variation among judges is considered acceptable in most DA procedures. Sugar and fat concentrations had strong effects on sensory properties of the ice cream. Samples were different for all attributes ($p<0.001$, except for 'milky/dairy'—$p<0.01$), indicating that these sensory attributes were affected by sugar and/or fat levels. Replications were not a notable source of variation except for 'color', 'coolness/cooling' and 'creamy' ($p<0.01$), and the judge by replication interation was not significant except for 'milky/dairy', 'almond', 'creamy' ($p<0.05$), 'sweetness' ($p<0.01$) and 'melting rate' ($p<0.001$). This suggested that overall, the panel was quite reproducible in its ratings. The sample by replication interaction was not significant except for 'doughy/pasty/elastic' ($p<0.05$), indicating that there was no cup-to-cup variation in samples. The judge by sample interaction provided a measure of consistency among judges in the panel. It was not significant for 7 of the attributes, but it was for the remaining 8. Note that inconsistencies were more frequent for texture/mouthfeel attributes (6) than for flavor attributes (2). This could be because in the early part of the DA (e.g., term generation and training), flavor concepts were formed mostly from a standard representing the flavor note, whereas texture/mouthfeel concepts were formed mostly from standard samples with or without the attribute (Table 2). It could also be the result of a generally better understanding of flavor concepts than texture/mouthfeel by panel members. Overall, panel performance could have been improved with more extensive training procedures.

Mean descriptive ratings for the 15 attributes across the 9 samples were compared (Table 4). Response surface methodology (RSM) was also used to relate the intensity of sensory attributes and instrumental measures to sugar and fat concentrations. The regressions relating analytical measures to sugar and fat were significant for 10 of the 15 attributes (e.g., buttery, vanilla, almond, sweetness, coolness/cooling, fatty, creamy, doughy/pasty/elastic, ice crystals, mouthcoating afterfeel) and for 1 of the 4 instrumental measures (hardness, Fig. 1).

Color differences were found among the low-sugar (LS) samples, with the low-fat (LF) sample being more yellow than the medium- (MF) and high-fat (HF) samples (Table 4). This 'whit-

Table 2—Descriptive attributes (flavor, temperature, texture, mouthfeel), definitions and standards

Attributes	Definitions	Standards
Appearance		
Color	White to off-white (Munsell 5Y 9/1) to pale yellow (Munsell 5Y 9/4)	Color chips on the scale
Flavor		
Milky/Dairy	Intensity of the milky (whole milk)/dairy flavor	Base* diluted with whole milk, half and half, and whipping cream
Buttery	Intensity of the buttery aroma	Base* + butter flavor (Schilling®)
Vanilla	Intensity of the natural vanilla flavor	Base* + vanilla (two-fold, Bourbon)
Custard/Eggy	Intensity of the cooked egg aroma (as in custard)	Base* + bits of omelet and custard
Almond	Intensity of the almond flavor	Base* + almond extract (Schilling®)
Sweetness	Intensity of the sweetness (sucrose-like)	Base* + sucrose
Coolness/Cooling	Cooling effect that takes place over the first 3 sec after putting the sample in the mouth	NA
Texture/Mouthfeel		
Melting rate	Rate at which the ice cream turns from a solid to a liquid	NA
Fatty	Perception of the fat content in the ice cream	Base* + dairy fat
Creamy	Smooth mouthfeel of stirred yogurt	NA
Fluffy/Aerated	Perception of the air content of the ice cream	NA
Doughy/Pasty/Elastic	Elasticity of the ice cream as you scoop it with a spoon	NA
Ice crystals	Overall amount of ice crystals perceived in the ice cream that does not melt with the rest of the sample	NA
Mouthcoating afterfeel	Coating left in the mouth after the ice cream has been swallowed	NA

* Base ice cream was vanilla ice cream from the Penn State Creamery.

Table 3—Analyses of variance of the descriptive attribute ratings (13 judges): degrees of freedom (df), F-ratios, and error mean squares (MSE)

	F-ratios						
	Judges (J)	Replications (R)	Samples (S)	J × R	J × S	R × S	MSE
Color	22.11***	9.19**	9.85***	1.79	1.23	1.38	3.07
Milky/Dairy	6.29***	0.35	2.79**	1.86*	1.15	1.14	8.36
Buttery	6.52***	0.04	11.43***	1.08	1.09	0.81	6.69
Vanilla	8.56***	0.01	17.53***	0.96	1.57*	1.34	4.72
Custard/Eggy	5.70***	0.37	6.29***	1.70	1.41*	0.64	7.49
Almond	10.85***	1.02	8.31***	2.34*	1.37	0.46	5.87
Sweetness	6.87***	0.38	33.06***	2.38**	1.32	1.31	4.97
Coolness/cooling	15.38***	11.24**	29.13***	0.66	1.27	1.90	4.38
Melting rate	9.49***	0.42	6.71***	3.60***	1.99***	2.02	5.55
Fatty	6.01***	0.27	52.53***	1.78	1.91***	2.01	3.37
Creamy	13.17***	11.52**	37.92***	2.27*	1.84**	0.51	3.84
Fluffy/Aerated	2.28*	0.26	5.85***	0.56	1.77**	0.69	7.23
Doughy/Pasty/Elastic	3.89***	1.96	41.84***	0.77	2.02***	2.09*	4.93
Ice crystals	29.88***	0.73	40.96***	0.83	2.01***	1.35	4.98
Mouthcoating afterfeel	2.53**	0.02	23.49***	0.56	1.39	0.73	5.29
df	12	1	8	12	96	8	96

*,**,*** significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively.

ening' effect has been reported in many foods to which dairy fat is added. The milky/dairy flavor of sample 1 (LS/LF) was lower than that of the other samples (Table 4). An increase in buttery flavor was noted both with increased fat (expected) and with increased sugar (unexpected). A slightly-concave, but mostly linear response surface was found as a function of sugar and fat (Fig. 1a). Vanilla flavor increased linearly with sugar content, and independent of fat, as shown by the angled, but flat response surface (Fig. 1b). This could have been the result of a cognitive association between sweetness and vanilla flavor. A similar effect was observed for the custard/eggy and almond attributes (Table 4).

Results for sweetness provided a good check of panel training and performance. As anticipated, sweetness ratings increased with sugar content. A slight increase in perceived sweetness was also found with increased fat content (the opposite was expected). The RSM regression for sweetness had significant linear ($p<0.001$) and quadratic ($p<0.05$) components (Fig. 1c). The mouthfeel properties contributed by fat could account for the perceived increase in sweetness. Relation between sweetness and viscosity has been demonstrated (Burns and Noble, 1985).

The cooling properties of samples clearly decreased as sugar content increased (Table 4, Fig. 1d). Perceived melting rate was affected more by fat content than by sugar content. As expected, perceived intensity of the fatty attribute increased with fat content, but it increased even more with sugar content (Table 4, Fig. 1e). The difference among fat levels was particularly notable in the low-sugar samples, with mean ratings of 3.6, 6.1 and 9.6 for the LF, MF and HF samples, respectively. This suggested that medium to high sugar levels in the ice cream could partially mask the perceived fatty character from fat.

Ratings for the creamy attribute closely followed the pattern for the fatty attribute, with a significant increase in creaminess with increased fat and sugar (Fig. 1f). The fluffy/aerated character of the ice cream seemed to increase with sugar content and to decrease with fat content. The doughy/pasty/elastic character increased with both sugar and fat (Table 4). The perception of ice crystals in the ice cream clearly was an inverse, concave function of total solids, whether those solids were fat or sugar (Fig. 1g). The mouthcoating afterfeel increased mostly with sugar content (Table 4).

The matrix of mean ratings for the 15 attributes across the 9 samples was analyzed by principal component analysis with no rotation. The first two principal components (PCs) accounted for 77% and 9% of the variance, respectively. In the scree test (Cattell, 1966), these PCs had eigen values >1, and the scree plot showed a break at the third eigen value. The correlation matrix and the distribution of the attribute vectors in the principal component space (Fig. 2) suggested some redundancy among attributes. Highly significant positive correlations were found among attributes vanilla, almond, buttery, custard/eggy, sweetness, fatty, creamy, doughy/pasty/elastic, and mouthcoating afterfeel. Some

Table 4—Mean descriptive analysis ratings on a 16.5-cm scale by a panel of 13 trained judges (n = 26); mean hardness, tackiness and melt rate (n = 3); mean degree of liking (DOL) of texture/mouthfeel, flavor (aroma/taste), and overall degree of liking on a 9-point scale by young adult consumers (n = 146; 73 men, 73 women) and corresponding Fisher's Least Significant Difference (LSD) at $p < 0.05$ for the 9 ice cream samples[b]

	Descriptive analysis							
	Appearance	Flavor						
Samples[a]	Color	Milky/Dairy	Buttery	Vanilla	Custard/Eggy	Almond	Sweetness	Coolness/Cooling
1 (LS,LF)	10.0a	6.3b	4.0d	4.1d	5.7d	3.7e	4.1e	12.7a
2 (LS, MF)	8.1b	9.3a	5.1cd	7.2c	6.0cd	4.9de	6.9d	12.6a
3 (LS, HF)	7.0c	9.3a	7.3b	7.9bc	8.3ab	5.7cd	8.3c	9.6bc
4 (MS, LF)	6.4c	8.8a	5.9c	8.1bc	8.8a	6.0cd	8.0cd	10.3b
5 (MS, MF)	8.0b	9.0a	7.5b	8.3bc	7.3bc	6.7bc	9.1bc	10.1b
6 (MS, HF)	7.0c	8.5a	8.1ab	8.5b	9.0a	6.3bc	9.8b	9.8bc
7 (HS, LF)	7.0c	8.8a	8.3ab	10.1a	8.3ab	7.4ab	11.0a	8.8c
8 (HS, MF)	8.3b	8.3a	8.4ab	9.0ab	9.1a	7.5ab	11.7a	6.7d
9 (HS, HF)	6.9c	8.4a	9.0a	10.0a	9.2a	8.1a	11.9a	6.3d
LSD	1.0	1.5	1.4	1.2	1.5	1.3	1.2	1.2

	Descriptive analysis						
	Texture/Mouthfeel						
Samples	Melting rate	Fatty	Creamy	Fluffy/Aerated	Doughy/Pasty/Elastic	Ice crystals	Mouthcoating afterfeel
1 (LS, LF)	9.7a	3.6g	3.7e	5.3d	3.1f	10.5a	3.9f
2 (LS, MF)	9.2ab	6.1f	8.0d	7.1bc	5.6e	7.5b	5.7e
3 (LS, HF)	6.7d	9.6cd	9.2bc	6.4cd	7.5d	4.7d	7.6d
4 (MS, LF)	8.1bc	7.5e	8.6cd	7.8abc	5.9e	6.3c	6.9de
5 (MS, MF)	7.0cd	10.7ab	10.0b	8.2ab	9.0c	5.0d	8.9bc
6 (MS, HF)	6.4d	10.4bc	9.6bc	5.4d	9.8bc	4.1de	9.2b
7 (HS, LF)	8.7ab	9.3d	10.1b	9.0a	9.7bc	4.7d	7.7cd
8 (HS, MF)	7.3cd	10.7ab	11.6a	8.1ab	11.7a	3.4ef	10.0ab
9 (HS, HF)	6.7d	11.6a	11.5a	7.2bc	10.8ab	3.1f	11.0a
LSD	1.3	1.0	1.1	1.5	1.2	0.9	1.3

	Instrumental measures			Hedonic ratings		
Samples	Hardness (g)	Tackiness (g)	Melt rate (%/min)	DOL Texture/Mouthfeel	DOL Flavor (Taste and Smell)	Overall DOL
1 (LS, LF)	10358	1350	2.57	4.6d	3.9f	3.9e
2 (LS, MF)	5491	1079	2.14	5.8c	5.4e	5.4d
3 (LS, HF)	6646	1573	0.93	5.9bc	5.8cd	5.8bcd
4 (MS, LF)	2438	1081	2.89	6.3ab	6.0bcd	6.0b
5 (MS, MF)	3031	1195	2.63	6.6a	6.5a	6.5a
6 (MS, HF)	4228	1526	2.39	5.9bc	6.1bc	6.1ab
7 (HS, LF)	1312	766	2.70	5.7c	6.3ab	5.9bc
8 (HS, MF)	1339	925	3.12	5.0d	5.9cd	5.5cd
9 (HS, HF)	1875	1010	3.55	5.1d	5.7de	5.4d
LSD	NA	NA	NA	0.4	0.4	0.4

[a] L, M, H = low, medium, high; S, F = sugar, fat.
[b] Within a column, means sharing letters are not significantly different.

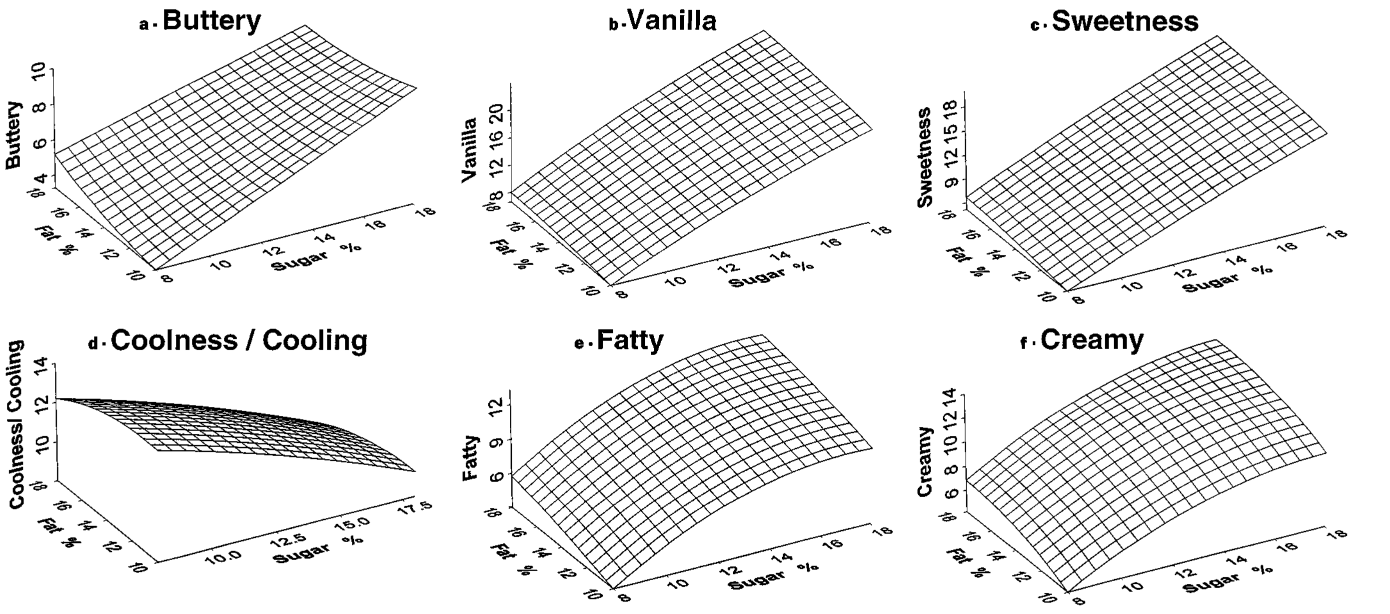
of these might be causal relations, others might be due to separate factors like sugar and/or fat content, and yet others might be attributed to the panel not clearly separating and recognizing different perceived attributes from the ''impressions'' or ''influences'' of variables on perception. Other positive correlations were found among melting rate (sensory), coolness/cooling and ice crystals, which clearly were causal relations, i.e., ice crystals cause a cooling sensation and a high melting rate. The attributes color, fluffy and milky were not correlated with any other sensory attributes. The attributes fluffy and milky, which appeared closely linked in the space formed by the first two PCs (Fig. 2), were separated along the third PC. This PCA clearly showed that the ice cream samples differed along a dimension (PC 1) which was a contrast between the attributes vanilla, almond, buttery, custard/eggy, sweetness, fatty, creamy, doughy/pasty/elastic, and mouthcoating afterfeel at one end, and the attributes melting rate, coolness/cooling and ice crystals at the other end. There were no separations between properties which may have been attributed to sugar and those which were typical of fat. This could be due to the common contribution of both sugar and fat to mouthfeel, or to their frequent association in many foods (Drewnowski and Greenwood, 1983). The distribution of the 9 samples in the PC space did not reveal any obvious trend.

Instrumental measurements

As sugar increased in the samples, hardness increased and tackiness decreased (Table 4). Hardness was inversely related to fat and sugar contents by a concave response surface (Fig. 1h). These differences could be attributed to changes in freezing point as a result of higher solute concentrations. At a given temperature, if the water content is higher, a sample would be less hard and more tacky. The slope of the melt curve at the medium and high fat levels increased as sugar content increased (Fig. 3). High slope values mean samples melt at a faster rate than those with low slope values. The time to 50% melt ''half-life of the sample at 25°C'' was also measured. It is inversely related to melting rate. At any given fat level, time to 50% melt decreased as sugar content increased. The melt data also suggested some interaction of fat and sugar in melting behavior.

Relationships between descriptive attributes and instrumental measures

Another PCA was run on the matrix of mean descriptive and instrumental measures for the 9 samples, and the first two PCs are represented (Fig. 4). Even though the first PC (which accounts for 70% of variance) remains a contrast between attributes listed earlier (for the PCA of descriptive ratings only), the second PC (which accounts for 15% of variance) seems to be an instrumental dimension based on melt rate and tackiness. The high correlation between instrumental hardness and sensory attributes coolness/cooling and ice crystals was expected. Hardness was inversely related to sugar and fat content (as indicated by placement of sweet and fatty vectors opposite the hardness



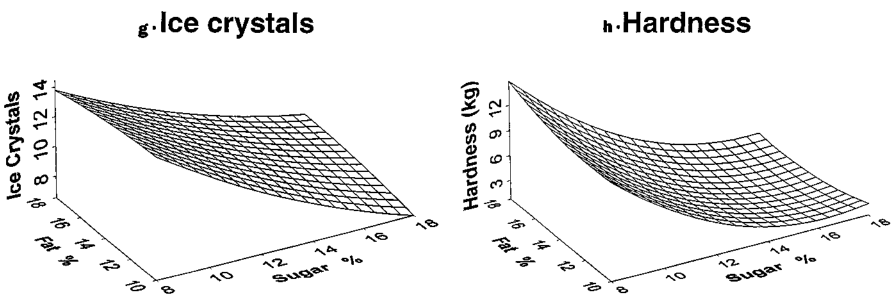


Fig. 1—RSMs relating the analytical variables to sugar and fat (response surfaces are shown only for selected analytical parameters for which the regression equation vs sugar and fat levels was significant, e.g., at $p<0.05$ or lower). The regression equation used in RSM is shown in the text. The intensity of the sensory attributes was evaluated on a 15-point scale.

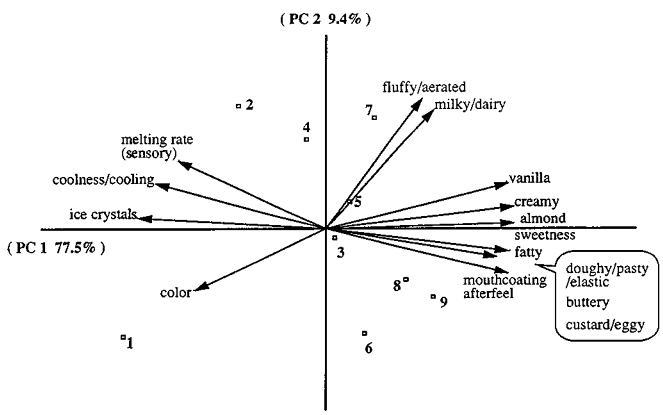


Fig. 2—Principal component analysis (PCA) of the matrix of mean descriptive ratings across the nine ice cream samples. Both the sensory attributes (represented as vectors) and the ice cream samples (represented as points, labeled 1 through 9–see Table 1 for sample identification) are shown in the space represented by principal components (PCs) 1 and 2.

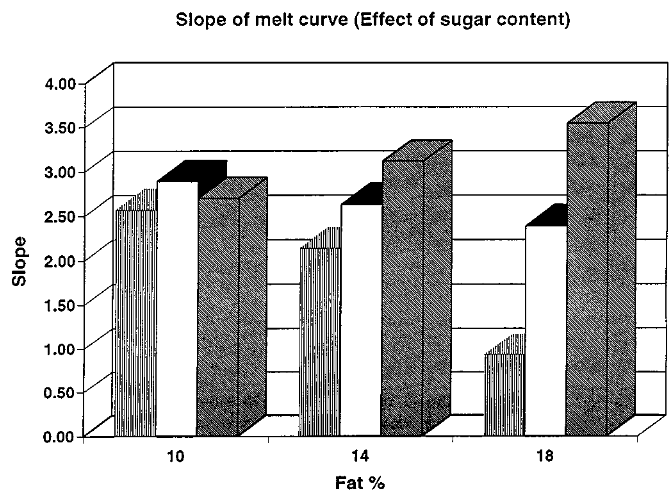


Fig. 3—Effect of sugar content on melt rate for low, medium and high-fat ice cream samples. (low (8%), medium (13%), and high (18%) sugar, respectively.)

vector). Both hardness and tackiness were inversely related to the fluffy/aerated attribute, an indicator of overrun. There was no relation between melt rate (instrumental) and sensory attribute melting rate, as shown by the right angle between the two vectors, and the low correlation ($r = -0.14$). This could be because the instrumental measurement does not accurately reproduce the mouth environment in which the ice cream is melted, or a result of interrelationships between each of these attributes and the other variables in the design.

The distribution of the 9 samples in the PC space did not change much from that observed in the PCA of sensory attributes only. That was expected given the limited increase in matrix size brought about by the addition of the instrumental measures, and the fact that some of them might have been redundant with descriptive attributes. The separation of samples based on sugar content (1,2,3 vs 4,5,6 vs 7,8,9) became more obvious, however (along PC 1).

Hedonic ratings by consumers

Degree of liking of texture/mouthfeel, flavor (taste and smell) and overall degree of liking was also measured for the 9 samples in a population of 146 young adult consumers (73 men–24.6 ±

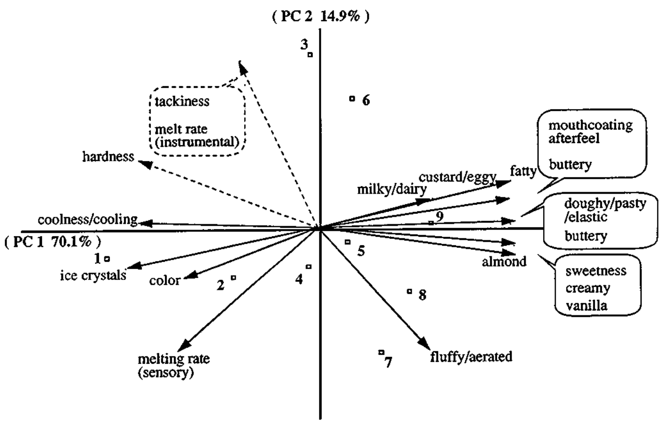


Fig. 4—PCA of sensory and instrumental measures combined across the nine ice cream samples. Both analytical measures (represented as vectors) and ice cream samples (represented as points) are shown on PCs 1 and 2.

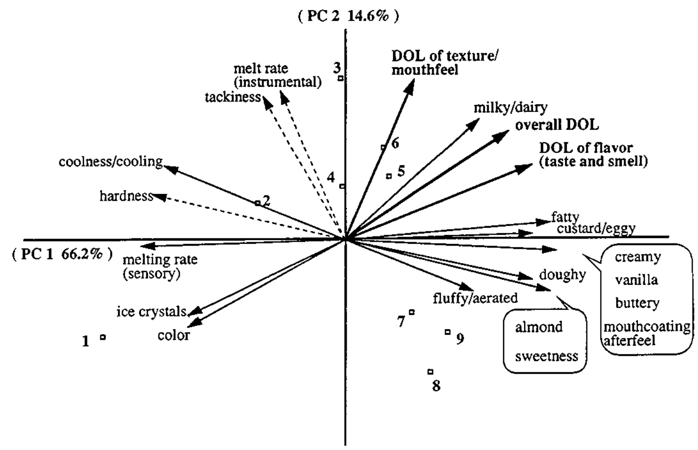


Fig.5—PCA of sensory, instrumental and hedonic measures combined across the nine ice cream samples. Both analytical/hedonic measures (represented as vectors) and ice cream samples (represented as points) are shown on PCs 1 and 2.

Table 5—Correlations between descriptive attributes or instrumental measures and hedonic ratings (df = 7)

Variable	DOL Flavor	DOL Texture/Mouthfeel	Overall DOL
Color	−0.74	−0.55	−0.74
Milky/Dairy	0.82**	0.71*	0.84**
Buttery	0.72*	0.09	0.58
Vanilla	0.83**	0.26	0.70*
Custard/Eggy	0.64	0.13	0.55
Almond	0.73*	0.08	0.57
Sweetness	0.73*	0.06	0.57
Coolness/Cooling	−0.49	0.19	−0.32
Melting rate	−0.63	−0.32	−0.62
Fatty	0.80**	0.27	0.70*
Creamy	0.82**	0.23	0.70*
Fluffy/Aerated	0.63	0.30	0.51
Doughy/Pasty	0.71*	0.04	0.56
Ice crystals	−0.79*	−0.20	−0.68*
Mouthcoating	0.68*	0.09	0.57
Hardness (ITM)	−0.81**	−0.28	−0.69*
Tackiness (ITM)	−0.23	0.17	−0.07
Melt rate (ITM)	−0.16	0.19	−0.05
DOL Flavor	1.00		
DOL Mouthfeel	0.71*	1.00	
Overall DOL	0.97***	0.84**	1.00

*, **, *** significant at p < 0.05, 0.01 and 0.001, respectively.

7.8 years of age, and 73 women–25.6 ± 7.1 years of age) (Guinard et al., 1996). Sample 5 (MS, MF) was most-liked. RSM was applied to the hedonic ratings. Dome-shaped response surfaces were obtained for all three degree of liking parameters, and optimal sugar and fat, respectively, were 13.2% and 14.0% for degree of liking of texture/mouthfeel, 14.1% and 15.4% for degree of liking of flavor, and 14.3% and 14.8% for overall degree of liking (Guinard et al., 1996).

Relationships among descriptive attributes, instrumental measures and hedonic ratings

To investigate which analytical variables were effective predictors of consumer acceptance, Pearson's correlation coefficients among variables were calculated (Table 5), PCA was applied to the matrix of mean analytical and hedonic measures across samples (as an exploratory tool), and multiple (linear) and polynomial regression techniques were used to relate hedonic ratings to analytical measures.

The arrangement of vectors in the PC space (Fig. 5) was consistent with correlations (Table 5). DOL of flavor correlated positively with almond, buttery, doughy/pasty/elastic, mouthcoating afterfeel and sweetness ($p<0.05$), and with vanilla, milky, creamy, and fatty ($p<0.01$). It also correlated negatively with color and ice crystals ($p<0.05$), and with hardness ($p<0.01$). Note that of these predictors of DOL of flavor, about half were texture/mouthfeel variables. This suggests texture/mouthfeel characteristics likely affected the perception of flavor (e.g., flavor release).

The only significant linear correlation between DOL of texture/mouthfeel and analytical variables was a positive correlation ($p<0.05$) with the attribute milky, obviously not a causal relation. Furthermore, no multiple (linear) regression could be generated to relate DOL of texture/mouthfeel to the descriptive and instrumental measures. The polynomial regressions, however, provided meaningful relationships between DOL of texture/mouthfeel and some analytical variables. Highly significant ($p<0.001$) inverted-U-shaped relationships were found between DOL of texture/mouthfeel and the variables sweetness, ice crystals, creamy, and doughy/pasty/elastic (Fig. 6). Similar relationships were also found with the variables fatty, coolness/cooling, mouthcoating afterfeel and hardness ($p<0.05$).

The DOL of flavor and overall DOL vectors were closely linked in the PC space. The correlation matrix and the multiple regressions showed that these two hedonic variables had similar predictors, consistent with their highly significant correlation ($r=0.97$, $p<0.001$). Positive predictors of overall DOL were vanilla, creamy, fatty ($p<0.05$), and milky ($p<0.01$), and negative ones were color, ice crystals and hardness ($p<0.05$). The variable milky was the best predictor of DOL of flavor and overall DOL. It appeared in both equations generated by stepwise regression analysis (Table 6).

Results clearly indicated linear regression methods provided limited understanding of relationships between hedonic and analytical variables. Polynomial regressions were required for curvilinear relations (which seemed to predominate in the prediction of DOL of texture/mouthfeel).

General discussion

Fat level (within the 10–18% range) did not have as strong an effect as sugar on flavor or even mouthfeel characteristics. We expected most of the texture/mouthfeel attributes measured by DA to vary more (or at least as much) with fat level than with sugar level, based on the general belief that fats and oils contribute mostly texture and mouthfeel (Best, 1991; Hatchwell, 1994). We found the opposite, i.e., the curvature of RSMs used to relate these attributes to sugar and fat levels was more pronounced along the sugar axis than along the fat axis. Consistent with a prior finding that sugar content determines textural creaminess (Stampanoni, 1993), our study confirmed that be-

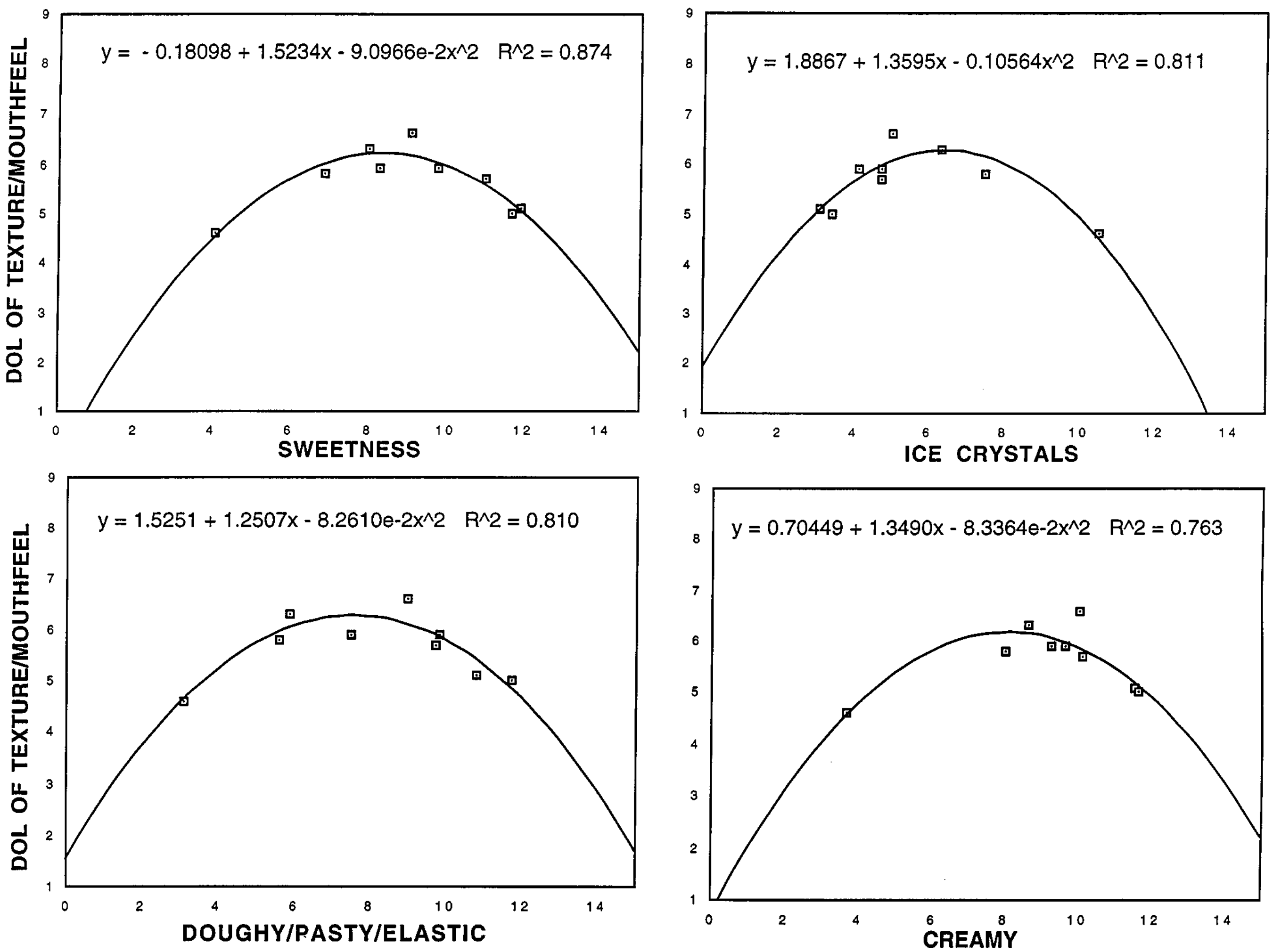


Fig. 6—Significant ($p<0.001$) second-order polynomial regressions between DOL of texture/mouthfeel and the variables sweetness, ice crystals, doughy/pasty/elastic and creamy ($N=9$). Regression equations and coefficients of determination are shown.

Table 6—Multiple regression equations relating DOL Flavor and Overall DOL to the analytical (sensory and instrumental) variables, and model parameters ($n = 9$)

Variable		Equation	Model parameters R^2	F-ratio
DOL Flavor	=	0.50 + 0.40 Milky + 0.22 Vanilla	0.81	13.18**
Overall DOL	=	0.06 + 0.65 Milky	0.70	16.26**

**significant at $p < 0.01$.

sides contributing to flavor, sugar also has some critical structural properties which affect texture and mouthfeel.

In a similar study of the influence of fat, sugar and non-fat milk solids on taste, flavor and texture, Stampanoni Koeferli et al. (1996) reported that the addition of fat increased primarily buttery, creamy and mouthcoating characteristics and reduced melting rate, coldness and ice crystal perception. The level of sugar mainly increased sweetness, caramel and vanillin notes, and decreased milkiness. Non-fat milk solids caused a decrease in coldness, ice crystal and melting rate perceptions, and an increase in creaminess and mouthcoating. Investigators indicated that the 3 variables (e.g., sugar, fat and non-fat milk solids) did not act as flavor/taste potentiators or suppressors, but rather as flavor/taste modifiers. The range of fat (3–12%) in their study was quite different from ours (10–18%, the range of sugar, 12–20%, was similar), but we concur with their observations. The origins of these flavor modifications by sugar and fat, whether they be physiological (Lynch et al., 1993), psychological (Stampanoni, 1993), or physico-chemical (Plug and Haring, 1994) require further study.

Regarding instrumental measures, hardness and tackiness were related to physico-chemical characteristics (sugar and fat contents, ice crystals). Sensory and instrumental measures of melting behavior were not related.

Significant predictors of acceptability could be found among the analytical variables. Interestingly, when linear regression methods were used to investigate relationships between hedonic ratings and analytical variables, 10 of the variables were significant predictors of DOL of flavor, but only 1 was a significant predictor of DOL of mouthfeel. On the other hand, when polynomial regression techniques were used, significant curvilinear (inverted-U-shaped) relationships were found between DOL of texture/mouthfeel and variables like sweetness, ice crystals, coolness, fatty, creamy, doughy, mouthcoating and hardness. This appears to indicate a fundamental difference between flavor preferences and texture/mouthfeel preferences. More research is needed to understand consumer preferences for texture and mouthfeel properties (Guinard and Mazzucchelli, 1996).

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