THE SENSORY PROPERTIES OF ICE CREAM AND FROZEN DESSERTS

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1 INTRODUCTION

Ice cream and frozen desserts offer a unique combination of highly desirable sensory properties. These properties can be classified under the categories of appearance (color, smoothness,...), flavor (taste, smell, trigeminal sensations, temperature), and texture/mouthfeel (hardness, viscosity, creaminess,...). The mechanisms by which we perceive these sensory properties are examined, with a special focus on flavor release and cooling properties. The reasons why ice cream is such a widely liked food are then explored. Indeed, preferences for the various stimuli in ice cream may be innate or learned. Implications for satiety mechanisms, particularly sensory-specific satiety are discussed.

The methodology used to assess the sensory properties of frozen desserts is reviewed critically. Analytical sensory tests, such as difference tests and descriptive analysis, should be used with trained judges to provide qualitative and quantitative information about the sensory properties of frozen desserts. Instrumental measurements of sensory properties should also be used as a necessary complement to sensory analytical tests, particularly for color and texture/mouthfeel assessments. Affective tests such as hedonic scaling or preference tests should be used with consumers representative of the target population to assess acceptance of those products. Quality ratings should be avoided altogether, except within the context of a quality assurance program. The statistical methods used to analyse sensory and/or instrumental data, consumer data, and their relationships are also reviewed.

The effects of ingredients and processing on the sensory properties and acceptability of frozen desserts are discussed, with a focus on sugar and fat effects on ice cream sensory properties. In a study of the effects of sugar and fat on the sensory properties of vanilla ice cream, we found that increased sugar caused higher vanilla, almond, buttery, custard/eggy, sweetness, fatty, creamy, doughy and mouthcoating characteristics, and lower coolness, ice crystals, melt rate (instrumental) and hardness (instrumental). Increased fat caused higher buttery, custard/eggy, and sweet flavor, fatty, creamy, doughy and mouthcoating texture, and lower color, ice crystals, and melting rate.

Understanding the sensory determinants of consumer acceptance of frozen desserts is critical to successful product development. In a study of the effects of sugar and acid on vanilla frozen yoghurt acceptability, we found a significant linear inverse relation between degree of liking and titratable acidity, suggesting frozen yoghurt consumers seek to combine the sensory properties of ice cream (low acidity) with the nutritional properties of yoghurt (low fat, active enzyme culture). Response surface methodology was subsequently used to relate hedonic ratings to sugar and fat levels in vanilla ice cream. The level of sugar had a greater effect on liking of flavor, liking of texture/mouthfeel and overall liking than did fat. Acceptability was positively related to the vanilla, creamy, fatty and milky characters, and negatively related to color, ice crystals and instrumental hardness.

Ice cream and frozen desserts have strayed away from today's eating trends. Despite the large number of reduced-fat, low-fat, or non-fat frozen desserts now manufactured for the calorie-conscious consumer, sale statistics in most Western countries show that premium ice cream still accounts for most of the sales of packaged frozen desserts. Premium (and super-premium) ice creams happen to contain more fat (and sometimes more sugar) than do regular and economy ice creams. So what is it that makes premium ice cream such an irresistible dessert ?

Ice cream and frozen desserts are highly palatable foods because they combine a variety of desirable sensory properties. These properties can be categorized under the general headings of appearance (including color), aroma (the smell of the ice cream, perceived by sniffing), flavor (the combination of sensations perceived by the chemical senses when the food is placed in the mouth, that is, taste, smell perceived retronasally, trigeminal sensations (for example cooling, and temperature), and texture/mouthfeel (Figure 1).

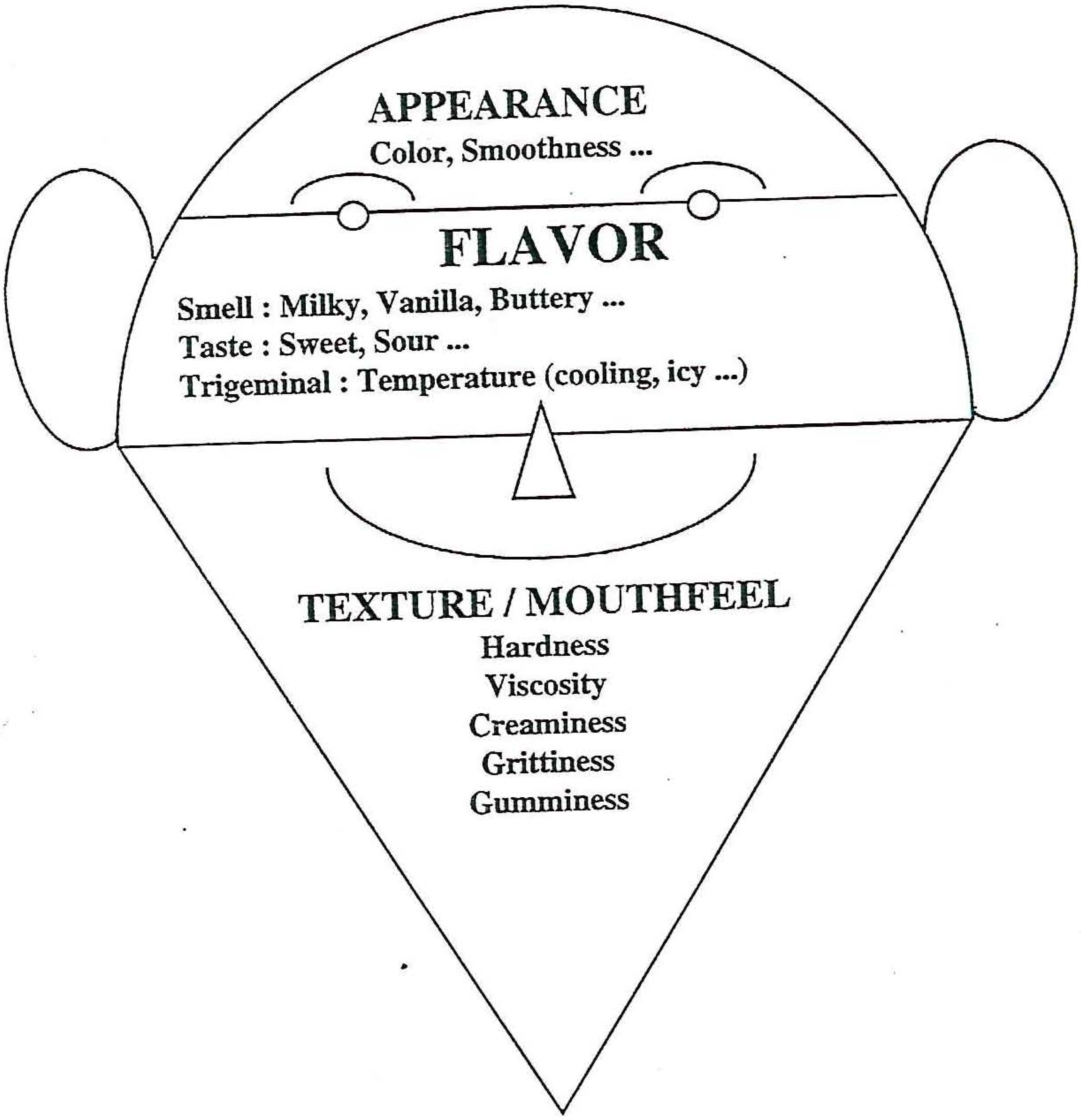

Figure 1: The sensory properties of ice cream and frozen desserts.

Sensation is the result of the interaction between a stimulus and a sensory system. Let us examine briefly the human sensory system, ice cream as a complex food stimulus, and what makes their interaction so unique.

2 THE HUMAN SENSORY SYSTEM

Color is perceived by a three-cone receptor system located in the retina. Each cone is sensitive to a different wavelength range in the visible spectrum. As a result, color is three-dimensional (hue, brightness and saturation), and instrumental measures of color, using Hunter's L, a, b system for example, are generally better suited for color assessments than sensory panels.

The aroma of ice cream (and the olfactory component of flavor, perceived retronasally) are perceived as volatile compounds released from the ice cream which interact with receptors located in olfactory cilia protruding into the mucous layer over the olfactory epithelium. This small patch of tissue is located high up in the nasal cavity, conveniently close to the olfactory bulb, the part of the brain that processes the qualitative and quantitative components of smells.

Taste is limited to five basic qualities (sweet, sour, salty, bitter and umami – the taste of monosodium glutamate), and is perceived as a result of the interaction of tastants with receptors located in taste cells which in turn are found in taste buds. Those taste buds are found in some of the papillae (fungiform and circumvallate) which coat the tip, sides and dorsal surface of the tongue.

The sensory modalities responsible for perceiving texture and mouthfeel may be divided into three distinct groups [1]: mechanoreceptors in the superficial structures of the mouth such as hard and soft palate, tongue, and gums; mechanoreceptors in the peridontal membrane surrounding the roots of the teeth; and mechanoreceptors of the muscles and tendons involved in mastication. Tactile sensations initiated by those mechanoreceptors all feed into the trigeminal nerve.

Free trigeminal nerve endings in the nasal and oral cavities are also sensitive to temperature and irritant chemical stimuli (for example capsaicin, nicotin, ammonia, acetic acid, etc.) through various kinds of thermoreceptors and nociceptors [2].

3 ICE CREAM AS A COMPLEX FOOD STIMULUS

Ice cream is a frozen foam, which combines aqueous and lipid phases with a gaseous overrun. Because of its relatively high carbohydrate, protein and fat contents, it displays interesting flavor-release properties. For example, release of water-soluble volatile compounds should be fast and release of fat-soluble compounds should be slow or delayed [3], resulting in a long-lasting flavor experience. Because ice cream is a frozen dessert (cold and solid at first, then semi-solid to liquid at swallowing), flavor release is delayed and reduced compared to what it would be for a semi-solid food system of similar composition at room temperature. The cold temperature also reduces the perceived intensity of the taste qualities (sweet, sour) of the ice cream.

Preferences for sensory stimuli may be innate or learned. Preferences (or liking) for the sensory properties of frozen desserts, whether innate or learned, are very strong across cultures. As a result, there seems to be a well-developed cognitive association in the minds of consumers between ice cream and indulgence and pleasure. Frozen desserts are high in sugar, and sweetness is innately pleasant – the result of the association between sugars and calories. They are also high in fat, and fatty foods seem to be (innately?) preferred by young children [4], supposedly because fat imparts a creamy and smooth mouthfeel. The only innately unpleasant sensation from ice cream should be its cold temperature because it stimulates free endings of the trigeminal nerve in the oral cavity, and so-called trigeminal stimuli typically are innately unpleasant because they signal potential harm (a newborn for example will react negatively to having a bit of ice cream placed in his mouth). Yet we learn to override this initial rejection, and to actually seek it [2]. That could be because the cooling effect is somewhat moderate, compared to that of an ice cube, for example (as a result of the presence of fat, sugar and other solids in ice cream). The reasons why we learn to like that cooling sensation probably are (1) sensation-seeking behavior (similar to the 'cheap thrill' of eating a crunchy snack or a spicy dish), and (2) refreshment (frozen desserts are perceived as refreshing, particularly in the summer).

The implications of this unique set of sensory properties for intake regulation are significant. First, the fat in ice cream (and in other solid or semi-solid foods) is said to be 'hidden' because consumers typically do not detect small but significant fat variations in these products [5]. Second, the cold temperature of ice cream reduces the perceived intensity of the other stimuli in the ice cream (at least initially, until the ice cream is melted in the mouth – but most of it has been swallowed by then). As a result, sensory-specific satiety* – one of the mechanisms for short-term regulation of food intake (immediate, for example 2 min after ingestion) – is probably not as well expressed when we eat ice cream as it should be, given the levels of sugar and fat in it; and termination of eating a frozen dessert is more likely to occur because of gut-level regulation mechanisms (medium-term, for example 20 min after ingestion). In summary, we probably go on eating ice cream longer (and therefore more) than we should because the expression of its satiating effects is limited or at least delayed.

4 EVALUATING THE SENSORY PROPERTIES OF ICE CREAM

The dairy industry is a very traditional industry. So-called dairy judging is a strongly established set of practices which seek to rate the quality of dairy products (including frozen desserts) using experts, mostly by identifying downgrading factors (defects) in the product. The ADSA's Ice Cream Score Card [7] exemplifies this approach to the sensory evaluation of frozen desserts. The ADSA (American Dairy Science Association) developed and revised the ice cream scorecard in 1987 for use in the Annual Collegiate Dairy Products Evaluation Contest. Its use should be confined to that type of event (the importance and value of which are not questionned here...). That scorecard breaks a number of rules and principles in sensory evaluation: it combines analytical (perceived intensity or instrumental measures) with hedonic aspects; it also produces one number (a quality rating or score) for describing something that is truly multidimensional. Hence, two very different ice creams might

* *As a food is eaten to satiety, the pleasantness of the taste of that food and the desire to eat it decrease more than those of foods which have not been eaten [6]. Because the sensory properties of the ingested foods play an important role in the specificity of these changes, they have been called "sensory-specific satiety".*

receive identical ratings. It also assumes that the dairy judges (experts) use that scorecard in the same way. We have shown for other commodities that this is not likely to be the case (low consistency across experts for quality ratings) [8].

This type of tool does not meet the needs of the frozen dessert industry. Table 1 provides a list of suitable methods for evaluating the sensory properties of frozen desserts and their respective purposes. Analytical sensory tests such as difference tests and descriptive analysis should be used with trained judges to provide qualitative and quantitative information about the sensory properties of frozen desserts. Instrumental measurements of sensory properties should also be used as a necessary complement to sensory analytical tests, particularly for color and texture. Affective tests such as hedonic scaling or preference tests should be used with consumers representative of the target population to assess acceptance of those products. Quality ratings should be avoided altogether, except within the context of a quality assurance program [9].

Table 1: Methods for evaluating the sensory properties of frozen desserts

Analytical methods
Instrumental measurements
Color (Hunter's L, a, b, Munsell Color System)
Texture/mouthfeel (Texture Analyzer, rheology, melting properties, crystallography)
Gas chromatography / Mass spectrometry
Enzymatic assays (sugars)
Composition measures
Sensory methods
Difference tests (Paired-comparison, duo-trio test, triangle test, A-not-A test, Same-different test) and derived measures of difference (R-index, d')
Descriptive analysis (Quantitative Descriptive Analysis®, Spectrum Method®, Free-Choice Profiling)
Time-intensity (and Dynamic Flavor Profile)
Consumer testing
Focus groups (concept and product testing)
Paired-preference test
Preference ranking
Hedonic scaling (9-point hedonic scale)
Purchase intent scaling (5-point PI scale)
Quality control
In/out method
Quality ratings
Spectrum Method®
Difference from control

The statistical methods used to analyse sensory and/or instrumental data, consumer data, and their relationships are just as critical as the sensory or instrumental methods used to collect that data. These methods and their applications are summarized in Table 2. Significant sources of variations in those data sets are typically determined using analysis of variance techniques. Multiple mean comparisons (among treatments for example) can be done with Fisher's Least Significant Difference, Duncan's Multiple Range Test or other tests. Because analytical methods, whether instrumental or sensory descriptive, characterize samples along many variables, multivariate statistical methods are required to characterize those variables that account for most of the variance in the data, to understand the relationships among the original variables, and to characterize and represent the difference among the samples (in a reduced number of dimensions). An example of such a technique which can be used to analyse instrumental or sensory descriptive data is Principal Component Analysis (PCA). With this technique, relationships among variables (instrumental measures or sensory attributes) and differences among samples can be characterized along a limited number of principal components, which are linear combinations of the original variables, and which account for decreasing amounts of the variance in the data, from PC 1 to PC 2 to PC 3, etc. If one is only interested in the degree of similarity or difference among the samples, cluster analysis can be applied to those same data sets. There has recently been a shift in the focus of sensometricians (sensometrics is the application of statistics to the analysis of sensory data) from understanding relationships between sensory and instrumental data to developing techniques for relating consumer preference or hedonic data to sensory descriptive and/or instrumental data. Partial least square regression and (internal or external) preference mapping are examples of such developments [10].

Table 2: Statistical methods for analysing instrumental, sensory and consumer data

Univariate statistics
Binomial statistics (Tables of minimum number of correct judgements, of minimum differences among sums of ranks)
Analysis of variance
Multiple mean comparisons (Fisher's Least Significant Difference, Duncan's Multiple Range Test)
Pearson product-moment correlation coefficient
Linear and polynomial regression
Multivariate statistics
Principal component analysis
Procrustes analysis (of free-choice profiling data)
Cluster analysis
Multiple regression
Response surface methodology
Partial least square regression
Internal and external preference mapping

We used the sensory evaluation and statistics approaches and techniques outlined above to answer two fundamental types of questions: (1) How do sensory properties of frozen desserts relate to ingredients and processing? and (2) Which sensory properties drive consumer acceptance of frozen desserts? What follows is an outline of some recent findings in these two research areas.

5 HOW DO SENSORY PROPERTIES OF FROZEN DESSERTS RELATE TO INGREDIENTS AND PROCESSING ?

Butterfat, sugar, overrun and specific flavor are critical determinants of the sensory quality of ice cream, and their effects have been investigated extensively. 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 [11]. 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 [12]. Within the 3–12% range, fat was shown to increase primarily the buttery, creamy and mouthcoating characteristics of ice cream and to reduce its melting rate, coldness and ice crystal perception, whereas sugar increased sweetness, caramel and vanillin notes, and decreased milkiness [13]. Non-fat milk solids caused a decrease in coldness, ice crystal and melting rate perceptions, and an increase in creaminess and mouthcoating [13]. Other descriptive studies of sensory properties of vanilla ice cream have focused on the effects of time–temperature changes during storage [14] and of homogenization [15], on sources of error in sensory texture profiling [16] and on vanilla flavor and base interactions [17].

We investigated the effects of sugar and fat on the sensory properties of vanilla ice cream [18]. Specific objectives of the study 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, and (2) to investigate relationships between descriptive and instrumental measures of textural properties. Vanilla ice cream with 8, 13 or 18% sucrose and 10, 14 or 18% butterfat was evaluated by descriptive analysis using a variation of the Quantitative Descriptive Analysis (QDA) method [19] with 15 judges, and by Instrumental Texture Measurements (ITM). 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/s, 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 versus time. Melt rate was the slope of the melt curve. Ice cream samples were tempered to about -10°C before analysis.

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 (QDA).

Response Surface Methodology (RSM) was 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 (for example buttery, vanilla, almond, sweetness, coolness/cooling, fatty, creamy, doughy/pasty/elastic, ice crystals, mouthcoating afterfeel) and for one of the four instrumental measures (for example hardness). The response surfaces relating perceived sweetness and fatty character to sugar and fat levels are shown in Figure 2.

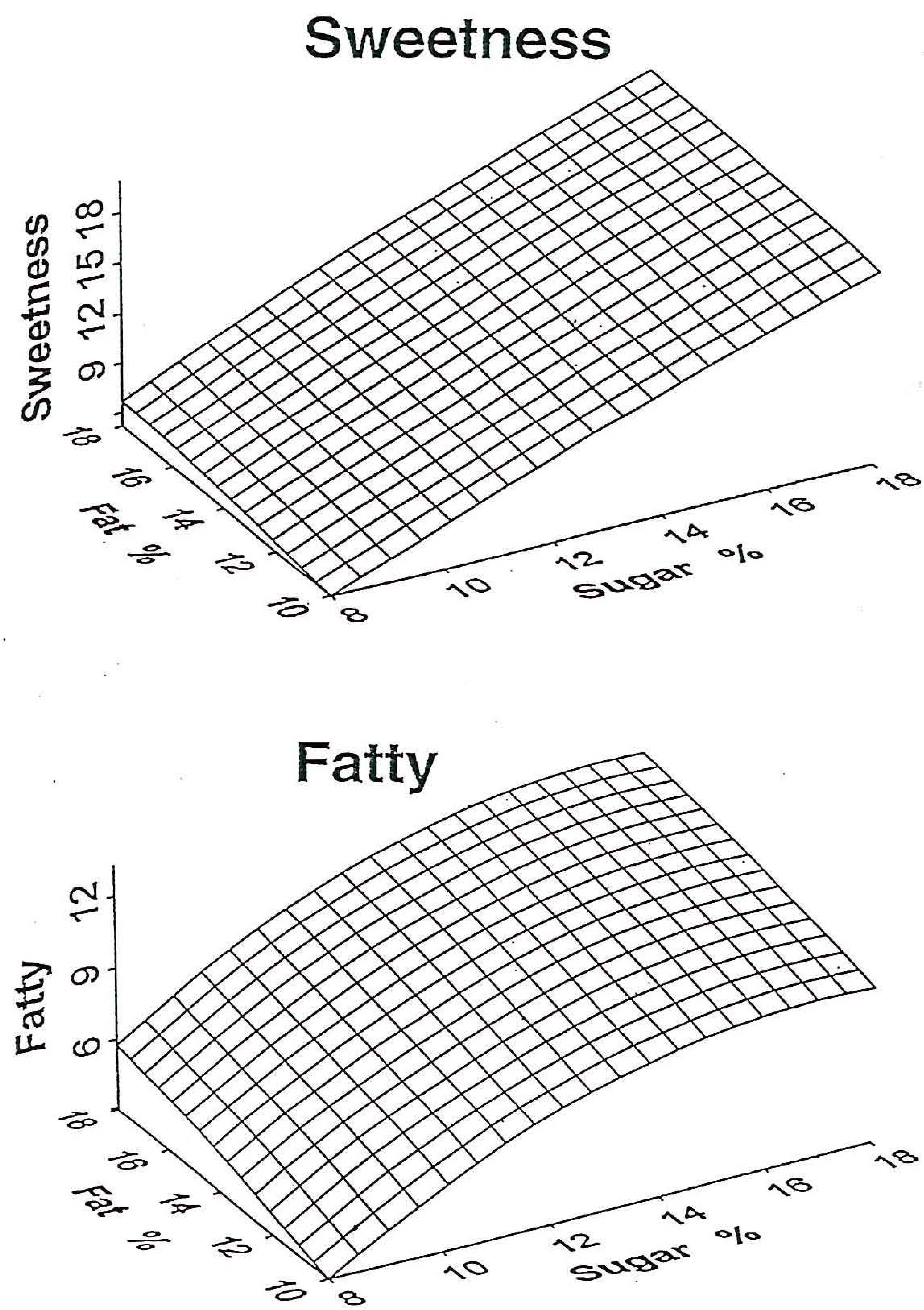

Figure 2: Response surfaces relating perceived sweetness and fatty intensities to sugar and fat concentrations in vanilla ice cream.

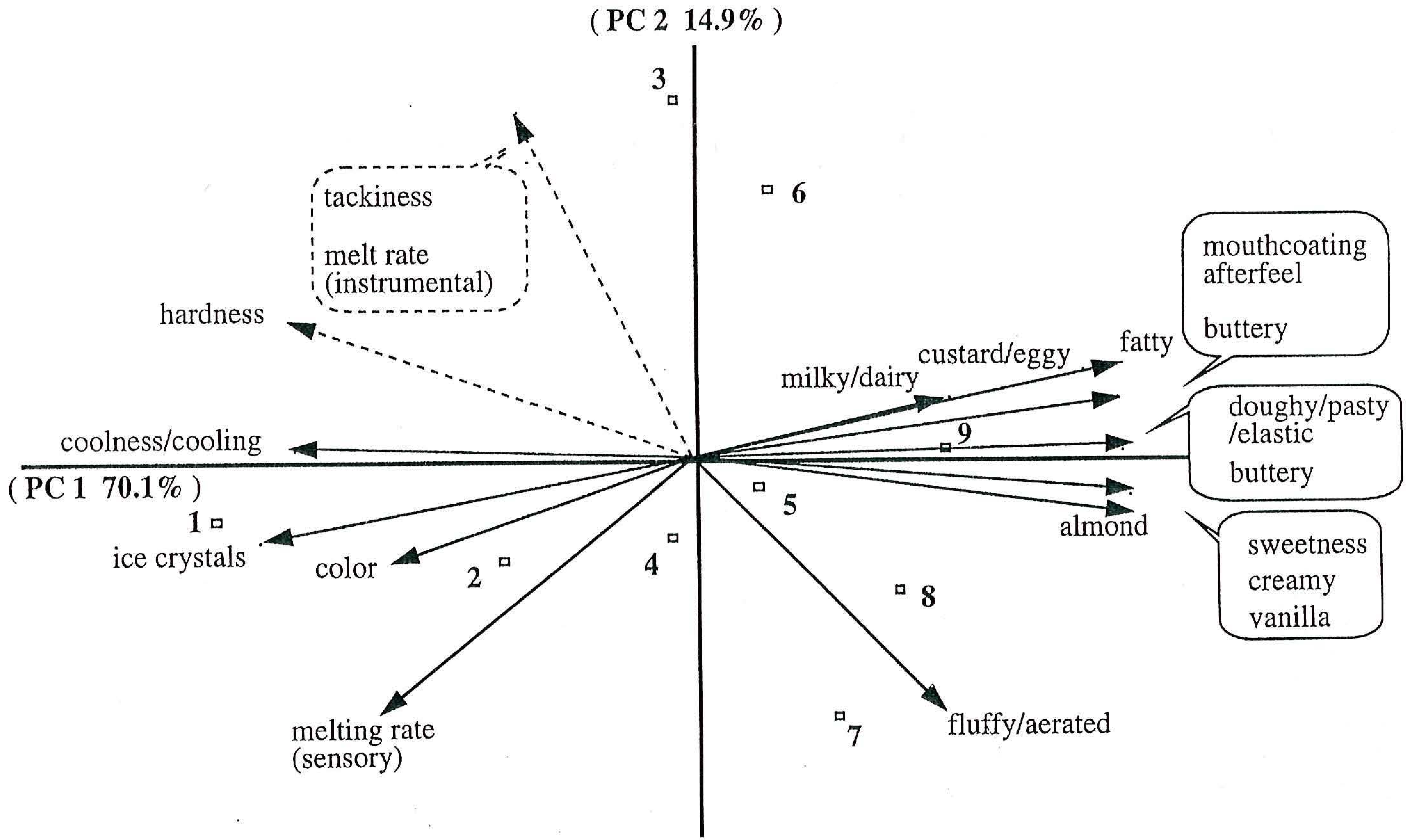

Figure 3: Principal component analysis (PCA) of the matrix of mean descriptive analysis ratings and instrumental measures combined, across the nine vanilla ice cream samples (1=LS/LF, 2=LS/MF, 3=LS/HF, 4=MS/LF, 5=MS/MF, 6=MS/HF, 7=HS/LF, 8=HS/MF, 9=HS/HF; L=low, M=medium, H=high; S=sugar, F=fat). Both analytical measures and ice cream samples are shown on PCs 1 and 2.

The matrix of mean ratings for the 15 attributes across the nine samples was analysed by principal component analysis. 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 [5].

Another PCA was run on the matrix of mean descriptive and instrumental measures for the nine samples (Figure 3). Even though the first PC (which accounts for 70% of variance) remained a contrast between attributes listed earlier (for the PCA of descriptive ratings only), the second PC (which accounts for 15% of variance) seemed 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 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 nine samples in the PC space did not change much from that observed in the PCA of sensory attributes only. The separation of samples based on sugar content (1,2,3 versus 4,5,6 versus 7,8,9) became more obvious, however (along PC 1).

Key findings from that study were as follow. Fat level (within the 10–18% range) did not have as strong an effect on flavor or even mouthfeel characteristics as sugar did. 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 [20,21]. We found the opposite, that is, 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 [22], our study confirmed that besides contributing to flavor, sugar also has some critical structural properties which affect texture and mouthfeel. Regarding instrumental measures, hardness and tackiness were related to physico-chemical characteristics (sugar and fat contents, ice crystals), but sensory and instrumental measures of melting behavior were not related.

6 WHICH SENSORY PROPERTIES DRIVE CONSUMER ACCEPTANCE OF FROZEN DESSERTS ?

Understanding the sensory determinants of consumer acceptance of frozen desserts is critical to successful product development. In a study of the effects of sugar and acid on vanilla frozen yoghurt acceptability among 141 college students

[23], we found a significant linear inverse relation between degree of liking and titratable acidity in frozen yoghurt, independent of sugar concentration (Figure 4). The best-liked samples were those with the lowest acidity (0.23% TA as lactic acid). Degree of liking of frozen yoghurt was not correlated with dairy product consumption. No significant difference was found between males and females for overall degree of liking of frozen yoghurt or overall dairy product intake, yet consumption of frozen yoghurt was higher among female students. The results of that study suggested that frozen yoghurt consumers sought to combine the sensory properties of ice cream (low acidity) with the nutritional properties of yoghurt (low fat, active enzyme culture).

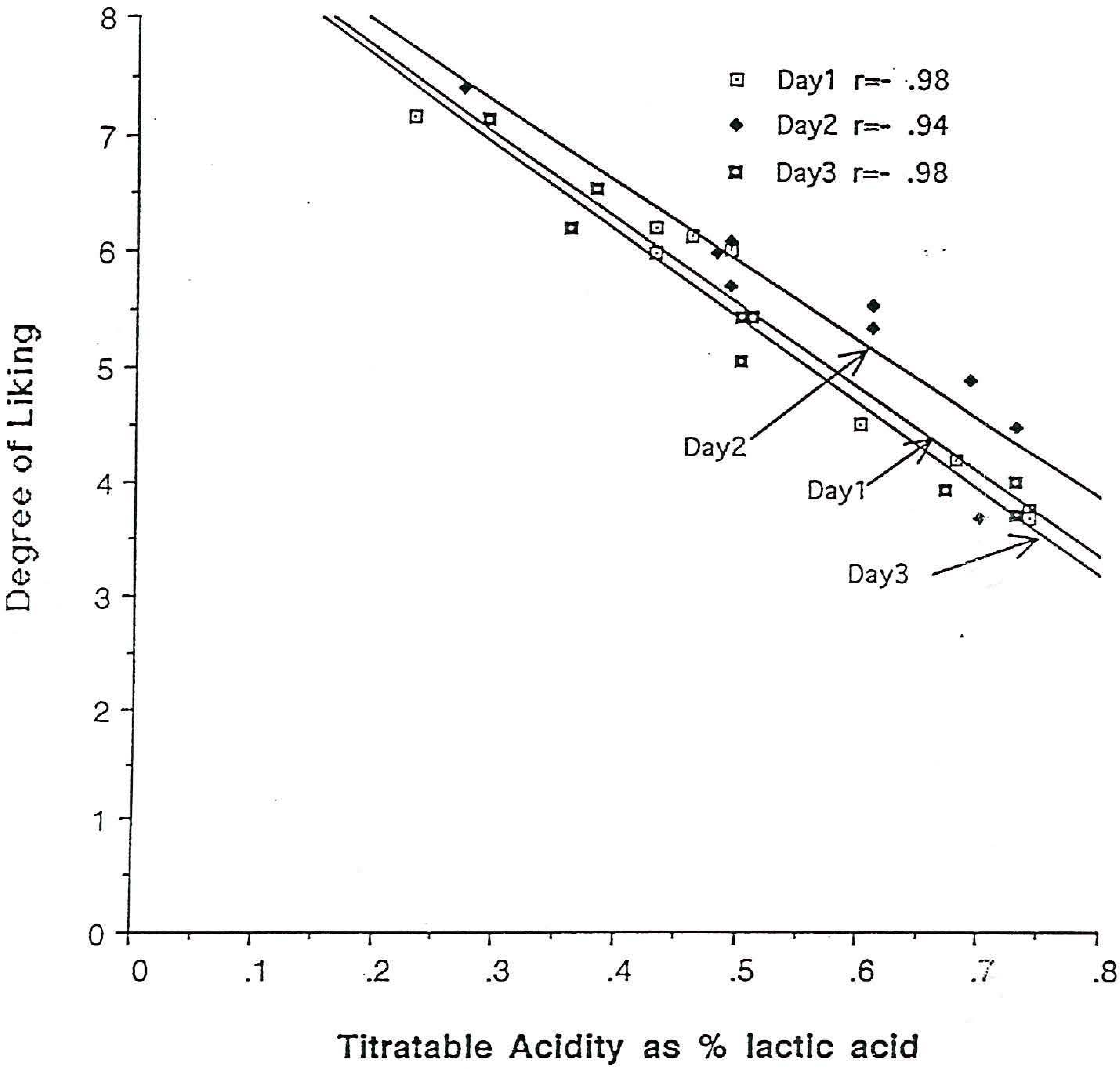

Figure 4: Degree of liking versus titratable acidity in vanilla frozen yoghurt for three populations of young adult consumers corresponding to 3 days of testing (n = 40, 47 and 54, respectively, for Days 1, 2 and 3).

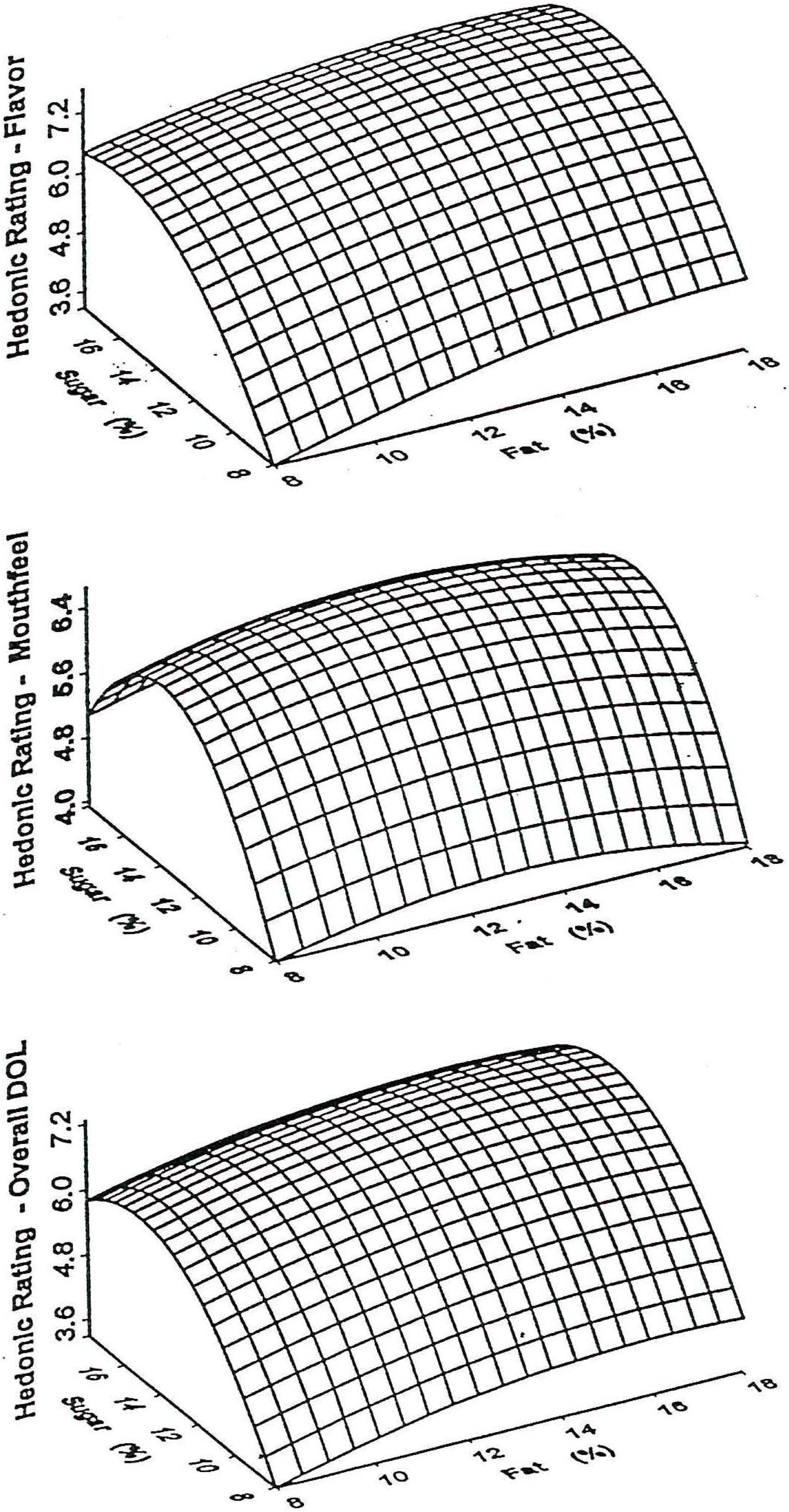

Figure 5: *Response surfaces relating degree of liking of flavor (taste and smell), degree of liking of texture/mouthfeel and overall degree of liking to sugar and fat concentrations in vanilla ice cream.*

In our study of the effects of sugar and fat on the sensory properties of vanilla ice cream, acceptance of the nine samples in the design was also measured [24] among 146 college students (73 men and 73 women), who tasted and rated on a 9-point hedonic scale their degree of liking of the texture and mouthfeel, flavor (taste and smell), and overall degree of liking of the samples. Hedonic ratings differed significantly among samples, and the best-liked sample for texture and mouthfeel, flavor, and overall degree of liking contained 13.54% sugar and 14.99% fat. Men and women differed significantly in their liking for the flavor of the samples; men rated the flavor of the ice creams higher than women did. There was no gender difference for degree of liking of texture and mouthfeel or for overall degree of liking. Response surface methodology was used to relate hedonic ratings to sugar and fat percentages in the ice cream. Dome-shaped response surfaces were obtained for all three degree of liking parameters, and optimal sugar and fat, respectively, were 13.16% and 14.02% for degree of liking of texture and mouthfeel, 14.07% and 15.35% for degree of liking of flavor, and 14.30% and 14.77% for overall degree of liking (Figure 5). Based on the curvature on the response surfaces, we can say that the level of sugar had a greater effect on liking of flavor, liking of texture/mouthfeel and overall liking than did fat. Acceptability was positively related to the vanilla, creamy, fatty and milky characters, and negatively related to color, ice crystals and instrumental hardness [18].

Frozen desserts are very complex food systems which combine unique and desirable sensory properties. While the relation between ingredients and processes and sensory properties is fairly well understood, much research is needed to understand which sensory attributes drive consumer acceptance of frozen desserts and how they might affect satiety and food intake.

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