J. Dairy Sci. 84:12–20

Quantitative Descriptive Analysis and Principal Component Analysis for Sensory Characterization of Ultrapasteurized Milk

K. W. Chapman, H. T. Lawless, and K. J. Boor
Dept. of Food Science, Cornell University, Ithaca, NY 14853

ABSTRACT

Quantitative descriptive analysis was used to describe the key attributes of nine ultrapasteurized (UP) milk products of various fat levels, including two lactose-reduced products, from two dairy plants. Principal components analysis identified four significant principal components that accounted for 87.6% of the variance in the sensory attribute data. Principal component scores indicated that the location of each UP milk along each of four scales primarily corresponded to cooked, drying/lingering, sweet, and bitter attributes. Overall product quality was modeled as a function of the principal components using multiple least squares regression (R^2 = 0.810). These findings demonstrate the utility of quantitative descriptive analysis for identifying and measuring UP fluid milk product attributes that are important to consumers.
(**Key words:** quantitative descriptive analysis, principal component analysis, ultrapasteurized)

Abbreviation key: OLS = ordinary least squares, **PC** = principal components, **PCA** = PC analysis, **PCR** = PC regression, **PLS** = partial least squares, **QDA** = quantitative descriptor analysis, **UP** = ultrapasteurization, ultrapasteurized.

INTRODUCTION

Extending the shelf life of fluid milk product will contribute to the competitiveness of the dairy industry in the beverage market. As an inverse relationship exists between product shelf life and the volume of product inventory that can be maintained at distribution centers, products with shorter shelf lives have relatively high distribution and inventory costs. Further, out-of-date products lead to financial losses for milk processors. Thus, processing strategies that extend the shelf life of dairy product are of economic interest to milk processors. Ultra-high temperature processing and ultrapasteurization (**UP**) represent two currently applied approaches for extending dairy product shelf lives beyond those obtained by conventional pasteurization. UHT milk is thermally processed at temperatures between 135 and 150°C for 1 to 5 s, then the milk is packaged under aseptic conditions that render the milk shelf stable without refrigeration. The thermal processing of UP milk is similar to that of UHT milk, with treatment at or above 138°C for at least 2 s, (FDA, 1999) but the milk is not aseptically packaged. In comparison with the typical 10 to 21 d shelf life of fluid milk processed under conventional high temperature short time conditions (at or above 72°C for at least 15 s; FDA, 1999), UP products have extended shelf lives of at least 60 d under refrigerated conditions (Boor and Nakimbugwe, 1998).

As product quality drives consumer acceptance and demand, the ability to measure sensory attributes characteristic of high quality products is necessary for the development and production of products that meet consumer expectations. The traditional dairy judging approach for evaluating fluid milk for sensory characteristics is based on scoring a product against a specified list of defects commonly found in conventionally pasteurized milk. Traditional dairy judging has been criticized for failure to predict consumer acceptance, lack of objectivity in quality assessments, difficulty in assignment of quantitative scores, and lack of utility for combining analytically oriented attribute ratings with affectively oriented quality scores (Claassen and Lawless, 1992). In addition to these shortcomings, the application of traditional judging strategies to UP products raises further analytical challenges as changes in UP product characteristics can be more subtle and occur over a longer period of time than changes typically encountered in conventionally pasteurized milk (Boor and Nakimbugwe, 1998; Shipe, 1980). Thus, as the dairy industry moves toward production of extended shelf life products, the need emerges to develop appropriate sensory tools that are sensitive and specific for these products.

A quantitative descriptive analysis (**QDA**) approach has gained acceptance for sensory evaluation of various food and dairy products (Stone and Sidel, 1998), including conventionally pasteurized milk (Phillips et al.,

Received June 26, 2000.
Accepted August 10, 2000.
Corresponding author: W. Chapman; e-mail: kwc3@cornell.edu.

1995; Quinones et al., 1998), ice cream (Ohmes et al., 1998; Roland et al., 1999), and cheese (Ordonez et al., 1998). The principle of QDA is based on the ability to train panelists to measure specific attributes of a product in a reproducible manner to yield a comprehensive quantitative product description amenable to statistical analyses. In a QDA approach, panelists recruited from the general public work together in a focus group to identify key product attributes and appropriate intensity scales specific to a product. This group of panelists is then trained to reliably identify and score product attributes. As panelists generate the attribute terms, the resulting descriptions are meaningful to consumers, and thus, analyses provide information amenable to modeling predictions of consumer acceptability. QDA results can be analyzed statistically and then represented graphically.

Principal component analysis (**PCA**) is a widely used multivariate analytical statistical technique that can be applied to QDA data to reduce the set of dependent variables (i.e., attributes) to a smaller set of underlying variables (called factors) based on patterns of correlation among the original variables (Lawless and Heymann, 1998). The resulting data can then be applied to the following: profiling specific product characteristics; comparing and contrasting similar products based on attributes important to consumers; and altering product characteristics with the goal of increasing market share for a given set of products.

The objectives of this study were to: 1) assess the utility of QDA for evaluating UP milk products, 2) identify the principal components (**PC**) contributing to sensory evaluation of UP milk products, and 3) develop a model for predicting overall UP milk product quality as a function of PC quantification.

MATERIALS AND METHODS

For each milk product, paperboard gable-top cartons (three layer: polyethylene, paperboard, and polyethylene) were collected on the same day from each dairy plant. For each sampling period, testing was performed on a total volume of one quart (1890 ml) or more. For some products four half pints (947.2 ml) or two pints were commingled (947.2 ml). The UP milk products, container sizes, and sample codes are listed in Table 1. Randomly selected cartons of milk were analyzed upon receipt in the laboratory (approximately 2 d postpasteurization) as well as after 30 ± 1 and 60 ± 1 d of storage at 6°C. Analyses included chemical [freezing point (model 4D3 Cryoscope, Advanced Instruments, Norwood, MA), acid degree value (Shipe et al., 1980), vitamin A (Marshall, 1992) and vitamin D_3 (Thompson et al., 1982) concentrations, fat determination (Marshall, 1992), and total solids (Marshall, 1992)], microbiological (Marshall, 1992), standard plate count, coliform count, and growth inhibitor determination, and sensory evaluation (Chapman et al., 1998). Only the results from sensory evaluation are presented in this paper.

Sensory Analyses

Attribute terms for evaluation of UP milk samples throughout product shelf life were developed by 12 panelists (staff and graduate students from the Cornell University Food Science Dept.) using QDA methodology (Phillips et al., 1995). Briefly, ballot development and panelist training were accomplished during seven working sessions. The descriptive terms developed for each major sensory attribute category are listed in Table 2. Attributes were quantified with an intensity scale from 0 to 10; where 0 = attribute not detected and 10 = attribute extremely strong. Overall quality rating was measured with a scale of 1 to 10, where < 6 was considered "poor," 6 to 7 was "fair," and 8 to 10 was "good." The intensities of all attributes except viscosity were rated on a scale of 0 (not present) to 10 (extremely strong). A viscosity rating of 0 was equivalent to the viscosity of nonfat HTST milk; 2.75 was equivalent to low fat (1%) HTST milk; 5.5 was equivalent to reduced-fat (2%) HTST milk; and 8.9 was equivalent to whole HTST milk (3.25%).

Physical reference standards determined by panel consensus, listed in Table 3, were used to develop the proper descriptive language, to reduce the amount of time required to train the panelists, and to calibrate the panel in the use of the intensity scale. After the terminology development phase, the 12 panelists were trained in the evaluation of UP milk. Training consisted of evaluating UP milk samples varying in fat content, degree of freshness, with and without lactose reduction, by use of the descriptive terms developed to describe and quantify aroma, flavor, texture, and aftertaste characteristics on a scale from 0 to 10. The reference samples listed in Table 3 were presented along with the UP milk samples. This procedure was repeated until panel consensus was achieved. A computerized data collection system (Compusense *five*, Guelph, ON, Canada) was introduced during the last training session to ensure panelist familiarity with the scorecard.

At each testing period, sample containers were mixed by inversion, then, in dim light, 60 ml of sample was poured into 148-ml plastic cups (with blind three-digit codes), capped with the appropriate plastic lid, and then presented to panel members seated in individual booths when the samples reached 15°C. Panelists evaluated the milk according to the method described in Chapman

Table 1. Ultrapasteurized (UP) milk products and their sample codes.

	UP milk product			
Milk Code	Plant	Fat level	Container size	Other
1NFQ100LR	1	Nonfat	Quart	100% Lactose reduced
1LF70LR	1	Low fat	Quart	70% Lactose reduced
1RFHP	1	Reduced fat	Half pint	
1RFQ	1	Reduced fat	Quart	
1RFHG	1	Reduced fat	Half gallon	
2NFQ	2	Nonfat	Quart	Fortified (condensed skim)
2RFHP	2	Reduced fat	Half pint	
2FFHG	2	Full fat	Half gallon	
2FFP	2	Full fat	Pint	

et al. (1998). Overall quality ratings were included with the QDA, for the following two reasons: the ratings have been used in the past with the traditional dairy judging and our milk quality program requires this rating for our clients. The 12 panelists performed independent observations on randomized samples of milk.

Statistical Analyses

The data were analyzed with Minitab ver. 12 (Minitab, State College, PA), except for the orthogonal comparisons, which were analyzed using SAS ver. 6.11 (SAS Institute Inc., Cary, NC). Descriptive statistical measures (Table 4) were first calculated for all attributes at 60 d using scores from the 12 panelists. Analysis of variance was performed on each attribute using a randomized block design for balanced data, with panelists as repeated measures (Ott, 1993). Where F-test indicated a significant difference between treatment means, Tukey paired comparisons and orthogonal comparisons were used to determine where the means were different. Significance of differences was defined as $P < 0.05$. Principal components analysis was applied with the factor analysis (Lawless and Heymann, 1998). PCA was applied to the means of eight of the attributes ($n - 1$, where n = # of products). (Table 5 lists the attributes used.) The attributes not selected were those that had consistently low values, indicating that the attribute was rarely present, had high standard deviation, or was highly correlated with another attribute or both. The analysis extracted the most significant variables with minimum loss of information. Kaiser's criterion (eigenvalue > 1) was applied to determine the number of final factors from the initial ones (Massart et al., 1988). To facilitate interpretation of the results, the factors were orthogonally rotated (which leads to uncorrelated factors), following the 'Varimax' method (Massart et al., 1988).

Table 2. Descriptors used with quantitative description analysis to analyze ultrapasteurized milk.

Aroma	Flavor	Texture	Aftertaste
Cooked	Cooked	Viscosity	Drying
Caramelized	Sweet	Drying	Metallic
Grainy/malty	Caramelized	Chalky	Bitter
Other	Bitter	Lingering	Other
	Metallic		
	Other		

Modeling

The overall quality ratings (dependent variables) were modeled as a function of the four Varimax rotated PC for "cooked," "dry lingering," "sweet," and "bitter" scores for the UP products (independent variables). Models were constructed using ordinary least squares (**OLS**), principal components regression (**PCR**), and partial least squares regression (**PLS**) routines in SCAN for Windows Release 1.1 (Minitab, State College, PA). PCR and PLS models were calculated with one to four components. In each case, the best fit equations (those with the highest R^2) and those with the best predictive ability (lowest residual predictive sum of squares, or residual PRESS) were obtained.

RESULTS AND DISCUSSION

Descriptive Analyses

Mean panelist ratings of overall UP milk quality and attribute intensities for aroma, flavor, texture, and aftertaste after 60 ± 1 d of storage at 6°C are listed in Table 4. In general, the average viscosity rating of UP milk increased as percent fat increased. The ratings for nonfat UP milks were approximately the same as for HTST 1% milk. This increase in viscosity could be considered advantageous for low fat UP milks, as according to Pangborn (1985), panelists preferred the viscosity of 2% fat milks to those of milks with lower fat contents. The higher perceived viscosities of the UP milks compared with HTST products could be due to one or more

Table 3. References used during training to analyze ultrapasteurized milk.

Attribute	Reference	Position
Very cooked	Traditionally pasteurized milk, processed within 24 h	8.0
Extremely cooked	Ultrapasteurized milk, processed within 48 h	10.0
Extremely caramelized	Sweetened condensed milk, caramel, burnt sugar	10.0
Cereal milk	Milk steeped in Grape Nuts cereal	5.5
Slightly sweet	4% glucose	3.7
Extremely sweet	10% glucose	10.0
Medium viscosity	2% milk	5.5
Extremely drying	Concord grapes	10.0

of the following factors: higher temperature processing may cause an increase in milk viscosity (Hill 1988); protein fortification (sample 2NFQ) and/or 100% lactose reduction (sample 1NFQ100LR). The apparent increase in perception of 100% lactose-reduced milk viscosity may be related to the increase in perception of sweetness in these products. Lactose reduced milk is perceived to be sweeter than untreated milk as a consequence of the conversion of lactose to glucose and galactose (Bodyfelt et al., 1988). The increase in perception of sweetness may cast a halo effect on viscosity perception. A halo effect occurs when one sensory attribute is rated as more intense or more hedonically positive due to the perception of other sensory attributes that may not be logically related (Lawless and Heymann, 1998). A halo effect has been demonstrated previously in fluid milk samples in which the addition of a just-perceivable level of vanilla extract to low fat milk resulted in increased ratings for sweetness, creaminess, and liking (Clark and Lawless, 1994; Lavin and Lawless, 1998). The viscosity of sample 1LF70LR, a 70% lactose-reduced low fat milk, was perceived to be similar to those of the reduced-fat milks (samples 1RFHP, 1RFQ, and 2RFHP).

Tukey paired comparisons showed significant differences between products for overall product quality and intensities of cooked aroma, caramelized aroma, cooked flavor, sweet flavor, caramelized flavor, bitter flavor, viscosity, bitter aftertaste, and lingering aftertaste. The largest differences were between lactose-reduced UP milk and regular (nonlactose reduced) UP milk, with respect to sweetness.

Orthogonal contrasts (Table 5) showed that the panelists did not differentiate between products from the two plants with regard to the overall product quality; however, there was a significant difference between all other attributes except for metallic flavor, drying, and chalky. Lactose-reduced milks were significantly different from all other milks in sweet flavor, caramelized flavor, and viscosity. Nonfat milks were rated lower in overall quality than the full fat milks. For the overall quality rating, nonfat milks were significantly different

Table 4. Mean panelists'[1] ratings of ultrapasteurized milk at d 60 ± 1.

	Plant 1					Plant 2			
	1NFQ100LR	1LF70LR	1RFHP	1RFQ	1RFHG	2NFQ	2RFHP	2FFHG	2FFP
Overall quality rating[2]	6.5[b]	6.9[ab]	7.6[ab]	7.4[ab]	6.9[ab]	6.6[b]	6.2[b]	7.3[ab]	7.7[a]
Cooked aroma[3]	4.2[ab]	5.3[ab]	4.8[ab]	5.8[a]	6.0[a]	4.3[ab]	3.5[b]	4.9[b]	4.2[ab]
Caramelized aroma	2.0[ab]	2.0[ab]	2.2[a]	1.5[ab]	2.0[ab]	0.4[b]	1.0[ab]	1.3[ab]	1.2[ab]
Grainy/malty aroma	0.7[a]	1.0[a]	0.8[a]	0.9[a]	1.3[a]	0.6[a]	0.2[a]	0.8[a]	0.3[a]
Cooked flavor	4.7[ab]	4.7[ab]	5.2[ab]	6.3[a]	5.9[ab]	3.5[b]	4.5[ab]	4.7[ab]	4.4[ab]
Sweet flavor	4.4[a]	3.7[a]	1.3[b]	1.5[b]	1.1[b]	1.0[b]	0.6[b]	1.0[b]	1.3[b]
Caramelized flavor	1.4[ab]	1.7[a]	1.1[ab]	0.9[ab]	1.3[ab]	0.5[b]	0.6[ab]	0.9[ab]	0.8[ab]
Bitter flavor	0.4[ab]	0.4[ab]	0.2[b]	0.1[b]	0.8[ab]	1.0[ab]	1.2[a]	0.4[ab]	0.1[b]
Metallic flavor	0.9[a]	0.7[a]	0.3[a]	0.5[a]	0.5[a]	0.6[a]	0.3[a]	0.3[a]	0.1[a]
Viscosity	2.6[b]	3.1[ab]	3.8[ab]	3.5[ab]	4.5[a]	2.3[b]	3.1[ab]	5.0[a]	4.3[a]
Drying	2.6[a]	2.3[a]	2.9[a]	2.7[a]	2.5[a]	2.0[a]	2.8[a]	2.1[a]	2.2[a]
Chalky	0.4[a]	0.6[a]	0.9[a]	0.7[a]	0.3[a]	0.5[a]	0.5[a]	0.5[a]	0.3[a]
Drying aftertaste	3.0[a]	3.1[a]	3.5[a]	3.4[a]	3.6[a]	2.5[a]	2.9[a]	3.0[a]	2.8[a]
Metallic aftertaste	0.6[a]	0.4[a]	0.5[a]	0.6[a]	0.8[a]	0.3[a]	0.3[a]	0.3[a]	0.3[a]
Bitter aftertaste	0.2[b]	0.3[ab]	0.2[b]	0.1[b]	0.7[ab]	0.7[ab]	1.8[a]	0.3[ab]	0.9[ab]
Lingering aftertaste	2.7[b]	3.0[b]	3.3[b]	2.9[b]	3.4[b]	2.7[b]	3.7[a]	3.0[b]	3.0[b]

[a,b]Means within the same row (attribute) with different superscripts differ ($P < 0.05$).

[1]n = 12.

[2]Overall quality rating 1 to 10, where < 6 is poor, 6 to 7 is fair, 8 to 10 is good.

[3]Intensity of attribute: 0 = none, 10 = extremely strong.

Table 5. Orthogonal contrasts[1] of ultrapasteurized milk at 60 ± 1 d.

Attributes[2]	Plant 1 vs. Plant 2	Lactaid vs. Regular	Nonfat vs. Other	Reduced fat vs. Other	Full fat vs. Other
Overall quality rating	NS	NS	*	NS	*
Cooked aroma	*	NS	*	NS	NS
Caramelized aroma	*	NS	NS	NS	NS
Grainy/malty aroma	*	NS	NS	NS	NS
Cooked flavor	*	NS	*	*	NS
Sweet flavor	*	*	*	*	*
Caramelized flavor	*	*	NS	NS	NS
Bitter flavor	*	NS	NS	NS	NS
Viscosity	*	*	*	NS	*
Drying aftertaste	*	NS	NS	NS	NS
Metallic aftertaste	*	NS	NS	*	NS
Bitter aftertaste	*	NS	NS	NS	NS
Lingering aftertaste	*	NS	NS	NS	NS

[1]NS = Not significantly different.
[2]No significant comparison for metallic flavor, drying, chalky.
*$P < 0.05$.

from milks with higher fat contents; likewise full fat milks were significantly different from milks with lower fat contents.

Nonfat milks were rated significantly lower in viscosity than milks with higher fat despite protein fortification in sample 2NFQ, which might have increased perceived product viscosity. Reduced fat milk sample viscosities were not perceived as different from viscosities of either the nonfat or the full fat samples.

To create a visual profile or "fingerprint" of product attributes, spider plots were created by plotting average intensity values on each scale, and then joining the points (Stone and Sidel, 1998). Figure 1 shows attributes of a reduced-fat UP milk at d 2, 29, and 61. This plot illustrates that "cooked aroma" and "cooked flavor" were the product's most prominent characteristics, as previously suggested for both UP and UHT products (Blanc and Odet, 1981; Hansen, 1987; Shipe, 1980) and that the perception of these attributes decreased over time, as reported by Boor and Nakimbugwe (1998). Caramelized aroma, caramelized flavor, and grainy/malty aroma also dissipated with time. By d 61, "bitter flavor," "drying," "bitter aftertaste," and "lingering aftertaste" characteristics became apparent. These attributes appear to contribute to the reduction in the overall quality rating. At least some of these characteristics may be a consequence of protease and lipase enzyme activities that can survive UHT processing conditions (Driessen, 1983; Manji, 1986).

As shown in Figure 2, nonfat UP milk differs from the reduced-fat UP product on initial day. The reduced-fat UP milk had less "caramelized aroma," "grainy/malty aroma," "caramelized flavor," and less "lingering

Table 6. Varimax rotated principal component factor loadings for ultrapasteurized milk attributes.

Attributes	PC1	PC2	PC3	PC4
Cooked aroma	**0.971**[1]	0.013	0.034	–0.208
Caramel aroma	0.497	–0.539	**–0.567**	–0.252
Grainy/malty aroma	**0.964**	0.021	–0.231	0.032
Cooked flavor	**0.702**	–0.547	0.091	–0.350
Sweet flavor	0.038	0.082	**–0.969**	–0.146
Bitter flavor	–0.186	–0.003	0.191	**0.946**
Dry texture	0.004	**–0.942**	–0.101	–0.092
Lingering aftertaste	–0.003	**–0.758**	0.389	0.413
Proportion of total variance	33.1%	25.7%	19.0%	16.6%

[1]Loadings with an absolute value greater than 0.560 are shown in bold type.

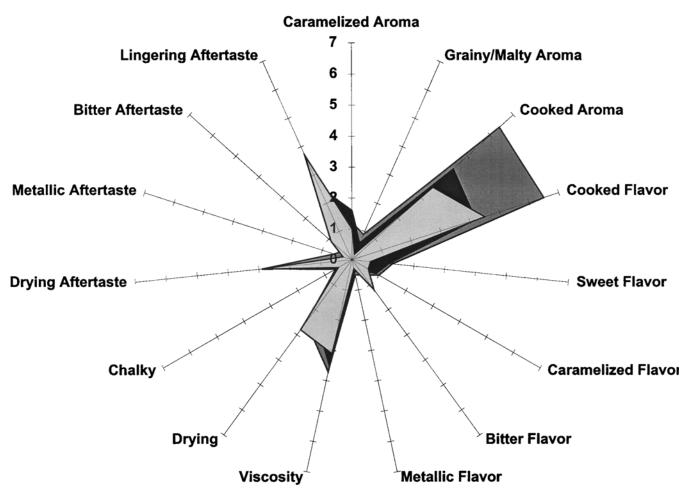

Figure 1. Sensory profiles of reduced fat milk (sample 1RFHP) stored at 6°C. Individual attributes are positioned like the spokes of a wheel around a center (zero, or not detected) point, with the spokes representing attribute intensity scales, with higher (more intense) values radiating outward. Legend: dark grey area is d 2, black area is d 29, and light grey area is d 61.

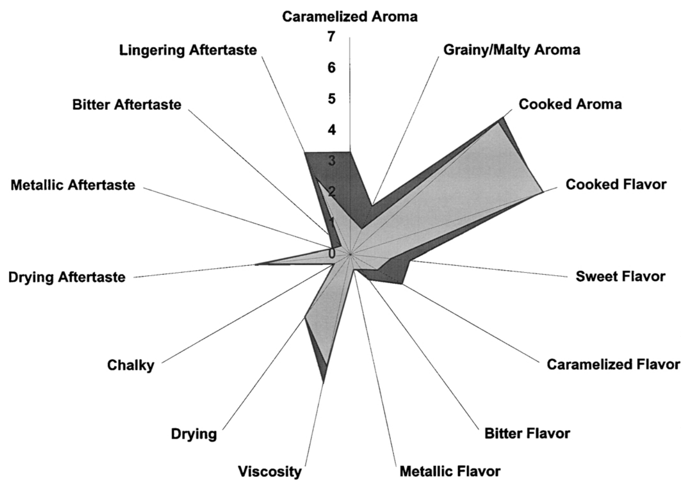

Figure 2. The profiles of nonfat milk (sample 2NFQ) and reduced fat milk (sample 2RFHP) on initial days. Legend: light grey = sample 2RFHP, dark grey = sample 2NFQ.

aftertaste" than the nonfat UP milk. These products also differed in overall quality ratings. The reduced-fat UP milk (sample 2RFHP), which had an overall quality rating of 8.1, was rated significantly higher than the nonfat milk (sample 2NFQ) at 6.4.

Principal Components Analysis

With descriptive sensory data, several dependent variables may be correlated with one another. Following ANOVA, several individual sensory descriptors may discriminate among the samples, but multiple descriptors may be driven by the same underlying causes. PCA is a multivariate technique that provides a method of extracting structure from a variance-covariance or correlation matrix. PCA identifies patterns of correlation among dependent variables and substitutes a new variable, called a factor, for the group of original attributes that were correlated. The analysis then identifies a second and third group of attributes and derives a factor for each, based on the residual variance (that which is left after the variance accounted for by the previous factor has been removed). The attributes will have a correlation with the new dimensions, called a factor loading, and the products will have values on the new dimensions, called factor scores. The factor loadings are useful in interpreting the dimensions, and the factor scores show the relative positions among the products in a map (Lawless and Heymann, 1998). Thus, PCA transforms original dependent variables into new uncorrelated dimensions to simplify the data structure, eliminate descriptor redundancies, and indicate potential latent causal variables.

PCA was applied to the mean attribute ratings listed in Table 4 to simplify interpretation of data from 15 attributes measured on nine products. One important aspect of PCA includes determination of the number of fundamentally different properties (PC) exhibited by the data set. As the first four PC generated from this analysis had eigenvalues > 1 (Kaiser criterion; Massart et al., 1988) and accounted for 94.4% of the total variance in the data set, these four PC were retained. These four PC were then subjected to Varimax rotation to bring them into closer alignment with the original variables (Lawless and Heymann, 1998). The Varimax rotated factor loadings, which represent correlations between PC and the original attribute measurements, are shown in Table 6 (varimax rotated PC factor loadings). Loadings with an absolute value greater than 0.560 (shown in bold type) represent a strong influence. PC1 is entirely related to the following "cooked" attributes: cooked aroma, grainy/malty aroma, and cooked flavor. PC2 has large negative loadings for dry and lingering. PC3 is largely negatively related to sweet attributes: caramel and sweet. PC4 is almost entirely influenced by bitterness.

PCA also produces factor score values (Table 7) that specify the location of each product along each of the Varimax rotated PC. The resulting graphs illustrate relationships (i.e., product position) among the UP products (Figures 3 and 4). With this strategy of perceptual mapping, products that are similar to one another

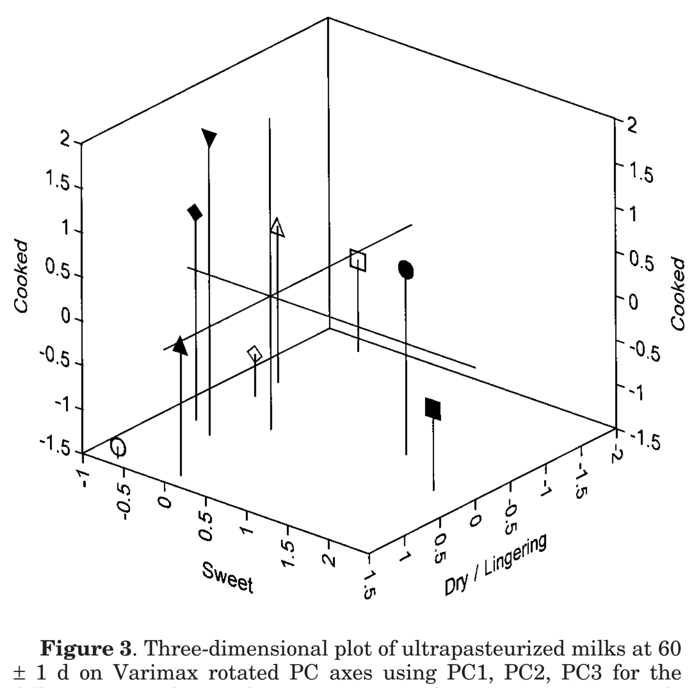

Figure 3. Three-dimensional plot of ultrapasteurized milks at 60 ± 1 d on Varimax rotated PC axes using PC1, PC2, PC3 for the following: sample 1NFQ100LR (■), sample 1LF70LR (●), sample 1RFHP (▲), sample 1RFQ (◆), sample 1RFHG (▼), Sample 2NFQ (□), sample 2RFHP (○), sample 2FFHG (△), and sample 2FFP (◇).

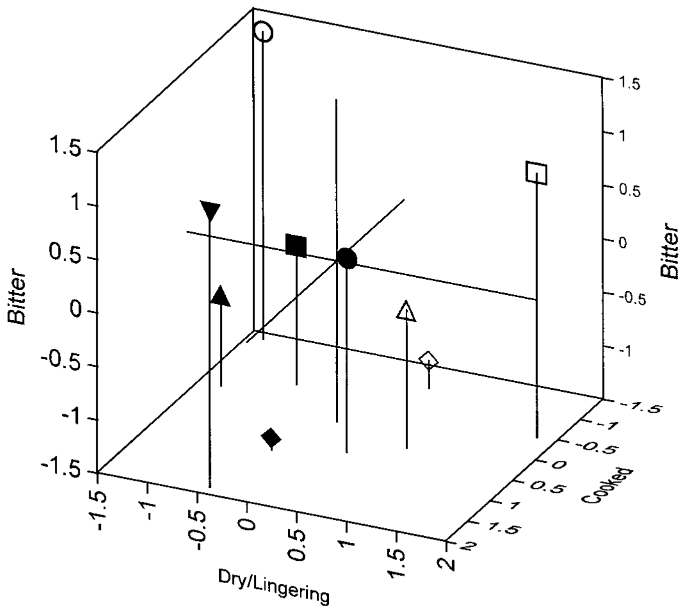

Figure 4. Three-dimensional plot of ultrapasteurized milks at 60 ± 1 d on Varimax rotated PC axes using PC1, PC2, PC4 for the following: Sample 1NFQ100LR (■), sample 1LF70LR (●), sample 1RFHP (▲), sample 1RFQ (◆), sample 1RFHG (▼), Sample 2NFQ (□), sample 2RFHP (○), sample 2FFHG (△), and sample 2FFP (◇).

are positioned close to one another in the map, and products that are very different are far apart (Coxon, 1982, Lawless and Heymann, 1998; Schiffman et al., 1981). Figure 3 shows each product's location on the "cooked" (PC1), "drying/lingering" (PC2), and "sweet axis" (PC3). As one would expect, the two lactose-reduced milks (samples 1NFQ100LR and 1LF70LR), which are sweeter than other UP milks, are close together on the "sweet" axis and are also separated from the other milks. The milks of the same fat levels are within close proximity of each other. Figure 4 shows each product's location on the cooked (PC1), drying/lingering (PC2), and bitter (PC4) axis. Sample 2RFHP is differentiated from the rest because of high bitterness. Once again, the milks of the same fat levels are within close proximity of each other. All of the products from plant 1 are grouped together, while all of the products from plant 2 are grouped together, suggesting that the products from the same plant are more similar to each other than to the products from the other plant. The reduced-fat milk from plant 2 (sample 2RFHP), which had the lowest overall quality rating, is positioned by itself; while the full fat pint (sample 2FFP), which had the highest overall quality rating, was positioned in the center.

Table 7. Varimax rotated principal component factor scores for ultrapasteurized milk at 60 d.

Milk Code	PC1 Cooked	PC2 Dry/lingering	PC3 Sweet	PC4 Bitter
1NFQ100LR	−0.591	−0.0668	−2.05	−0.205
1LF70LR	0.584	0.364	−1.34	0.312
1RFHP	−0.0265	−1.28	−0.0114	−0.650
1RFQ	0.834	−0.277	0.669	−1.39
1RFHG	1.83	−0.449	0.355	1.06
2NFQ	−0.473	1.79	0.475	0.966
2RFHP	−1.38	−1.36	0.695	1.36
2FFHG	0.257	0.818	0.618	−0.215
2FFP	−1.03	0.459	0.588	−1.24

Overall Quality Modeling

A regression model can be used to estimate the overall product quality rating based on measurement of its attributes. To this end, mathematical models expressing overall quality as a function of the PC values of UP milk were constructed. The coefficients (the b terms) were fitted by OLS, PCR, and PLS, using a matrix of the four PC for the UP milk products as the independent variables and the overall quality rating as the dependent variable using the following formula:

$$\text{Overall quality} = b_o + b_1PC1 + b_2PC2 + b_3PC3 + b_4PC4.$$

The analysis resulted in the fits described in Table 8. The PCR best fits (highest R^2) were for models derived from four components. The model with one component had the lowest R^2, but the best (lowest) PRESS (predictive error sum of squares). Also with PLS, the one component model had the lowest PRESS. With PLS, all four components had the same R^2 (R^2 value = 0.810), which was the same as OLS. PLS is better suited than OLS in situations in which combinations of levels of the independent variables cannot be set at optimal levels or where the sample:measurement ratio is less than three (Siebert, 1999). The best model for prediction of overall quality at d 60 was

$$\text{Overall quality rating} = 7.01 + 0.127\ \text{cooked} + 0.013\ \text{dry/lingering} + 0.154\ \text{sweet} - 0.424\ \text{bitter}.$$

In general, as shown by the model, perception of bitter flavor had the most dramatic effect on overall quality perception, as illustrated by the fact that the "bitter" attribute bears the only coefficient in the model that is significantly different from zero ($P = 0.02$). As both "dry/lingering" and "sweet" attributes had negative factor loadings, these attributes would be expressed more accurately as "not dry/lingering" and "not sweet" (Table 6). As both attributes were positive in the regression equation, products perceived as being more dry/lingering and more sweet were considered less desirable.

Table 8. Fitting results for overall quality rating using ordinary least squares (OLS), principal components regression (PCR), and partial least squares regression (PLS).

Components	R^2	Resid. PRESS[1]	R^2cv[2]	b_0[3]	b_1	b_2	b_3	b_4
OLS								
4	0.810	3.03	–0.396	7.01	0.127	0.0127	0.154	–0.424
PCR								
1	0.415	1.78	0.177	7.01	0.0165	–0.222	0.0782	–0.239
2	0.623	1.86	0.144					
3	0.628	3.45	–0.591					
4	0.810	3.03	–0.396					
PLS								
1	0.810	2.56	–0.179	7.01	0.127	0.0127	0.154	–0.424
2	0.810	2.57	–0.186					
3	0.810	3.03	–0.396					
4	0.810	3.03	–0.396					

[1]Resid. PRESS = residual predictive error sum of squares.

[2]R^2cv = cross validated R^2.

[3]b terms are the coefficients for the overall quality model.

Use of QDA for Product Positioning

The generation of quantitative descriptive sensory data can contribute to a well-defined competitive marketing strategy. Product positioning can assist target customers in understanding and appreciating a specific product's characteristics in relation to those of its competitors' products. In this strategy, each brand within a set of competitive products is thought to occupy a certain position in a customer's "perceptual space" (Urban et al., 1987). In general, marketers have two broad objectives in mind when undertaking perceptual mapping. One objective is to determine where a target brand is positioned versus the competition. The other objective is to help identify determinant product attributes that influence customer choice within the product class (Kohli and Leuthesser, 1993). These determinant attributes must be important to customers and must also exhibit differences across brands. Regardless of the importance of a product attribute, if brands are not perceived to differ in that attribute, then the attribute will not be influential in customers' decisions. Perceptual mapping could contribute to strategic product positioning for development and marketing of new dairy products.

As a follow-up to this study, a consumer study of UP milk using preference mapping would be advisable to assess the personal response by current and potential customers and to correlate their responses with the trained panel.

In conclusion, QDA and PCA can contribute to strategic product positioning for development and marketing of new dairy products, including UP and other fluid milk products.

ACKNOWLEDGMENTS

The authors thank the New York State Dairy Promotion Advisory Board for financial support and for its concern for improving the quality of dairy products. We gratefully acknowledge advice and technical assistance from Karl Siebert and assistance with computer software from Lynn Whited.

REFERENCES

Blanc, B., and Odet, G. 1981. Appearance flavour and texture aspects: Recent developments. New Monograph on UHT Milk. IDF Document 133:25.

Bodyfelt, F. W., J. Tobias, and G. .M. Trout. 1988. Sensory Evaluation of Dairy Products. Van Nostrand/AVI Publishing, New York, NY.

Boor, K. J., and D. N. Nakimbugwe, 1998. Quality and stability of 2% fat ultrapasteurized fluid milk products. Dairy Food Environ. San. 18:78–82.

Chapman, K. W., L. C. Rosenberry, D. K. Bandler, and K. J. Boor. 1998. Light-oxidized flavor development and vitamin A degradation in chocolate milk. J. Food Sci. 63:930–934.

Claassen, M. R., and H. T. Lawless. 1992. A comparison of descriptive terminology systems for the sensory analysis of flavor defects in milk. J. Food Sci. 57:596–621.

Clark, C. C., and H. T. Lawless. 1994. Limiting response alternatives in time-intensity scaling and examination of the halo-dumping effect. Chemical Senses 19:583–594.

Coxon, A.P.M. 1982. Three-way and further extensions of the basic model. Pages 186–241 *in* The Users Guide to Multidimensional Scaling. Heinemann Educational Books, London.

Driessen, F. M. 1983. Lipases and proteinases in milk: occurrence heat inactivation and their importance for the keeping quality of milk products. Ph.D. Thesis, Agric. Univ. Wageningin, Netherlands.

FDA. 1999. Grade "A" Pasteurized Milk Ordinance. U.S. Dept. of Health and Human Services, Public Health Service.

Hansen, A. P. 1987. Effect of ultra-high-temperature processing and storage on dairy food flavor. Food Technol. 41:112–116.

Hill, A. R. 1988. Quality of ultra-high-temperature processed milk. Food Technol. 42:92–97.

Kohli, C. S., and L. Leuthesser. 1993. Product positioning: a comparison of perceptual mapping techniques. J. Prod. Brand Mgt. 2:10–19.

Lavin, J. G., and H. Lawless. 1998. Effects of color and odor on judgments of sweetness among children and adults. Food Qual. Pref. 9:283–289.

Lawless, H. T., and H. Heymann. 1998. Pages 606–608 *in* Sensory Evaluation of Food: Principles and Practices. Chapman & Hall, New York, NY.

Manji, B. 1986. Serum protein denaturation and age gelation in sterilized milks. Ph.D. Thesis, Univ. of Guelph, Ontario, Canada.

Marshall, R.T., ed. 1992. Standard Methods for the Examination of Dairy Products. 16th ed., Am. Publ. Health Assoc., Inc., Washington, DC.

Massart, D. L., B.G.M. Vandeginste, S. N. Deming, Y. Michotte, and L. Kaufman. 1988. Principal components and factor analysis. Pages 339–369 *in* Chemometrics: A Textbook. Elsevier, Amsterdam.

Ohmes, R. L., R. T. Marshall, and H. Heymann, 1998. Sensory and physical properties of ice creams containing milk fat or fat replacers. J. Dairy Sci. 81:1222–1228.

Ordonez, A. I., F. C. Ibanez, P. Torre, Y. Barcina, and F. J. Perez-Elortondo. 1998. Application of multivariate analysis to sensory characterization of ewes' milk cheese. J. Sensory Studies 13:45–55.

Ott, R. L. 1993. Analysis of variance for some standard experimental designs. Pages 844–856 *in* An Introduction to Statistical Methods and Data Analysis. Wadsworth Publishing Co., Belmont, CA.

Pangborn, R. M., K.E.O. Bos, and J. S. Stern. 1985. Dietary fat intake and taste responses to fat in milk by under, normal, and overweight women. Appetite 6:25–40.

Phillips, L. G., M. L. McGiff, D. M. Barbano, and H. T. Lawless. 1995. The influence nonfat dry milk on the sensory properties, viscosity, and color of lowfat milks. J. Dairy Sci. 78:1258–1266.

Quinones, H .J., D. M. Barbano, and L. G. Phillips. 1998. Influence of protein standardization by ultrafiltration on the viscosity, color, and sensory properties of 2 and 3.3% milks. J. Dairy Sci. 81:884–894.

Roland, A. M., L. G. Phillips, and K. J. Boor. 1999. Effects of fat replacers on the sensory properties, color, melting, and hardness of ice cream. J. Dairy 82:2094–2100.

Schiffman, S. S., M. L. Reynolds, and F. W. Young. 1981. Introduction to Multidimensional Scaling. Academic, New York, NY.

Shipe, W. F. 1980. Analysis and control of milk flavors. pages 201–239 *in* The Analysis and Control of Less Desirable Flavors in Foods and Beverages. G. Charalambous, ed. Academic Press, Orlando, FL.

Shipe, W. F., G. F. Senyk, and K. B. Fountain. 1980. Modified copper soap solvent extraction method for measuring free fatty acids in milk. J. Dairy Sci 63:193–198.

Sidel, J. L., H. Stone, and J. Bloomquist. 1981. Use and misuse of sensory evaluation in research and quality control. J. Dairy Sci. 64:2292.

Siebert, K. J. 1999. Modeling the flavor threshold of organic acids in beer as a function of their molecular properties. Food Qual. Pref. 10:129–137.

Stone, H., and J. L. Sidel. 1998. Quantitative descriptive analysis: developments, applications, and the future. Food Technol. J. 52:48–52.

Thompson, J. N., G. Hatina, and W. B. Maxwell. 1982. High performance liquid chromatographic determination of vitamin D in fortified milks, margarine, and infant formulas. J. Assoc. Anal. Chem. 65:624–631.

Urban, G. L., J. R. Hauser, and N. Dholakia. 1987. Mapping consumers' product perception. Pages 103–120 *in* Essentials of New Product Management. Prentice-Hall, Englewood Cliffs, NJ.