Application of principal component analysis (PCA) as a sensory assessment tool for fermented food products

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Abstract The objective of the work was to use the method of quantitative descriptive analysis (QDA) to describe the sensory attributes of the fermented food products prepared with the incorporation of lactic cultures. Panellists were selected and trained to evaluate various attributes specially color and appearance, body texture, flavor, overall acceptability and acidity of the fermented food products like cow milk curd and soymilk curd, idli, sauerkraut and probiotic ice cream. Principal component analysis (PCA) identified the six significant principal components that accounted for more than 90% of the variance in the sensory attribute data. Overall product quality was modelled as a function of principal components using multiple least squares regression ($R^2=0.8$). The result from PCA was statistically analyzed by analysis of variance (ANOVA). These findings demonstrate the utility of quantitative descriptive analysis for identifying and measuring the fermented food product attributes that are important for consumer acceptability.

Keywords Lactic cultures · Fermented foods · Quantitative descriptive analysis · Principal component analysis · ANOVA

Fermented foods are food substrates that are invaded or overgrown by edible microorganisms better known as ‘Probiotics’ whose enzymes hydrolyze the polysaccharides, proteins and lipids (Kristo et al. 2003) to non-toxic products with flavours, aromas and textures pleasant and attractive to the human consumer. Among the fermented food products dairy based fermented foods are used widely as healthy food and considered as important part of the diet (Nagata et al. 1998). The incorporation of probiotic bacteria (La Torre et al. 2003) as dietary adjuncts has given rise to increased consumption of probiotic products of Europe, the United States and Asia (Lambrecht et. al. 2007). Soymilk based fermented food i.e. soy curd may provide additional benefit for the consumer due to their hypolipidemic (Trindade 2001), anticholesterolemic, antiatherogenic properties and reduced allergenicity (Murti 2006). Consequently soymilk based yogurt offers a considerable appeal to a growing segment of consumers with certain dietary and health concerns (Messina et al. 1994; Lui 1997). However, recent addition of probiotic ice cream provides a numerous nutritional benefits in the context of B vitamins to the consumers and such fermented food product has arisen successfully in the market. Cereal based fermented product idli is a dietary supplement to the consumers. Idli is prepared by natural fermentation with the incorporation of probiotic bacteria into the blend that increased the nutritional quality of the processed idli. The changes during fermentation include an increase in free sugar, non protein nitrogen, free nicotinic acid in idli that also affect its physical properties like appearance, texture, flavor, aroma, acidity and overall acceptability. These are the most vital parameters from acceptability point of view by the consumers. In these studies, trained sensory panels and instrumental measurements were used together to draw conclusions and making decision on fermented food quality

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(Donkor 2007). Universal testing machine Instron (Model no. 4301) was used to determine the hardness in terms of compressive load and cohesiveness in terms of load of shear of the fermented foods that are directly related to the physical properties of the food samples. However, human subjects go beyond the physical component to describe wide range of factors involved in aftertaste sensations such as color and appearance, flavor, texture and acidity (Díaz and Navaza 2003). Sensory panels provide complementary information to instrumental method, and neither can be replaced. Previous studies have established a wide range of instrumental shear force values corresponding to different portions of the consumer texture scale, which enabled commercial processors to relate the meaning of instrumental compressive load, shear values in terms of relative toughness of curd and idli samples Lyon and Lyon, 1990; 1991; Stone et al. 1974; Stone and Sidel 1993, 2004, 2006, 2007.

The objective of this work was to use a multivariate statistical method, viz principal component analysis (PCA) (Massart et al. 1988; Naes et al. 1996), along with quantitative descriptive analysis (QDA) to analyze the variations of physical and sensory properties of fermented foods after fermentation. PCA operation makes it possible to distinguish the food samples and also to identify the most important variables in a multivariate data matrix (Díaz and Navaza 2003).

Materials and methods

Fermented food samples Fermented dairy products i.e. cow milk curd and soymilk curd, probiotic ice cream; cereal based fermented food idli and vegetable fermented food

sauerkraut were used in this study. The curd sample was prepared with the incorporation of lactic cultures (2% by volume) into the cow milk and soymilk and allowed to incubate at 37 °C temperature for 16 h; probiotic ice cream was obtained by addition of probiotic milk curd (14% w/w) to the ice cream mix before chilling and then was allowed to freeze to produce ice cream and was kept at −20 °C for preservation. Idli was prepared with the different blend ratio of rice and dal (2:1, 3:1 and 4:1) for different period of fermentation h; sauerkraut was prepared from cabbage with 2.5% salt which was fermented at 25 °C for 3 weeks.

Measurement of pH of food samples The pH of the fermented food sample was measured using a digital pH meter (model no. L1-120, Elico Pvt Limited; Hyderabad, India). The pH of the food samples was measured initially and at the end of the fermentation; for probiotic ice cream the pH was analyzed at different time intervals of storage. This measurement was performed in triplicate for each fermented food sample.

Quantification of organic acids The determination of total acidity in terms of lactic acid was performed by direct titration method.

The acidity of lactic acid was as calculated: 1 ml 0.1 (M) NaOH≡0.009 g of lactic acid.

Rheological measurements A 5 Newton load was applied to the load cell and the compressive load was measured from the highest peak of the graph generated by the Instron universal Testing Machine (model no. 4301) for each of the curd sample. The highest peak of the graph indicates the maximum compressive load of the curd sample. Table 1

Table 1 Compressive load and load of shear of cowmilk and soymilk curd and idli at different h of fermentation

Fermented food sample	Fermentation h	Compressive load (Newton)
Cow milk curd	8	2.1±0.1
	10	3.0±0.1
	12	3.6±0.2
	14	3.8±0.1
	16	4.2±0.2
Soy milk curd	8	0.8±0.1
	10	1.2±0.1
	12	1.6±0.3
	14	2.1±0.1
	16	2.6±0.3
Idli (rice : dal :: 2:1)	8	Load of shear (dimensionless)
	10	0.2±0.1
	12	0.3±0.1
	14	0.8±0.2
	16	0.6±0.2
		0.4±0.1

The experiment was done in triplicate

Here±indicates standard error

Fig. 1 Change in pH with fermentation h (at 43 °C) in cowmilk curd and soymilk curd inoculated with 2% inoculum (v/v) of *S. thermophilus*. (Solid line indicates cow milk curd and dotted line indicates soymilk curd) (The experiment was done in triplicate)

shows the compressive load of the curd sample and the load of shear incase of idli obtained through different period of fermentation. The load of shear was calculated by applying 5 Newton load in the load cell to determine the area under first highest peak (Area 1) of the compressive load and then the area under second highest peak (Area 2) of the compressive load. The ratio of the area 2 to Area 1 is the measure of load of shear (dimensionless).

Sensory analysis of fermented food samples To present the samples to the panellists, they were placed in white dishes, with blind codes with two digits, with stainless steel forks and knives. Each panellist in his/her white lighted booths received his/her samples in a random presentation order and answered the questions at their computers. Between the samples given the mouth was cleaned with water. To analyze flavor and texture the panellists put on their mouth an adequate amount of food samples. All the food samples were presented by pair evaluated in appearance, texture, flavor, mouthfeelness, acidity and overall acceptability.

Quantitative descriptive Analysis (QDA) 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. Panelists were recruited from the staff members of Dept. of F.T.B.E Jadavpur University with a focus to identify key product attributes and appropriate intensity scales specific to the 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 are analyzed statistically and then represented graphically.

Principal Component Analysis (PCA) 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

Fig. 2 Changes in pH and total acidity of different Blend ratios of polished parboiled Rice : Decorticated Black Gram, 2:1, 3:1 and 4:1) subjected to different period of fermentation (0,4,7,10,13,16,19 and 22 h) of Idli Batter. (The experiment was done in triplicate)

Fig. 3 Estimation of lactic acid in cow milk curd and soymilk curd (at 43 °C of incubation) at different fermentation h. (Solid line indicates soymilk curd and dotted line indicates cow milk curd) (The experiment was done in triplicate)

patterns of correlation among the original variables (Lawless and Heymann 1998). PCA of the fermented food samples was performed by the following method. Data were collected from the panellists after scoring through Hedonic rating scale. The data of various attributes stated above were arranged in ascending or in a descending order and put into the software SPSS 16 in data view mode. Then data were reduced by data analysis and the independent and dependent variables were selected and a two dimensional figure of the analysed sample was obtained.

Results and discussion

Change of pH in food samples The initial pH of soy milk was 7.3 and it was slightly higher than as previously reported and pH of soy curd was determined at different fermentation h at 43 °C incubation, and at the end of fermentation the pH

reported was 4.3. pH varies with the different period of fermentation h of milk curd and at the end of fermentation it was about 5.3 (Fig. 1). Fermentation was monitored upto 13 h and since prolonged incubation is usually not desirable for commercial production in the food industry, supplementation to improve fermentation time may be essential. In idli, pH varies from 4.2 to 5.9 with different period of blend ratio of rice and dal (Fig. 2). In sauerkraut the pH obtained was 3.4 after 3 weeks of fermentation.

Total acidity in terms of lactic acid The total acidity of fermented foods in terms of lactic acid was measured and it was found that in sauerkraut the acidity was 1.07% where as in milk curd with 0.5:1.5 ratio of inoculums of *S. thermophilus* and *L. plantarum* was 1.36% whereas in soy curd it was 0.58%, in idli acidity differs with the different blend ratio (Figs. 2 and 3) respectively.

Table 2 Means and Standard Deviations for color and appearance, body texture, flavor, mouthfeelness, acidity and overall acceptability of various fermented foods

Attributes	Food samples							
	C Soy milk	P Soy curd	C Cow milk	P Cow milk curd	C Ice cream	P Ice cream	Idli (formed after 10 h)	Sauerkraut
Color and appearance	7.6±0.11 ^a	7.8±0.10	7.8±0.10	7.96±0.10 ^a	7.2±0.02	7.8±0.01 ^a	7.2±0.04	6.5±0.03
Body texture	7.3±0.10	7.6±0.20	7.6±0.10 ^b	8.0±0.10	6.9±0.10 ^b	7.3±0.03	7.6±0.08 ^b	6.6±0.06
Flavor	7.3±0.14	7.4±0.10	7.3±0.16	7.9±0.10	7.4±0.16	7.6±0.11	7.4±0.17	6.9±0.04
Mouth feelless	7.3±0.06	7.6±0.01	7.2±0.06	7.8±0.10	7.2±0.61	8.2±0.10 ^b	7.6±0.16	6.7±0.08
Acidity	1.2±0.01 ^a	1.3±0.30	1.34±0.02 ^a	1.1±0.10	1.3±0.06	1.2±0.03	1.1±0.19	1.1±0.19
Overall acceptability	7.6±0.03	7.7±0.10	7.29±0.05	8.0±0.30	7.6±0.03	8.6±0.20 ^b	7.8±0.91	6.9±0.40 ^b

Means followed with the same superscript alphabet within each column are not significantly different. For the sensory attributes a 9 point Hedonic scale was used (9=like extremely, 1=dislike extremely); C Control, P Probiotic. The experiment was done in triplicate

Here±indicates standard error

Table 3 Component matrix of Fig. IV

	Component Matrix ^{a,b} (cow milk curd)						Component Matrix ^{a,b} (soy milk curd)					
	Component						Component					
	1	2	3	4	5	6	1	2	3	4	5	6
appearance	.958	-.223	-.119	.133	.026	.000	.967	.206	.050	-.117	-.082	-.014
texture	.973	-.121	-.115	-.158	.016	.007	.977	-.113	-.077	.154	-.057	-.015
flavour	.987	.133	-.079	.000	-.038	-.027	.978	-.138	-.136	-.064	.003	.043
mouthfeelness	.966	-.114	.228	-.019	.023	-.014	.992	.001	-.078	-.045	.081	-.038
acceptability	.990	-.103	.077	.023	-.046	.023	.911	-.367	.188	.000	.017	.005
acidity	.884	.466	.008	.023	.023	.011	.899	.422	.074	.077	.040	.021

^a 6 components extracted^b Only cases for which inoculum concentration=1 are used in the analysis phase

The experiment was done in triplicate

Rheological properties of fermented foods In Universal Testing Machine Instron, 20% of 100 Newton load along with 15 mm depth was used to measure the compressive load of curd samples and idli after different fermentation h. Table 1 shows the rheological values of fermented food products.

Sensory evaluation The sensory ratings of individual products for appearance, body texture, flavor, mouthfeelness, acidity and overall acceptability are considered in this case. The acid character described by flavor was associated with different bacterial growth as well as supplementation in some cases. For example, probiotic fermented food products are more acidic compared to the food products before fermentation. La Torre et al. (2003) made similar observation in yogurts made with commercial and starter cultures. For the appearance of all of the food products with exception of the control food samples mainly in curd which apparently had a weak gel after formation, most of the panellists declared ‘liked very much’. In addition panellists

observed that all of the fermented food samples did not show syneresis after fermentation and during storage at 4 °C. Liu also reported of appearance and physical properties of acceptance of soy yogurt by consumer panels. Panellists recorded significant differences ($p<0.05$) in mouth feel among the products and selected control ones and concluded that, fermented foods prepared from probiotic cultures as having better moth feel. The QDA only for fermented soy milk (soy curd) here described in this paper. In this experiment the QDA of fermented milk product (curd) was performed by scoring through Hedonic rating scale and the traditionally sour curd having slightly acidic flavor with very smooth body surface, smooth mouthfeelness and white in color, having excellent consistency was considered to be ‘Like extremely’ and was scored as 9 i.e. the highest score was obtained by the panelists in this case of curd sample and by this way the gradual scoring was performed from 8-1 in the following manner: smooth surface, moderate acidic flavor, good

Fig. 4 Cow milk and soy milk curd inoculated with 2% inoculum (v/v) of *S. thermophilus*. (The experiment was done in triplicate)

consistency, and white colored curd was considered to be 'Like very much' and was scored 8, slightly rough surface having fair consistency curd sample was considered to be 'Like moderately' and was scored 7, rough surfaced, containing coarse particulate matter, more acidic, slightly yellowish in color curd was considered to be 'Like slightly' and was scored 6, butter like flavor, more acidic, intensely yellow in color, loose consistency curd was considered to be 'Neither like nor dislike' and was scored 5, having intense acidic flavor, not soothing for mouth feel curd was considered to be 'Dislike slightly' and was scored 4, loosened structure, ill smelled, dark yellow to greenish colored curd was considered to be 'Dislike slightly' and was scored 3, oily upper layer, unacceptable in taste was considered to be 'Dislike very much' and was scored 2 and the curd sample with deep green in color, completely distorted consistency, extremely bad flavored was considered to be 'Dislike extremely' and was scored as 1 i.e. the lowest score was obtained by the panelists.

Table 2 determines the description terms, definitions and materials used for quantitative descriptive analysis of fermented food products.

PCA of sensory attributes of fermented food products A software of SPSS version 16.0 was used to analyze the sensory attributes of fermented food products by using Principal Component Analysis (PCA), and maximum variance was found to be obtained at 98% and from this PCA score, it can be concluded that this type of fermented food products are acceptable for consumption. A two dimensional analysis of the Principal component was attempted using the component data matrix shown in Table 3. Two principal components namely PC 1 and PC 2 were extracted that accounted for 57.6% of the variance and 11.6% of variance respectively in six variable systems in case of cow milk curd prepared from 2% v/v of *S. thermophilus* (Table 3) and 57.2% of the variance and 12.5% of variance respectively in six variable systems in case of soy milk curd prepared from 2% v/v of *S. thermophilus* (Table 3). Maximum weightage was found in case of PC 1, in both case of cow milk and soy milk curd i.e., 57.6 % and 57.2% respectively of variation. Therefore, two dimensional component plots have been generated only for PC 1 and PC 2 as shown in Fig. 4. A one way ANOVA test was performed to determine whether any significant difference occurred in the food sample during fermentation and storage or not from difference in the mean values occurred in the same row (Table 2).

Conclusion

From the entire experiment it can be concluded that, Principal Component Analysis is very essential for ana-

lyzing the acceptability of fermented food samples and here, the overall acceptance of curd sample is dependent on the various attributes namely appearance, texture, flavour, mouthfeelness and also its acidity. From Fig. 4 and Table 3. 5 it can be concluded that the body texture of fermented food samples can be considered to be the principal attribute. On the other hand, the physical quality of the fermented food samples namely compressive load and load of shear are essential criteria for its acceptance as it is related to body texture.

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