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RESEARCH PAPER

Correlations among Instrumental Textural Characteristics, Sensory Score and Solids Content of *Dahi* – An Indian Fermented Milk Product

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ABSTRACT

The relationship among total solids content, textural and sensory parameters of *dahi* was investigated and reported here. The total solids (TS) content of fresh skim milk was adjusted to 9, 12, 15, 18, 21 and 24% using spray dried-skim milk powder. *Dahi* was prepared from these milks with adjusted TS and were chilled to 5°C. Firmness, consistency and viscosity index of *dahi* samples, measured by texture analyzer, showed a general increasing trend with increasing %TS in milk. Sensory scores were the highest at 15% TS. The TS content, texture and sensory quality were interdependent and instrumental texture parameters highly influenced the sensory scores. By univariate analysis, sensory score showed a linear relation with consistency and firmness exhibiting low RMS values. Relationships were much better with multivariate analysis as indicated by multiple regression involving consistency, firmness, viscosity index and their products indicating that the sensory acceptance of *dahi* is dependent on more than one textural parameter.

Keywords: Solids content, Sensory score, *Dahi*, Textural characteristics, Fermented dairy product, Instrument

In India, which is the largest milk producing nation in the world, the annual milk production is 133.54 million tons (2013 estimates) (FAO, 2015) out of which 6.9% is used for the production of fermented products, in which *dahi* occupies a major proportion. *Dahi* is prepared from pasteurized or boiled milk by souring with natural microflora or by the inoculated lactic acid bacterial culture. *Dahi* contains the same amount of total solids as that of milk from which it is made. Its chemical composition is very similar to another popular fermented product, yoghurt.

Two types of *dahi* are sold in market namely set and stirred type. Most of the *dahi* sold in market is of stirred type because of convenience in its manufacture, marketing and consumption. However, many consumers prefer firmly set curd. Set type *dahi* is sold in polystyrene and HDPE cups. *Dahi* prepared from buffalo milk has a firm body with a slightly soft granular texture whereas that prepared from cow milk is softer, slightly yellowish and has smoother texture. These differences are attributed to the variations in protein make up as well as carotene contents (colour) between cow and buffalo milk. The texture of *dahi* can be assessed by sensory or instrumental analysis. Many factors were found to be responsible for the texture and microstructure of *dahi* viz. milk total solids, fat content, culture addition, fermentation time, temperature and manufacturing process including heat treatment. Among these factors, milk total solids was reported to be most important (Bhattarai and Lal Das, 2013). Total solids in *dahi* varies from 12.93 to 15.73% (Younus *et al.*, 2002).

Relationships between subjective and objective responses have been studied by many researchers, for example between textural properties and sensory acceptance (Meullenet *et al.*, 1998; Skriver *et al.*, 1999; Drake *et al.*, 1999), and chemical characteristics and sensory properties (Janhoj *et al.*, 2006). Correlations between sensory score and instrumental textural parameters in food products has been a subject of immense interest and studied and reviewed by many workers (Szczesniak *et al.*, 1963; Breuil and Meullenet, 2001). Establishing a mathematical relationship will provide us explanations about product characteristics and help in wholistic quality evaluation of the products. Few papers are available describing the comparison of sensory and instrumental methods of textural analysis of semisolid food products such as yoghurts and *dahi*. The present study was conducted to analyse the correlations and variations in rheological and sensory characteristics of the *curd* as influenced by the levels of total solids in milk.

MATERIALS AND METHODS

Raw materials

Skim milk (9% TS) was procured from the Experimental Dairy of the Institute. Skim milk powder (SMP, Sagar Brand) was purchased from the local market.

Cultures

Dahi culture (*Lactococcus lactis* sub sp. *lactis* and *Lactococcus lactis* sub sp. *diacetylactis)* required for the preparation of *dahi* was obtained from the Dairy Microbiology Unit of the Institute.

Preparation of dahi

Skim milk (1.25 kg) was warmed to 40-45°C to which skim milk powder (SMP) (250 g) was slowly added and dispersed in the warm milk. The mixture was filtered through a muslin cloth to separate out un-dissolved lumps of the powder. These were again made into paste using little quantity of milk and passed through the muslin cloth. The milk obtained after complete filtration through muslin cloth was termed as concentrated milk (24.2% TS). The concentrated milk was diluted with distilled water to get TS levels of 12.6, 15.5, 18.4 and 21.3%. Skim milk used contained 9% TS. The milk samples (250 g each) were pasteurized at 63°C for 30 minutes by keeping them in water bath followed by cooling. After pasteurization, the contents of the beakers were cooled to 37°C. Starter culture was then, added to individual beakers by a sterile pipette, @ 1% of milk, i.e. 2.5 ml in each beaker. The inoculated milk from each beaker was transferred equally to two 100 ml – capacity polystyrene cups under hygienic conditions, one meant for analysis by texture analyser as well as sensory evaluation and another by cone penetrometer. The cups were then, marked and kept in an incubator for about 16 h at 37°C. After setting, the *dahi* was transferred to a refrigerator (5°C) and kept till further analysis. The *dahi* was evaluated for sensory, rheological and physico-chemical attributes.

Sensory analysis of *dahi*

For sensory analysis, a 9-point Hedonic scale by an expert panel was adopted. It is common notion that Hedonic scale should only be used by consumer panels, however in this study, this scale was considered as single continuum of likes and dislikes and as balanced bipolar scale around neutral center with four positive and four negative categories on each side (Periyam and Pilgrim,1957). The evaluation panel consisted of 10 persons trained in sensory evaluation of *dahi*. The persons included motivated and interested staff of the Institute and graduate students who were already well versed with quality aspects of *dahi* as it is regularly consumed item in the diet in most parts of India. Taste panels were conducted between 11.30 A.M. and 1.00 P.M.

The order of sample presentation in chilled condition to individual panelists was randomized. Samples were presented in duplicate. Panelists were asked to cleanse their palates with warm water after each tasting. The product attributes namely colour and appearance, flavor, body and texture and overall acceptance were rated on a 9-point hedonic scale, where 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely (Lawless and Heymann, 1999).

Rheological analysis of dahi

Firmness, consistency and viscosity index were measured using TA-XT Texture analyzer (Stable Microsystems, UK) (Plate 1) with the help of Texture Exponent 32 programme.

Plate 1: Texture analyser

An aluminium cylindrical probe (p/25) supplied by the manufacturer of the instrument was used for the analysis. The principle of operation of the Texture Analyzer is that the cylindrical probe (p/25) penetrates into *dahi* sample up to a predetermined distance (10 mm) during which it senses a resistance force which is directly proportional to the firmness of the set curd. The resistance offered by the *dahi* samples to the probe during the penetration was measured as the firmness (gm) of the curd. The area under the positive peak of the curve was measured as the consistency (gm-sec) of the curd and the area under the negative peak was measured as the viscosity index (gm-sec) of the curd. The viscosity index i.e. the area of negative peak is the reflection of total work done by probe during its withdrawal from the curd during the test (Bourne, 2002).

Hardness of *dahi* was also measured using cone penetrometer (Plate 2). Penetrometer is a simple instrument specially developed for measuring the hardness of fats crystalline in nature (DeMan *et al.*, 1976).

Plate 2: Cone penetrometer

However, this instrument was also used to measure the hardness of various other products. The principle of penetrometer is that when the cone is allowed to freely fall onto the product, it penetrates into the product and comes to stop when the resistance offered by the food equals the yield stress of the product (DeMan *et al.*, 1976). So the penetration value not only reflects hardness but also is a measure of the yield stress of the product. For the same reason, the depth of penetration can also be converted to hardness value in terms of kg per cm^2 (DeMan *et al.*, 1976). The depth of penetration of the rubber cone was converted into hardness value (H) (kg cm^{-2}) using the following formula (Sherman, 1979):

$$H = \frac{G * 10^{-3}}{\left[\pi h \left(\frac{\tan\alpha}{\cos\alpha}\right)\left(h + \frac{2r}{\tan\alpha}\right) + \pi r^2\right] * 10^{-4}}$$

where,

'h'	=	depth of cone penetration in the curd in mm
α	=	cone angle
r	=	radius of cone
G	=	weight of cone assembly

For measurement of extent of syneresis, the chilled *dahi* at 5°C was transferred carefully to 15ml centrifuge tubes using a spatula taking care to allow only minimum disturbance to the coagulum. The tubes were tightly capped and centrifuged in Remi centrifuge at 2000 rpm for 10 minutes. The whey separation was noted from the scale on centrifuge tube. The average of whey separation in the two tubes was recorded. The quantity of whey separated is directly proportional to the syneresis.

Correlation analysis

Pearson's correlation coefficient (r) which is a measure of the strength of the association between the variables was first computed using MS-Excel software. The following correlation analyses were done between the following: Firmness (Texture Analyser) *Vs* Sensory score; Firmness (Penetrometer) *Vs* Sensory score; Viscosity index *Vs* Sensory acceptance; Consistency *Vs* Sensory score; Viscosity index *Vs* Per cent TS; and Sensory viscosity *Vs* Per cent TS. The paired data were fitted to the following regression equations using MS Excel programme (2007 version):

Univariate linear regression models were:

Linear-linear : $Y = a + bx$

Linear-log : $Y = a+b. \ln x$

Linear-exponential: $Y = a.e^{bx}$

linear-power: $Y = a.x^b$

Polynomial 2nd order: $Y= b_0+b_1X+b_2X^2$

3rd order: $Y = b_0+b_1X+b_2X^2+ b_3X^3$

4th order: $Y = b_0+b_1X+b_2X^2+ b_3X^3+ b_4X^4$

5th order: $Y = b_0+b_1X+b_2X^2+ b_3X^3+ b_4X^4+ b_5X^5$

Multiple linear regression models were:

Two variables : $Y = b_o+b_1X_1+b_2X_2$

Three variables: $Y = b_o+b_1X_1+b_2X_2+b_3X_3$

Three to seven variables including interactions:

$Y = b_o+b_1X_1+b_2X_2+b_3X_3+b_4X_1.X_2+ b_5X_1.X_3+ b_6X_2.X_3+ b_7X_1.X_2.X_3$

where,

Y= response, X_1 = first variable, X_2 = second variable etc.

Y = Instrumental or Sensory viscosity

X = Sensory or Instrumental viscosity or % TS

a, b, b_0 , b_1, b_2, b_3 = Regression coefficients

The goodness of fit was evaluated by R^2 as well as RMS (Root Mean Square) value. The R-squared value means that its product with 100 indicates the percent variation that can be explained by the variable under consideration. The intercept in a multiple regression model is the mean for the response when all of the explanatory variables take on the value 0. Regression coefficient of a variable is interpreted as the change in the response based on a 1-unit change in the corresponding explanatory variable keeping all other variables held constant.

The goodness of fit of model under study was determined by computing RMS value. The lower the RMS value, the better was the goodness of fit. RMS value of less than 10.0 was considered as a good fit (Sawhney *et al.*, 1994). RMS was determined by the following equation (Sawhney *et al.*, 1994):

$$\mathrm{RMS} = \sqrt{\frac{\sum_{i}^{N}\left\{\left(wi - wi^{*}\right)/wi\right)^{2}\right\}}{N}} \times 100$$

where,

Wi = experimental observations

Wi*= calculated parameters

N= number of observations.

Statistical analysis

Data from instrumental and sensory evaluation were analyzed statistically using analysis of variance, F-test, t-test, correlation, and regression analysis using SPSS and Excel software. Most of the data were fitted into linear, exponential, or polynomial curves. All the equations for the fitted curves are not shown, but their corresponding R^2 values are provided.

Experiments were conducted in completely randomized design and the data were analysed by one ANOVA technique using SPSS software. Post Hoc tests of Tukey were carried out to determine the significant difference between any two treatments.

RESULTS AND DISCUSSION

Effect of total solids content on textural attributes of dahi

The textural attributes, viz. consistency, firmness and viscosity index, of *dahi* were significantly altered by increase in total solids content of milk from which it was prepared (Fig. 1 a-d). There was a statistically significant increase in the consistency after 18% TS (Fig.1a). These observations are attributed to decreasing moisture content with increasing TS level (Becker and Puhan, 1989). Curd particles are densely packed adhered together by denatured whey proteins. However, there was no significant difference between 21% and 24% TS levels. The firmness measured by texture analyser or cone penetrometer followed similar trend.

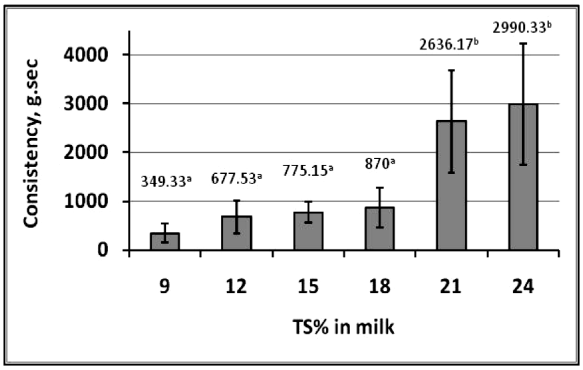
There was no significant change in firmness up to 15% TS level (Fig.1b) or 18% TS level (Fig.1c). The increase in firmness with TS was not linear, but stepped up with increase in TS ($P<0.05$). Maximum hardness was observed with the sample containing 21 % – 24% TS. The milk solids enhance the viscosity and stability of the curd (Baker *et al.*, 2012), hence alter textural characteristic of *dahi*. Bhattarai and Lal Das (2013) further noted that the higher the TSS of milk, better the texture of *dahi*. Similar observation was recorded in this study.

The trend of viscosity index is that of an overall increase with the increase in % TS (Fig.1d). The viscosity index gradually increased with TS% and at 24% TS, there was a slight decrease. This shows that *dahi* became more viscous with increasing TS%. This is attributed to decreasing water content in the samples and production of more mucilaginous compounds in the samples by microorganisms. Increased yogurt viscosity with the total solids content of milk was also observed by Wacher-Rodarte *et al.* (1993). The oral viscosity of yogurt or perceived thickness also reportedly increased with an increase in total solids content of milk (Skriver *et al.*, 1999).

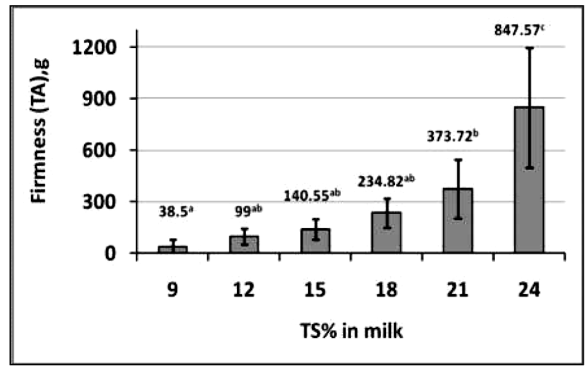
As TS content, especially protein content, increases the moisture availability decreases, hence firmness and consistency increases (Meena *et al.*, 2015). Increasing total solids especially proteins may be responsible for more production of exoplysaccharides resulting in firmer binding of coagulated casein particles (Zisu and Shah, 2003). This can also be seen in the increased viscosity index in high TS samples.

Effect of total solids content on sensory quality attributes of dahi

The overall acceptability was maximum for the sample containing 15 %TS. In the samples containing higher % TS, the sensory panelists were able to detect the presence of powdery flavour. However,



(a)



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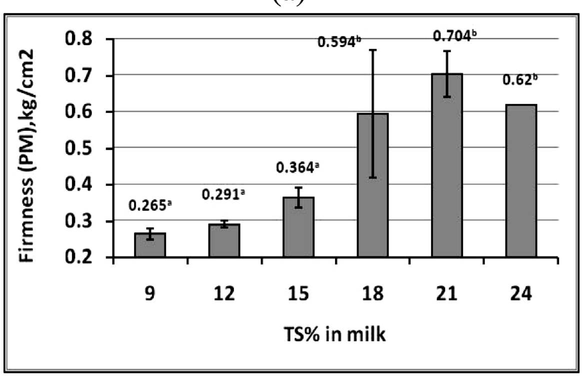
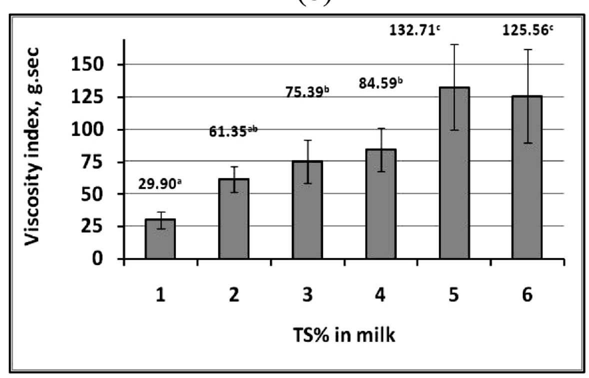
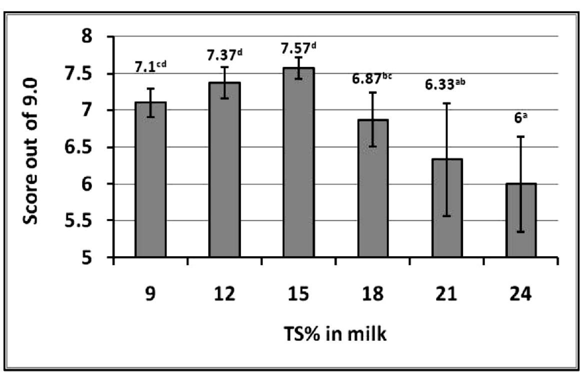


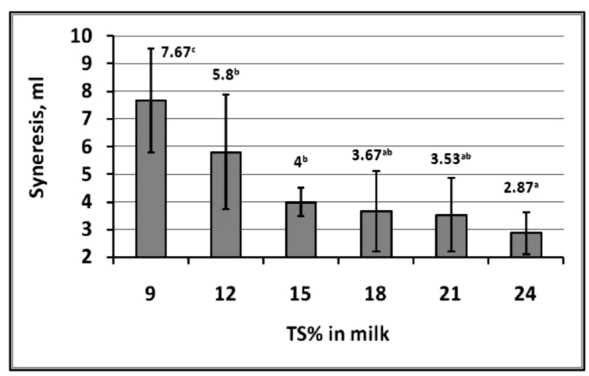
(c)



(d)



(e)



(f)

Fig. 1: Instrumental rheological properties and sensory acceptance score of *dahi* as influenced by TS% in milk (means of three replications and test performed in triplicate) (a) consistency (b) firmness(texture analyser) (c) firmness(penetrometer) (d) viscosity index (e) sensory score (f) syneresis

the flavor of SMP was able to mask the acidic tangy taste of *dahi*. The overall acceptability of 21% and 24% TS samples were significantly different from that of the control. Acceptability was least at 24% TS due to the sample having an excessively firm body and a very pronounced flavor of SMP which was devoid of the characteristic pleasing flavor of *dahi* (Fig.1e). The OA score for 9% TS *dahi* was 7.1 which increased to 7.37 and 7.57 by increasing the TS to 12 and 15% respectively. This decreased to 6.87, 6.33 and 6.0 at 18, 21 and 24% TS respectively. The trend followed a hyperbolic relationship, which was explained by Bourne (2002). At 15% TS, the *dahi* possessed good firmness which found favour with the judges. More than 15% TS though produced firmer *dahi*, did not much appeal to judges as they felt it was too firm. In the market, however, *dahi* made from toned milk (11.5% TS) is popularly sold; now it is recommended that the TS be increased to 15%TS for obtaining better BT attributes. Statistical analysis showed that the sensory acceptance did not change till 15%TS, but thereafter it significantly decreased (P<0.05). Chukki *et al.* (2013) reported that yoghurt prepared from 23% TS milk had low acceptability because of hard body and granular texture.

Effect of total solids content on syneresis of dahi

Whey separation (wheying-off) is defined as the expulsion of whey from the network which then becomes visible floating on the surface. Extent of syneresis is indicative of the quality of *dahi*. Consumers prefer *dahi* with no visible whey separation. Presence of separated whey indicates excessive fermentation and long stored *dahi*. So consumers tend to think that the curd showing whey separation is not fresh and hence not good. However, when well set curd is disturbed, the whey flows through the channels in the network and finally separates out. As TS increases, it holds more water, so the curd firms up and exhibits lower syneresis. Guler-Akin and Korkmaz (2009) identified total solid content as a major factor affecting whey syneresis which was found to negatively correlate with whey syneresis in yoghurts.

Syneresis of the curd followed a decreasing trend as the % TS of the *dahi* samples increased. Syneresis of all the samples differed significantly from that of the control sample (Fig.1f). The syneresis values were 7.7, 5.8, 4.0, 3.7, 3.5 and 2.9 ml respectively for 9, 12, 15, 18, 21 and 24% TS. This may be attributed to decreasing available water content in *dahi* with the increase in TS content. Statistical analysis showed that there was a significant decrease in syneresis when the TS% increased from 9% to 12% TS, but thereafter there was no significant change in syneresis up to 21%TS. There was a considerable decrease in syneresis shown by 24% TS sample (P<0.05).

Wheying-off negatively affects consumer perception of yogurt as consumers think there is something microbiologically wrong with the product. Hence, lack of visual whey separation is a crucial aspect of overall sensory consumer acceptance (Lee and Lucey, 2010). Yoghurt manufacturers use stabilizers, such as, pectin, gelatin and starch, to try to prevent wheying-off (Chandan and O'Rell, 2006). Another approach is to increase the total solids content of yogurt milk, especially the protein content, to reduce wheying-off. Spontaneous syneresis, which is contraction of gel without the application of any external force (e.g., centrifugation), is the usual cause of whey separation (Lucey *et al.*, 1998a). Spontaneous whey separation is related to an unstable network, which can be due to an increase in the rearrangements of the gel matrix or it can be induced by damage to the weak gel network (e.g., by vibration or cutting) (Lucey *et al.*, 1998a). The extent of rearrangement that occurs is related to the dynamics (average life-time) and relaxation of the protein-protein bonds as expressed in terms of the life time and to the resistance to yielding of the casein strands (Lucey, 2001). In this test, surface whey that is expelled from acid milk gels is gently poured off and quantified. This test has been used to evaluate whey separation in set-type yogurt gels (Lee and Lucey, 2006). Varghese and Mishra (2008) studied syneresis of *dahi* containing 14.5 – 15% TS. Several workers reported decreased syneresis in yoghurt with increasing TS content (Guler-Akin and Korkmaz, 2009; Harwalkar and Kalab, 1986; Jaros *et al.*, 2002). These results corroborate with the results obtained in the present study.

Correlations between sensory score and instrumental textural parameters

It was observed that as the TS increased, the sensory scores first apparently increased and then decreased significantly. Similarly there were changes in instrumentally measured parameters like consistency, viscosity index (VI), firmness and syneresis. Whether changes in instrumentally measured parameters show any relationship with sensory scores will be of interest, because by this way instruments can be calibrated for assessing *dahi* quality. Results in Table 1 indicate some of these correlations. It may be observed that TS had positive relation with all the parameters except sensory score and syneresis, and sensory score (OA score) had negative relation with all parameters except syneresis. Positive relationship of sensory score with syneresis may be explained by the negative influence of other parameters. As regards effect of TS, the highest r value was obtained for TS – VI (0.94) relationship, followed by TS-Syn (0.92), TS-FPM (0.92) and TS-con (0.91) relationships. As regards sensory acceptance score, its relationship with all the instrumental parameters was found to be fair, the best being with consistency measured by texture analyser. This can be understood because *dahi* texture depends on how balanced the culture organisms grow and how they respond to the changes during fermentation as similarly reported for yoghurt production (MacBean *et al.,* 1979).

Modeling of dependence of instrumental rheological characteristics and sensory score on total solids content

The data of TS and corresponding consistency, FTA, VI, SS, Syn and FPM were fitted to available models in Excel software and goodness of fit was checked by R^2 and RMS values. In general, it was seen that as the model tended to polynomial and with increasing order, the R^2 values got better and better as indicated by lower RMS values; the fitting at higher than 2nd order was not considered because of their complexity. The best models that were picked based on least RMS values were: TS-VI (9.75)- linear – log model; TS-SS (3.61) – polynomial second order; and TS-Syn (6.63) – power model. All the models that resulted in less than 10 RMS values are listed in Table 2. Binomial models are more preferred to describe the relationships, though polynomial second order showed better RMS values. Residual plots display the goodness of fit of the selected models, one for each attribute displayed in Fig. 2a.

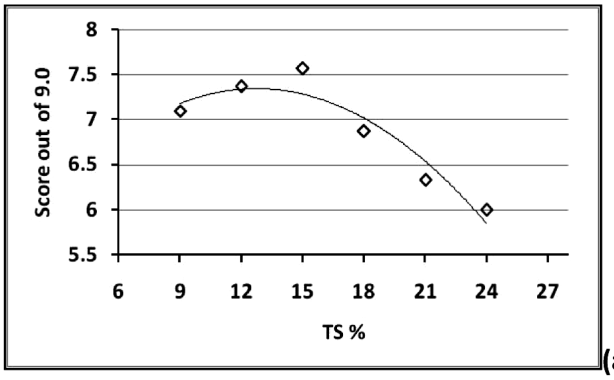
Total solids vs Textural characteristics

Total solid (TS) content was found to have a good positive correlation with viscosity index (VI) and syneresis as indicated by RMS values within less than 10 (Table 2). It means that as the TS increased VI also increased. This is as expected because more solids content means more production of mucilaginous compounds (Amatayakul *et al.,* 2006). However, it is surprising that TS content did not exhibit good predictability of consistency, firmness and penetrometer-hardness. Although it is expected that increasing TS should increase firmness and consistency, its low R^2 and high RMS values indicate complex nature of curd fermentation. Of course, R^2 and

Table 1: Correlation matrix

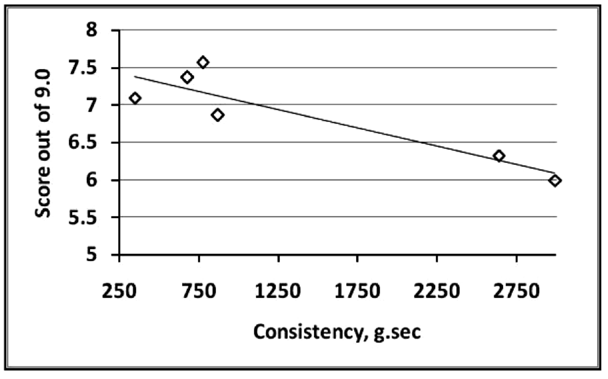
	SS	TS	Con	VI	FTA	FPM	Syn
SS	1						
TS	-0.82092	1					
Con	-0.90378	0.909332	1				
VI	-0.72956	0.942618	0.890914	1			
FTA	-0.87274	0.891376	0.903073	0.743574	1		
FPM	-0.81734	0.919323	0.82156	0.917339	0.705303	1	
Syn	0.543193	-0.92395	-0.71896	-0.89856	-0.71408	0.82731	1

Note: (SS=Sensory score; TS = Total solids %; Con=Consistency; VI = Viscosity index; FTA = Firmness by texture analyser; FPM = Firmness by penetrometer; Syn=Syneresis)



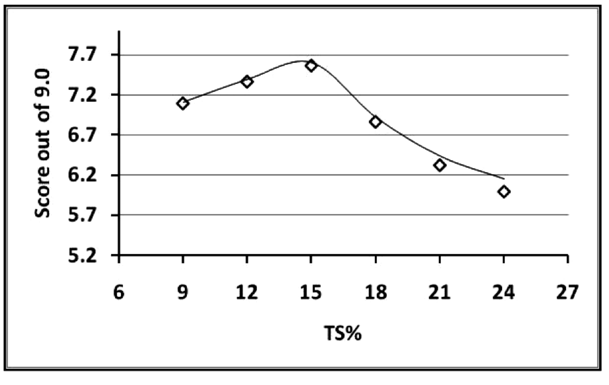
(a)

$$\text{Sensory score} = -0.0118(TS^2)+0.3015(TS)+5.4289$$
(RMS 2.51)



(b)

$$\text{Sensory score} = (-0.0005)\,Con + 7.5463$$ (RMS 3.28)



(c)

$$\text{Sensory score} = 3.5175+ Con(0.0125)+ FTA(0.1142)+ VI(-0.1632)+ Con.FTA(-0.000004)+ FTA.VI(-0.00141)$$ RMS 1.27

Fig. 2: Residual plots of some of selected best fit models for dependence of sensory score on (a) TS content of milk and (b) and (c) textural parameters analysed by Texture Analyser. (TS=total solids%; Con=consistency; FTA = firmness by texture analyser; VI = viscosity index;RMS = root mean square)

Table 2: Best fit* models for instrumental rheological characteristics' and sensory score dependence on total solids content

	Equation	RMS
VI	$= 71.57 \ln(TS)^{-131.75}$	9.75
	$= -0.18349(TS^2)+10.649(TS)-55.832$	9.88
SS	$= -0.0118(TS^2)+0.3015(TS)+5.4289$	2.51
	$= 0.0016(TS^3)-0.0896(TS^2)+1.5129(TS)-0.4488$	3.61
	$= -0.0888(TS)+8.3379$	4.4
	$= 8.5296\, e^{-0.013(TS)}$	4.6
Syn	$= 63.054\, (TS)^{-0.974}$	6.63
	$= 0.0252(TS^2)-1.1275(TS)+15.677$	7.68
	$= -0.0023(TS^3)+0.1404(TS^2)-2.9235(TS)+24.391$	7.73
	$= 12.015\, e^{-0.062}(TS)$	9.91
FPM	$= -0.0007(TS^3)+0.0338(TS^2)-0.4813(TS)+2.3799$	6.25

Note: Goodness of fit: RMS value <10.0 was considered as satisfactory
(VI = viscosity index; TS = total solids%; SS = sensory score; Syn=syneresis ; FPM = firmness by penetrometer)

RMS need not be always correlated, for example, for TS-consistency, R^2 was high (0.92), but RMS was also very high (23.58). Similarly, for TS-FTA, polynomial third order R^2 ranged from 0.96 – 1.0, but RMS was high between 11.33 – 52.00. In general, compared to the binomial models, polynomial equations gave a better R^2 values, but not always low RMS values. For a model to fit best, R^2 value should be high and RMS value should be least. R^2 value indicates a good fit of model, whereas low RMS value indicates a good predictability. For a model, both are very important.

Total solids vs Sensory score

TS –SS showed a low RMS value (4.4), but also showed a low R^2 value for linear and exponential binomial models. But polynomial 2nd order and third order models showed a high R^2 as well as low RMS values indicating a good fit in all respects. But a third order model is inconvenient for use. This is because, TS level up to a certain level (15%) showed a good acceptance, but thereafter decreased. Hence, polynomial equation fitted better than other binomial models. Bourne (2002) stated that sensory score has an inverted 'U' relationship with textural attributes, as also observed in the present study. Skriver *et al.* (1999) modeled non-oral and oral viscosities of stirred yoghurt by partial least squares regression, resulting in a three component model explaining 83·8% of the variation in non-oral viscosity and a two component model explaining 82·0% of the variation in oral viscosity. Non-oral viscosity was highly correlated with the complex modulus (G^*) from the dynamic oscillatory measurements (r=0·823) and the viscosity obtained from a Brookfield viscometer (with Helipath stand) operating at 5 rev./min (r=0·862).

Modeling of dependence of sensory score on instrumental rheological characteristics of dahi (univariate linear regression)

The data of sensory score and corresponding instrumentally measured rheological characteristics were fitted to various models available in MS Excel software. However, no efforts were made to improvise any model. It was observed that most of the fittings were not significant. Even polynomial models of higher orders were not a proper fit with very high RMS values. Sensory score showed good regression with consistency measured by Texture Analyser with RMS values ranging from 3.28 – 4.79. Sensory score also showed a good fit with TA-firmness (RMS value 3.91 and 3.96) and firmness measured by penetrometer (RMS value 4.79). Best fit models are delineated in Table-3. Residual plots presented in Fig.2b show that the scatter points more or less surrounded the trendline uniformly, which is the reason for low RMS values, but also lower R^2

values. For a model to be of any practical utility, high R^2 value and low RMS values are required.

Modeling of dependence of sensory score on instrumental rheological characteristics of dahi (multiple linear regression)

In the univariate linear regression it was observed that sensory score showed a good predictability with consistency, FTA and FPM with RMS values 3.28 – 4.79 (Table 3). Whether multiple linear regression would further improve predictability was verified by introducing two or more parameters (up to seven) into the model by multiple regression.

Table 3: Best fit* models for dependence of sensory score on instrumental rheological characteristics of *dahi* (simple univariate linear regression)

	Equation	RMS
SS	= (- 0.0005) Con + 7.5463	3.28
SS	= 7.5767 e^{-7E-05} (Con)	3.37
SS	= (-0.602) ln Con + 11.058	4.33
SS	= 12.83 $(Con)^{-0.09}$	4.49
SS	= (-0.0018) FTA + 7.3876	3.91
SS	= 7.4015. e^{-3E-04} (FTA)	3.96
SS	= (-2.6297) FPM + 8.1172	4.79

Note: Goodness of fit: RMS value <10.0 was considered as satisfactory
(SS= sensory score; Con=consistency; FTA = firmness by texture analyser; FPM = firmness by penetrometer)

It was observed that any two rheological parameters together used in the model did not improve the model performance indicated by model's non-significance or low R^2 values. However, when three characteristics were used, the model improved significantly (consistency+viscosity index+firmness measured by penetrometr; Syneresis+firmness measured by Texture Analyser + Firmness measured by penetrometer) as shown by R^2 values of 0.97 and 0.99, and RMS values 9.78 and 2.6, respectively. Four parameter model did not show any significance, whereas introducing more number of variables into the model enhanced the predictability. For example, consistency, FTA, VI and their products gave a good fit giving an R^2 value of 1.0 and RMS values ranging from 1.27 – 8.86, showing that the sensory score of *dahi* is dependent on not one textural parameter, but on all the three parameters studied. The best fit models are listed in Table 4 and the residual plot for the best model is displayed in Fig.2c.

Table 4: Best fit* models for dependence of sensory score on instrumental rheological characteristics of *dahi* (multiple linear regression)

	Equation	RMS
SS	= 3.5175 + Con(0.0125) + FTA(0.1142)+ VI(-0.1632) + Con.FTA (- 0.000004) + FTA. VI(-0.00141)	1.27
SS	= 7.448 + Con (-0.001) + VI (0.026) + FPM (-2.901)	9.78
SS	= 9.83 + Syn(-0.251) + FTA(-0.002) + FPM (-2.837)	2.6
SS	= 10.591 + Con(- 0.01642) + FTA(0.0) + VI(0.0) + Con.FTA (0.0000893) + Con.VI (0.000219) + FTA.VI(-0.00052) + Con.FTA.VI (-0.00000089)	4.75
SS	= -7.04537 + Con(0.083134) + FTA(0.083) + VI(-0.563) + Con.FTA(-0.000047) + Con.VI (-0.00051)	3.05
SS	= 5.938 + Con(0.01371) + FTA(-0.0066) + VI (- 0.1704) + Con.FTA (0.000067) + Con.FTA. VI(-0.00000084)	2.7
SS	= 3.6528 + Con(0.01255) + FTA(0.10742) + VI (-0.16357) + FTA.VI(-0.00133) + Con.FTA.VI (-0.000000047)	1.59
SS	= 4.4969 + Con(0.00593) + FTA(0.1171) + VI(-0.12611) + Con.VI (0.000048) + FTA.VI (-0.00154)	3.08
SS	= 5.383 + FTA(0.1197) + VI(-0.0926) + Con. FTA (0.0000036) + Con.VI(0.000091) + FTA. VI(-0.00166)	2.15
SS	= 7.9771 + VI(-0.0929) + Con.FTA(0.000075) + Con.VI (0.0000993) + FTA.VI(- 0.00028) + Con.FTA.VI(- 0.00000084)	8.86
SS	= 10.591 + Con(-0.01642) + Con.FTA (0.000089) + Con.VI (0.000219) + FTA.VI (-0.00052) + Con.FTA.VI(- 0.00000089)	10.23

Note: Goodness of fit: RMS value <10.0 was considered as satisfactory
(SS = sensory score; Con=consistency; VI = viscosity index; Syn=syneresis; FTA = firmness by texture analyser; FPM=firmness by penetrometer)

Sensory Score (SS) showed a fairly good relationship with consistency with an R^2 of 0.82 and 0.83 with corresponding 3.28 and 3.37. However, SS did not show good correlation with other attributes. Though RMS was low, R^2 was also low. SS is a complex phenomenon in which acceptance score is awarded by judges taking into consideration all sensory attributes in a wholistic manner. So, the score need not show a linear correlation with the textural attributes. Though polynomial orders showed high R^2, the same was mostly not significant. Narayana and Gupta (2013) also studied correlation between sensory scores and acidity of yoghurt employing Pearson's correlation and reported 'r' values up to 0.896. In the present study the 'r' values obtained were up to 0.92.

The sensory score exhibited a complex relationship with textural attributes, because two parameter multiple regression was not significant. Even three parameter multiple regression was not significant except two combinations: Con-VI-FPM & Syn-FTA-FPM. This shows penetrometer also yielded reliable results. These yielded R^2 values of 0.97 and 0.99 with corresponding RMS of 9.78 and 2.6. Introduction of more parameters in the model enhanced adjusted R^2 value of multiple regression. For example, Con-FTA-VI with their product combinations yielded highest R^2 of 1.0 and least RMS of 1.27 giving a best fit. Five to eight parameter multiple regression yielded good fit showing high R^2 and low RMS values. Patil *et al.* (1990) studied relationships between sensory texture descriptors and Instron texture profile (TP) parameters for *khoa* (a semi-solid Indian dairy product) to derive psychorheological models facilitating prediction of sensory texture from instrumental measurements. Significant correlations were observed between Instron hardness, and sensory firmness, crumbliness, stickiness and smoothness. Instron gumminess and chewiness showed similar or even better correlations with different sensory texture descriptors.

In a study reported by Meullenet *et al.* (1998) to evaluate twenty-one food samples from a wide variety of foods, high linear correlations were found between sensory and instrumental texture analysis (TPA) parameters for hardness ($r = 0.76$) and springiness ($r = 0.83$). No significant correlations were however, found between sensory and instrumental TPA parameters for cohesiveness and chewiness. Logarithmic transformations of data improved correlations between sensory attributes and their instrumental corollaries. The correlation between sensory hardness and the logarithm of instrumental hardness was improved to r=0.96. The correlation between the logarithm of both sensory and instrumental springiness was improved to r=0.86. The correlation between the logarithms of both sensory and instrumental chewiness was improved to r=0.54, which was significant at $P<0.05$. (Meullenet *et al.*, 1998). Pereira *et al.* (2005) investigated the usefulness of an array of statistical techniques to describe relationships between instrumental data and non-oral sensory texture profiling scores by using a range of model processed cheese analogs as example. They opined that compression data (large deformation), often used in correlation studies, need not necessarily lead to better correlation results with other instrumental parameters (Pereira *et al.*, 2005).

CONCLUSION

The firmness and consistency of *dahi* were highly dependent on the TS content of the milk from which it is made, and a positive correlation between them was recorded. It was also observed that *dahi* having total solids content of 15 % secured the highest sensory score. Higher TS levels resulted in *dahi* with firmer body and enhanced consistency, but this had negative influence on overall acceptability. Sensory score dependence on TS was best described by a polynomial quadratic model > linear > exponential model. Significant correlations were also obtained between instrumentally measured textural attributes and sensory acceptance score. Sensory score mostly depended on consistency and firmness (measured by texture analyser and cone penetrometer) which displayed linear, exponential and power relationships. Their dependence could be best predicted by multiple regression models of consistency, firmness, viscosity index and their products, however these are not recommended because of their complex nature in comparison to binomial models.

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