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Original article

Effect of milk composition on sensory attributes and instrumental properties of Indian Cottage Cheese (C*hhana*)

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ABSTRACT

This study investigated the effect of milk composition (cow-, buffalo-, and mixed- milk) on color, textural, rheological, microstructural and sensorial attributes of *chhana* (Indian cottage cheese). Principle component analysis and cluster analysis were used to correlate the quality attributes. Instrumental properties and sensorial descriptors for *chhana* that contributed most to the textural and sensory attributes were identified. *Chhana* containing 100% and 75% cow milk were found to have similar sensory attributes whereas *chhana* containing 100% and 75% buffalo milk had similar mechanical attributes.

1. Introduction

Soft cheese is characterized as soft textured and high moisture containing coagulated dairy product. Soft cheeses are used worldwide in various forms, for instance, cream cheese [1], white cheese, quark and ricotta [2]. In Indian dairy industry, soft-cheese analogues such as *paneer* and *chhana* are prepared utilizing cow milk or buffalo milk or often their mixture [3]. *Chhana*, also referred as Indian cottage cheese, is an indigenous dairy product used as a base material in the preparation of variety of traditional sweetmeats (*rosogolla, sandesh, chhana podo, chumchum, chhana murki,* etc.) [4]. *Chhana* production includes the coagulation of casein proteins by adding a suitable coagulant (citric acid, lactic acid, calcium lactate, etc.) to heated milk, resulting in entrapment of fat, water and water-soluble components [3]. It is manufactured mostly in unorganized sectors without any standard protocol by local confectioners and is limited to localized marketing for preparation of sweets. According to Food Safety and Standards Authority of India (FSSAI), *chhana* should not contain more than 70% moisture and less than 50% milk fat of the dry matter. Cow milk is considered as ideal raw material as it yields *chhana* of soft uniform texture and body [5,4]. However, buffalo milk yields a hard bodied and chewy textured product and hence, is not preferred for *chhana* manufacturing by the sweetmeat industry. Buffalo milk is commercially more viable as maintenance of buffaloes is cheaper and disease incidence is lower as compared to cows. Hence, it is essential to optimize the extent to which buffalo milk can be mixed with cow milk to produce *chhana* of acceptable physico-chemical and sensorial attributes.

The organoleptic properties of *chhana* vary significantly because of the differences in the localized manufacturing procedure adopted. Considering the significantly wide domestic market for *chhana*, it is important to standardize the manufacturing technology for commercial scale. Prior to commercialization, defining the product's key attributes that contribute to its sensory attributes is important as they are significantly influenced by the process parameters. There have been a number of attempts to develop and modify the manufacturing process of *chhana* [6,7,8]. Systematic studies on textural, rheological, microstructural and sensory quality with variation in the production process or milk composition for *chhana* have been lacking. It is therefore pertinent to investigate to what extent buffalo milk can be incorporated in cow milk to produce *chhana* exhibiting quality attributes (textural, rheological, microstructural and sensory) comparable to that produced using only cow milk. Major thrust of present study was therefore to investigate the textural, rheological and microstructural properties of *chhana* prepared from buffalo-, cow-, and mixed- milks and to correlate it with sensorial attributes. A product specific glossary consisting of both mouth and finger evaluated terms for *chhana* was prepared to correlate both sensory and instrumental parameters and measurements.

Abbreviations: BM, buffalo milk; CM, cow milk; MM, mixed milk; PCA, principal component analysis; PCs, principal components; G*, complex modulus; G', storage modulus; G", loss modulus; A_F, gel strength; z, interaction factor; , angular frequency; LVE, linear viscoelastic range; L*, lightness/darkness; a*, red/green; b*, yellow/blue; βLG, beta lactoglobulin; κCN, kappa casein.

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Nomenclature

Chhana Indian cottage cheese analogue

2. Materials and methods

2.1. Materials

Fresh raw buffalo milk (BM) (Murrah breed, 14–15 L/day production) and fresh raw cow milk (CM) (Jersey breed, 10–12 L/day production) was procured from a local dairy farm from Dhanas, Chandigarh (India) in the summer season (May–June 2019). Mixed milk (MM) samples were prepared by mixing BM and CM in desired proportions (75:25 - MM_1, 50:50 - MM_2, 25:75 - MM_3 by weight). Samples were collected and transported to the laboratory within 0.5 h of collection and immediately processed.

1% (*w/v*) citric acid solution was used as a coagulant. Anhydrous citric acid pellets were supplied by Loba Chemie Pvt. Ltd. (Mumbai) with following specifications: molecular weight – 192.13; assay – with min. Purity 99.5%. 1% citric acid solution was prepared by diluting 1 g of pellets in 100 mL distilled water.

2.2. Chhana making

Chhana was prepared from the BM, CM and mixed (MM_1, MM_2 and MM_3) milks following the method described by Chakraborty et al. (2020) [3]. 500 g milk was heated for 7–10 min till the temperature reached 90 ± 1 °C followed by cooling to coagulation temperature (70 ± 1 °C) for 5–7 min. 70 g citric acid solution (1% *w/v* concentration) was then incorporated slowly with constant stirring. Coagulation was completed within a minute and the coagulated mass along with the whey was left undisturbed for 10 min. The coagulum was separated using a muslin cloth, and hanged for about 10 min under the influence of gravity. It was then collected in a petridish, wrapped with aluminum foil to prevent moisture loss and was stored in a desiccator for further analysis. All the instrumental (except scanning electron microscopy) and sensory analysis was performed within 2 h of the preparation of the samples. *Chhana* manufacturing was performed for five times according to this method to check the repeatability of the final product characteristics.

2.3. Chemical analysis of chhana samples

2.3.1. Determination of moisture, fat, and protein contents

Moisture, fat, and protein contents of *chhana* samples were measured according to Bureau of Indian Standards (1981) [9]. All measurements were carried out in triplicate, and chemicals of analytical grade were used.

2.3.2. Chhana yield

The *chhana* yield was expressed as:

$$\%\text{Yield} = \frac{\text{Mass of chhana produced}}{\text{Mass of milk}} \times 100 \qquad (1)$$

2.4. Instrumental analysis

2.4.1. Visual color

Color of *chhana* samples was measured by using a Hunterlab colorflex spectrophotometer (Hunter Associate Lab, Reston, Virginia, U.S.A.) at room temperature (25 ± 2 °C) [10,11]. For all *chhana* samples, triplicate color measurements were performed, and the average values were reported.

2.4.2. Texture evaluation

Spreadability test was applied to the *chhana* samples using a spreadability rig unit of Texture Analyzer, TA.XT. Plus (Stable Microsystems, U.K.) as proposed by Rodriguez-Aguilera et al.,(2011a,b) [10,11]. All the measurements were replicated three times, and average values were used.

2.4.3. Rheology

To measure rheological properties of *chhana*, rheometer (MCR 102, Anton Par) was used. A 25 mm diameter serrated plate-plate geometry set up was used at a constant gap height of 1 mm to measure all the parameters. Amplitude sweep tests (LVE region - 1% strain) and frequency sweep tests (1% strain over the range of 0.1–10 rad/s) were carried out at room temperature (25 ± 2 °C).

2.4.4. Gel characteristics

Chhana was modeled as weak gel food following Eq. (2) [12] by computing the complex modulus (G*) using G' and G'' values. Curve fitting was performed using the following equation:

$$G^* = \sqrt{(G')^2 + (G'')^2} = A_F \omega^{1/z} \qquad (2)$$

where A_F - gel strength ($Pa{\cdot}s^{1/z}$), z - interaction factor in a three-dimensional structure, - angular frequency (rad/s).

2.4.5. Scanning electron microscopy

Chhana samples were lyophilized in a bench top freeze drying system (Chris Martin, Alpha T-Plus) and stored in a desiccator prior to microscopic measurements. The freeze dried samples were attached to SEM stub (aluminum holder) using double adhesive tape. The samples were coated with conducting film of gold using an ion-beam sputter coater (JFC 1100, JEOL) and examined at accelerating voltage of 20 kV in a scanning electron microscope (JSM 6100, Jeol, Japan).

2.4.6. Sensory analysis

Descriptive sensory profile analysis of selected *chhana* samples was carried out using a semi-trained panel [13]. Twenty reportedly healthy panelists from among the faculty members and postgraduate students of the Institute were screened thrice and fifteen panelists were selected ($n = 15$). They were trained in the characteristics and description of quality attributes of *chhana* through various significant terminologies in sensory assessment.

Before performing descriptive analysis, direct scaling was performed thrice to develop a detailed understanding of the product characteristics and its sensory attributes. The principal sensory parameters defining specific sensory quality of *chhana* (descriptors with definitions in Table 1) were discussed and determined during initial sessions. Panelists were asked to identify and explain the oral and finger-evaluated terms related to texture during training. Panelists assessed the samples using quantitative descriptive analysis (10-point product specific scale) on the basis of the intensity of principal sensory attributes [13].

Freshly prepared *chhana* was scooped into approximately even pieces in clear plastic plates, tempered to room temperature (25 ± 2 °C) and was randomly coded with 3-digit numbers before serving to the panelists. Water was used as palate cleanser before and during sensory analysis. Randomized order of presentation was followed for descriptive tests.

2.5. Statistical analysis

All the instrumental data were presented as means±standard error. Tukey's posthoc test was used to detect the significance of differences among the treatments at 95% confidence interval. Different superscripts were added to the values to elaborate the significant differences ($p < 0.05$). Principal Component Analysis (PCA) was applied on the descriptive sensory data using Unscrambler Statistical Package (Camo,

Table 1
List of descriptors with definition for *chhana*.

Descriptors	Definition
General evaluation	
Color	Visual estimation of intensity of lightness or yellowness/color of *chhana* surface
Odor/aroma	Cooked/milky/acid odor (smell of coagulant)/*chhana* whey
Overall quality	Overall sensation of quality in terms of likes or dislikes
Finger evaluation	
Surface properties	Uniform/non-uniform, smooth/crumbly/gritty
Firmness	Force applied when the*chhana* is placed between molar regions (teeth) to bite completely and to break it
Rubbery	Ability of *chhana* to regain the shape on removal of the applied force
Pasty	Ability of *chhana* to get evenly spread like paste when kneaded by applying force (when pressed between fingers)
Grainy	Ability of *chhana* to break into small granules or having prominent grains when subjected to structural breakage/ deformation
Oral evaluation	
Taste	Sweet/sour – fundamental taste sensation perceived by olfactory organ
After-taste	Taste perceived after the removal/swallowing of *chhana*
Adhesiveness (tongue)	*Chhana* placed on tongue, compressed with the soft palate slightly and released to assess tongue adhesiveness
Adhesiveness (teeth)	*Chhana* placed between teeth, compressed slightly and released to assess teeth adhesiveness
Chewiness	Number of chews needed to masticate *chhana* to a consistency suitable for swallowing

version 10.0, Oslo, Norway) [14]. The descriptors were considered as variables while *chhana* samples were considered as observations. Cluster analysis was conducted using Minitab version 19 to evaluate the relationship between these variables and observations.

3. Result and discussion

3.1. Preliminary analysis

MM_1(75% buffalo milk and 25% cow milk)*chhana* had higher moisture and protein percentage and hence, the yield was also higher as compared to other *chhana* samples while CM sample showed lowest yields in both seasons (Table 2). Higher yield of *chhana* can also be explained with the higher percentage of total solids in BM for better moisture retention as compared to CM [15]. As CM whey proteins (β-LG) denaturation occurs at a faster rate [16], partial substitution with CM (25%) led to higher yield and higher total protein content. Hence, the chance of adsorption of denatured CM whey proteins, followed by acidic denaturation of the casein micelle and subsequent entrapping with the fat globule occurs faster in partially substituted milk samples. Surface area available for adsorption of denatured whey proteins on fat globule and casein micelles decreased with decreasing proportion of BM in the mixtures. This affected the protein recovery and hence, the final yield. The more the protein recovery, the more entrapped water content due to moisture retention [17] and hence, this hypothesis is verified by experimental observations that MM_1 had the maximum moisture content as compared to other samples.

3.2. Instrumental analysis

3.2.1. Color

Lightness (L*) value was maximum (93.9) for BM *chhana*, and decreased with increasing proportion of CM in the mixed milk *chhana* samples and was minimum (87.2) for CM *chhana*. This may be due to the micelle aggregation phenomenon as casein micelles have been reported to scatter light [18,19]. The presence of higher amount of saturated fat in BM [20] lead to higher degree of light scattering and hence, L* value was maximum in BM *chhana*. The yellowness (b*) values increased with increasing proportion of CM in the mixed milk samples and was maximum for CM *chhana*. BM *chhana* had minimum a* value (−1.92) and was more greenish. It increased with increasing CM in the mixed milk samples leading to maximum a* value (−0.34) for CM *chhana*. This variation in a* and b* values can be due to the presence of the biliverdin pigment, which is present in BM and absent in CM [21].

3.2.2. Texture

Firmness of the heat-induced protein network is directly related to the water holding phenomenon [17] because water is entrapped more efficiently in a firm structure than in softer gels [23]. Firmness and work of shear were maximum in case of MM_1 *chhana* (Table 3). Since the process factors were similar, variations in firmness of *chhana* samples can be attributed to differences in milk composition and protein content mainly. Denatured whey proteins from CM in MM_1 lead to a modification in casein protein-whey protein ration [3] following more protein-protein interactions and hence, a firmer protein network was obtained [22]. Firmness of *chhana* decreased with decreasing proportion of BM content in the mixtures. Minimum firmness was observed for CM *chhana*.

Stickiness and work of adhesion of CM *chhana* was higher as compared to other samples (Table 3). Decrease in stickiness with increase of BM content in the *chhana* samples can be explained by the difference in fat contents of the samples (Table 2). Degree of fat dispersion contributes to stickiness and adhesiveness of the *chhana* samples. Olson & Johnson (1990) reported similar observations and

Table 3
Effect of composition on textural parameters of *chhana* samples.

Sample	Firmness	Work of shear	Stickiness	Work of adhesion
BM	22.35 ± 0.03^{a}	16.22 ± 0.14^{b}	-4.41 ± 0.09^{c}	-0.54 ± 0.04^{d}
MM_1	23.81 ± 0.08^{a}	18.19 ± 0.11^{a}	-5.77 ± 0.14^{b}	-0.64 ± 0.06^{c}
MM_2	20.03 ± 0.04^{b}	14.28 ± 0.19^{c}	-6.32 ± 0.15^{b}	-0.84 ± 0.05^{b}
MM_3	18.49 ± 0.10^{c}	12.89 ± 0.16^{d}	-7.96 ± 0.20^{a}	-0.98 ± 0.05^{a}
CM	15.47 ± 0.05^{d}	12.00 ± 0.09^{d}	-8.14 ± 0.18^{a}	-1.08 ± 0.03^{a}

Results represented as mean values± standard deviation of ten replicates; means with different superscripts in column differ significantly ($p < 0.05$).

Table 2
Composition of raw milk and *chhana* samples.

Milk used	SNF (%)	Raw milk			Lactose (%)	*CHHANA*			
		Moisture (%)	Fat (%)	Protein (%)		Yield (%)	Moisture (%)	Fat (%)	Protein (%)
BM	8.89 ± 0.11^{a}	84.18 ± 0.3^{e}	6.30 ± 0.12^{a}	4.61 ± 0.21^{a}	3.69 ± 0.14^{e}	15.32 ± 0.14^{b}	55.22 ± 0.22^{b}	22.51 ± 0.51^{a}	20.71 ± 0.37^{b}
MM_1	8.83 ± 0.27^{b}	84.54 ± 0.31^{d}	5.92 ± 0.27^{b}	4.48 ± 0.14^{ab}	3.85 ± 0.2^{d}	15.91 ± 0.13^{a}	56.05 ± 0.26^{a}	22.07 ± 0.32^{b}	21.33 ± 0.41^{a}
MM_2	8.76 ± 0.42^{c}	84.94 ± 0.34^{c}	5.62 ± 0.19^{c}	4.40 ± 0.19^{b}	3.91 ± 0.12^{c}	14.95 ± 0.11^{c}	54.66 ± 0.31^{c}	21.96 ± 0.27^{b}	20.10 ± 0.32^{c}
MM_3	8.68 ± 0.39^{d}	85.63 ± 0.1^{b}	5.31 ± 0.21^{d}	4.32 ± 0.26^{c}	3.95 ± 0.18^{b}	14.17 ± 0.17^{d}	53.93 ± 0.40^{d}	20.24 ± 0.21^{c}	19.86 ± 0.45^{c}
CM	8.62 ± 0.12^{e}	85.89 ± 0.47^{a}	5.07 ± 0.10^{e}	4.27 ± 0.10^{d}	3.99 ± 0.16^{a}	13.62 ± 0.15^{e}	52.82 ± 0.33^{e}	19.72 ± 0.30^{d}	19.09 ± 0.47^{d}

[a] Results represented as mean values with their standard deviation; means with different superscripts in columns differ significantly ($p < 0.05$); BM-buffalo milk; CM-cow milk; MM-mixed milk (BM:CM ratio in MM_1-75:25; MM_2-50:50; MM_3-25:75); SNF-solid not fat.

stated that low-fat cheeses exhibit a higher degree of stickiness (higher adhesive character) when masticated as compared to high-fat cheeses. This is evident in CM *chhana* samples with low fat content.

3.2.3. Rheology

Fig. 1 shows the effect of milk composition on the dynamic behavior of *chhana* samples by computing tanδ values from G′ and G″. tanδ values for MM_1 and BM samples indicated solid-like elastic nature. Lower tanδ values are indicative of more elastic character [24]. tanδ values for CM sample indicated more viscous character or weak gel like behavior (Fig. 1). The tanδ value of CM *chhana* was higher as compared to BM which revealed that CM sample showed weaker gel characteristics. Similar results are reflected in the textural data obtained (Table 3).

Table 4 lists the parameters obtained by fitting the experimental results in Eq. (1). The R^2 values indicated that the weak-gel model described well the gel characteristics for *chhana*. The polypeptide chains unfold during protein denaturation and expose their hydrophobic amino acid groups leading to protein aggregation, thus increasing the strength of the gel [25].It can be observed that A_F was maximum in MM_1*chhana* and it decreased with decreasing BM content in mixed milk samples. Higher A_F indicates an increase in interaction forces due to molecular bonding in the gel network [25]. This was also observed in tanδ values of MM_1 and BM samples as compared to CM indicating the dominance of firm elastic nature. In case of CM sample, hydration of protein and rearrangement of fat particles in the structure of *chhana* upon low calcium concentration may be responsible for weakening of the *chhana* matrix and lower viscoelastic properties.

3.2.4. Microstructure

Chhana samples when viewed by SEM (Fig. 2) were found to be continuous dense clusters created by the agglomerated casein particles with numerous intergranular spaces between them. These spaces were whey-filled and surrounded with fat globules and coalesced casein micelles. BM *chhana* sample was more crumbly. It had larger void spaces caused due to occlusion of open channels with proteins, fats and whey components as compared to CM sample. As BM has higher total solids (protein, fat, calcium mainly), the microstructure of the milk gel had larger but unevenly spaced coagulated particles. Kalab & Harwalkar (1974) [26] found that the microstructure of skim milk gel, containing 60% solids, had fused and firm casein micelle structures, while gel containing only 40% solids had lesser number of fused micelles and lacked firmness. CM *chhana* is described to contain more evenly distributed particulate surface when viewed by SEM. The protein matrix showed dense continuous network. The gel strands were found to be composed of small uniformly distributed particles (casein aggregates) and were linked together with greater number of small sized pores. Decrease in total solids by addition of CM in the mixed milk samples yielded more compact and evenly distributed protein matrix. Hence, BM *chhana* had different microstructural aspects as compared to CM *chhana* due to the difference in composition.

Table 4
Weak gel model for *chhana*.

Sample	A_F (Pa·s$^{1/z}$)	σ_A	z	σ_z	R^2
BM	16,462.15	9.70	5.89	0.15	0.994
MM_1	18,772.86	9.84	5.52	0.18	0.992
MM_2	8829.94	9.08	5.08	0.19	0.994
MM_3	7759.14	8.95	4.83	0.20	0.996
CM	6998.12	8.85	5.25	0.19	0.996

A_F - gel strength (Pa·s$^{1/z}$), z - interaction factor in a three-dimensional structure, σ_A - intercept, σ_z – x-variable; BM-buffalo milk; CM-cow milk; MM-mixed milk (BM:CM ratio in MM_1-75:25; MM_2-50:50; MM_3-25:75).

3.3. Sensory analysis

3.3.1. Principal Component Analysis (PCA)

PCA was applied on thirteen variables representing the sensorial attributes as listed in Table 1, for *chhana* samples. Biplot of the variables and the sample position generated depicts the correlation and positions of five samples along principal components (PCs) generated (Fig. 3a). Similar products are positioned in the graph in close proximity to each other, and different products are far apart [27].With minimal information loss, the most significant variables were derived from the analysis. A combination of Kaiser's criteria (eigen value >1) and the main components in the data set to retain the number of final factors from the initial ones was applied. Varimax rotated principal component factor loadings are reported in Table 5a representing correlations between PCs and variables.

The first and second PCs contributed about 87.2% and 8.6%variation respectively in the descriptive sensory data. Absolute factor loading

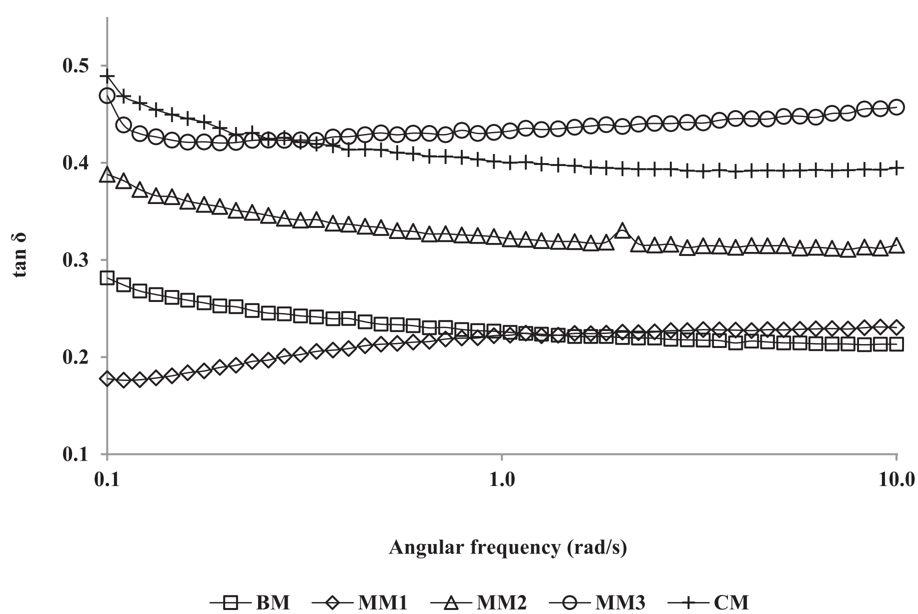

Fig. 1. Dynamic rheological behavior (tan δ) of *chhana* samples with respect to milk composition (strain = 1%) to define viscoelastic state of these samples; BM-buffalo milk; CM-cow milk; MM-mixed milk (BM:CM ratio in MM_1-75:25; MM_2-50:50; MM_3-25:75).

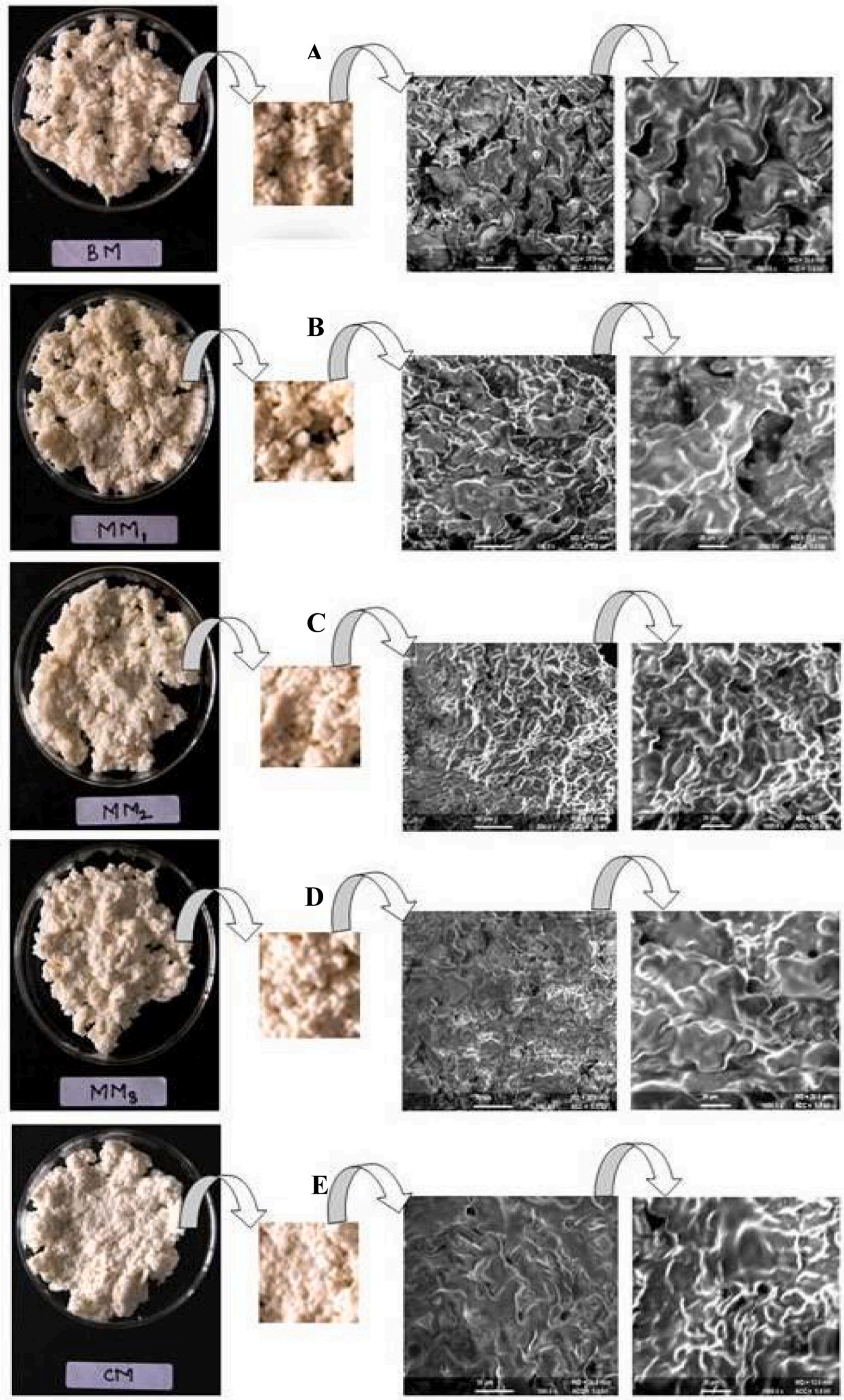

Fig. 2. Scanning Electron Microscopy images of *chhana* samples (digital image, SEM at 500×, SEM at 1000×) to understand the microstructure using (A) BM; (B) MM_1 (BM:CM::75:25); (C) MM_2(BM:CM::50:50); (D) MM_3 (BM:CM::25:75); (E) CM.

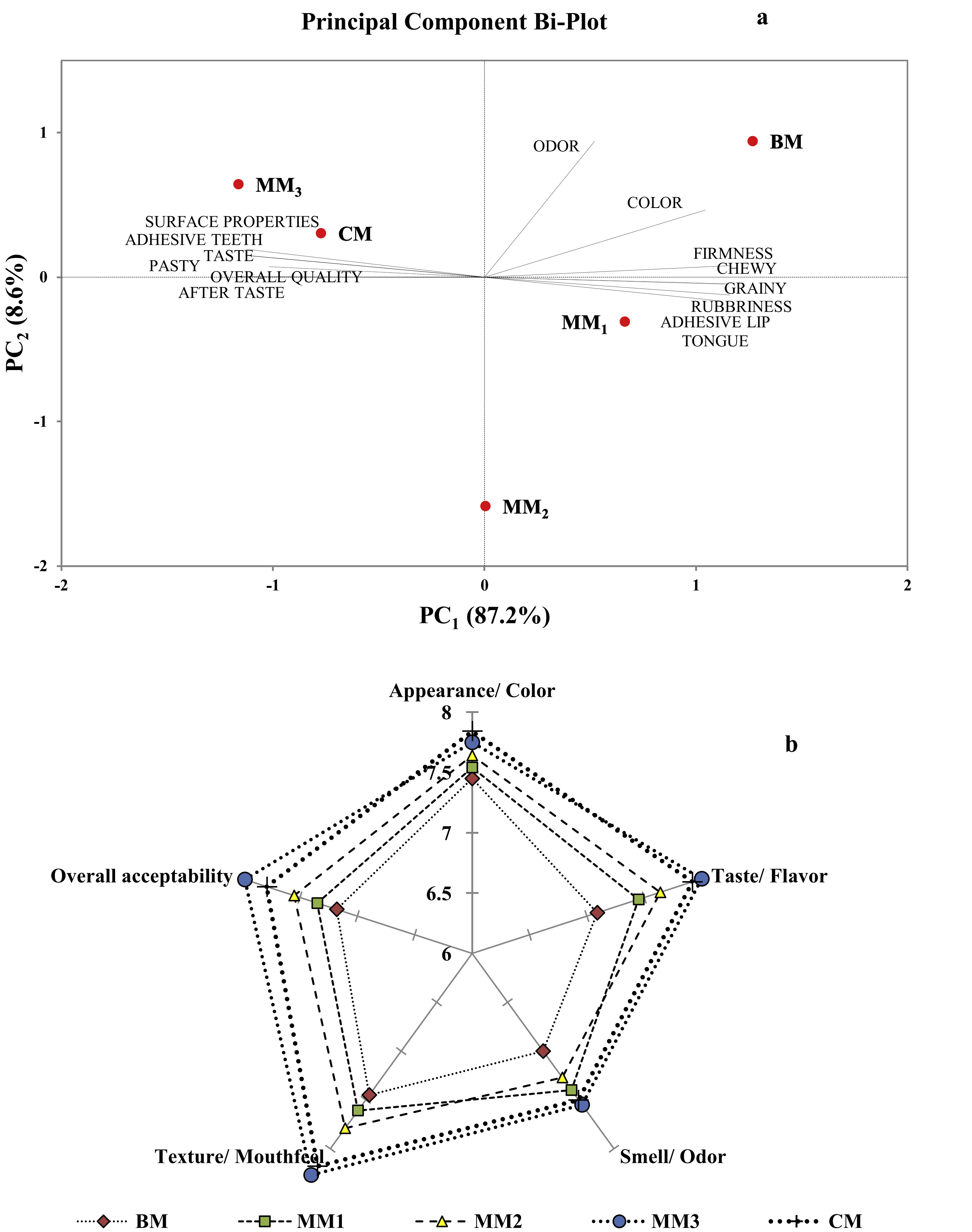

Fig. 3. a: Biplot (– score); Principal component 1 (PC_1) and Principal component 2 (PC_2) of *chhana* samples with % of variance shown; b: Hedonic scaling of the sensory profile of *chhana*; Individual attributes are located around a center (zero or not detected) point like wheel spokes, with spokes reflecting frequency levels of attributes, with higher (more intense) values radiating outward; BM-buffalo milk; CM-cow milk; MM-mixed milk (BM:CM ratio in MM_1-75:25; MM_2-50:50; MM_3-25:75).

Table 5a
Principal component factor loadings for sensory attributes of chhana samples.

Variables	PC_1	PC_2	PC_3	PC_4
Color	0.204	0.113	**0.447***	0.082
Odor	0.102	0.103	**0.895***	−0.020
Taste	−0.872	0.135	−0.427	**0.235***
After taste	−0.958	0.109	0.116	**0.376***
Surface properties	−0.996	**0.441***	0.083	0.031
Firmness	**0.993***	−0.045	0.143	0.022
Rubberiness	**0.973***	−0.157	0.115	0.184
Pasty	−0.996	**0.183***	0.083	0.031
Grainy	**0.989***	−0.116	−0.017	−0.015
Adhesiveness (tongue)	**0.964***	−0.045	−0.107	0.198
Adhesiveness (teeth)	−0.965	**0.157***	0.149	−0.116
Chewy	**0.992***	0.075	−0.062	0.075
Overall quality	−0.958	**0.221***	0.116	0.142
Variance explained (%)	87.2	8.6	2.6	1.5

Four PCs were extracted by applying PCA on the mean values of descriptive sensory scores by applying Varimax rotation; Numbers marked* are believed to be most important; BM-buffalo milk; CM-cow milk; MM-mixed milk (BM:CM ratio in MM_1-75:25; MM_2-50:50; MM_3-25:75); PCs – Principal components to determine the % of variance.
Bold and asterisk-marked high factor loading values (Table 5a, 5b) are of great significance; they explain the correlation between the PCs and the product characteristics

value corresponding to each sensory attribute determines the relationship between the main component and that particular sensory attribute (Table 5b). Four PCs with their own values >1 (Kaiser criterion) explaining 99% of overall variability in the data set (Table 5a) was used for further study among all the PCs extracted. The finger evaluated textural parameters (firmness, rubberiness, graininess), oral adhesive property (on tongue), and chewiness had higher loadings on the positive side of the PC_1 axis depicting more influence on the product quality. 87% of the total variance could be clarified by the first PC with eigen value of 11.33. Surface properties (sticky/moist/slippery/greasy), pasty nature, oral adhesive property (on teeth) and overall quality showed higher loadings in case of PC_2 axis with eigen value of 1.12 explaining 8.6% variation. Color and odor had higher loading along $PC_3$with eigen value of 0.34 explaining 2.6% variation. Sensory qualities (taste and after-taste) had higher loadings along PC_4 with eigen value of 0.20 explaining 1.5% variability (Table 5b). Asterisk-marked high factor loading values (Table 5a) are of great significance.

Taste, aftertaste, color, mouthfeel, texture and overall acceptability were evaluated through hedonic scaling (Fig. 3b). MM_3 had scored more in overall acceptability, mouthfeel and taste followed by CM. Hence, it can be suggested that samples with high sensorial scores (after-taste, odor, overall quality, color and taste) had lower scores in mechanical properties (textural firmness or stickiness and gel strength).

3.3.2. Cluster analysis

In a dendrogram, the lesser the height, the more will be the similarities. Height also determines the orders in which the clusters are joined. According to the dendrogram (Fig. 4), there were three major clusters- mechanical properties (cluster B), surface properties (cluster A) and sensory properties (cluster C). In this case there is a big difference between clusters A, B and C as depicted by the height differences.

In cluster variable analysis, the data contained thirteen variables (descriptors) and lead to the formation of twelve clusters with high similarity level (99.455) and very low distance level (0.01). Firmness, graininess, rubberiness and oral adhesiveness (on tongue) were closely related and had around 99% of similarity level. Graininess was correlated with same level of similarity with chewiness. Pasty and oral adhesiveness (on teeth) were correlated which in turn had similarity index of 97% with rubberiness. Color and odor also were correlated with a similarity level of 94.72%. During the formation of new clusters, the similarity level decreased after 7 clusters and the distance level increased. All the variables were joined in a single cluster in the final step. There were two clustered subgroups: BM, MM_1 & MM_2, and $MM_3$and CM. In observation analysis (figure not shown), MM_3 and CM were correlated with a similarity index of 92%. The textural and mechanical properties define these clusters and their variations. When compared with the PCA data, these results corroborated and were observed to be associated with the four PCs.

3.4. Discussion

A close inter-relationship between the sensory and instrumental properties of *chhana* as a milk gel was observed.BM and MM_1samples had higher protein& fat contents which resulted in fused coagulated casein micelles with considerably higher firmness. In contrary, MM_3 and CM samples had lower protein and fat content resulting in less firm coagulated individual casein micelles entities. MM_2 showed an intermediate behavior with moderate firm continuous coagulated casein micelles. Green et al., (1981) [28] reported that cheese firmness linearly increased as the concentration factor of milk increased (i.e., fat, protein, lactose and ash content), and protein network became apparently coarser and the curd became larger.

The color, texture and rheology of *chhana* may seem to be interpreted as an amalgamation of physical properties by the sense of sight and touch. According to sensory analysis, lower L* and higher b* values of the *chhana* samples (MM_3) had the highest overall quality. In case of sensorial firmness and other mechanical properties, BM and MM_1 were grouped together and instrumental firmness decreased with decreasing proportion of BM content in the mixtures. In case of sensorial stickiness and other surface properties, MM_3 and CM were grouped together with CM *chhana* having maximum instrumental stickiness and work of adhesion values (Table 3). Sindhu, (1996) [29] also reported that BM *chhana* was harder and chewy due to higher concentration of micellar

Table 5b
Factor scores for all the *chhana* samples.

Samples	PC_1 (firmness, rubberiness, grainy, chewy, and oral adhesiveness (tongue))	PC_2 (surface properties, overall quality, pasty nature, and oral adhesiveness (teeth)	PC_3 (color and odor)	PC_4 (taste and after taste)
BM	**1.268**	−0.943	**1.164**	**1.326**
MM_1	**0.664**	−0.307	−0.244	−0.203
MM_2	0.004	−1.584	−1.544	−1.543
MM_3	−1.163	**0.843**	**1.036**	**0.353**
CM	−0.773	**0.505**	**0.252**	**0.282**
Reference	**1.268**	−0.943	**1.164**	**1.326**
Variance explained (%)	87.2	8.6	2.6	1.5

BM-buffalo milk; CM-cow milk; MM-mixed milk (BM:CM ratio in MM_1-75:25; MM_2-50:50; MM_3-25:75); PCs – Principal components to determine the % of variance.
Bold and asterisk-marked high factor loading values (Table 5a, 5b) are of great significance; they explain the correlation between the PCs and the product characteristics

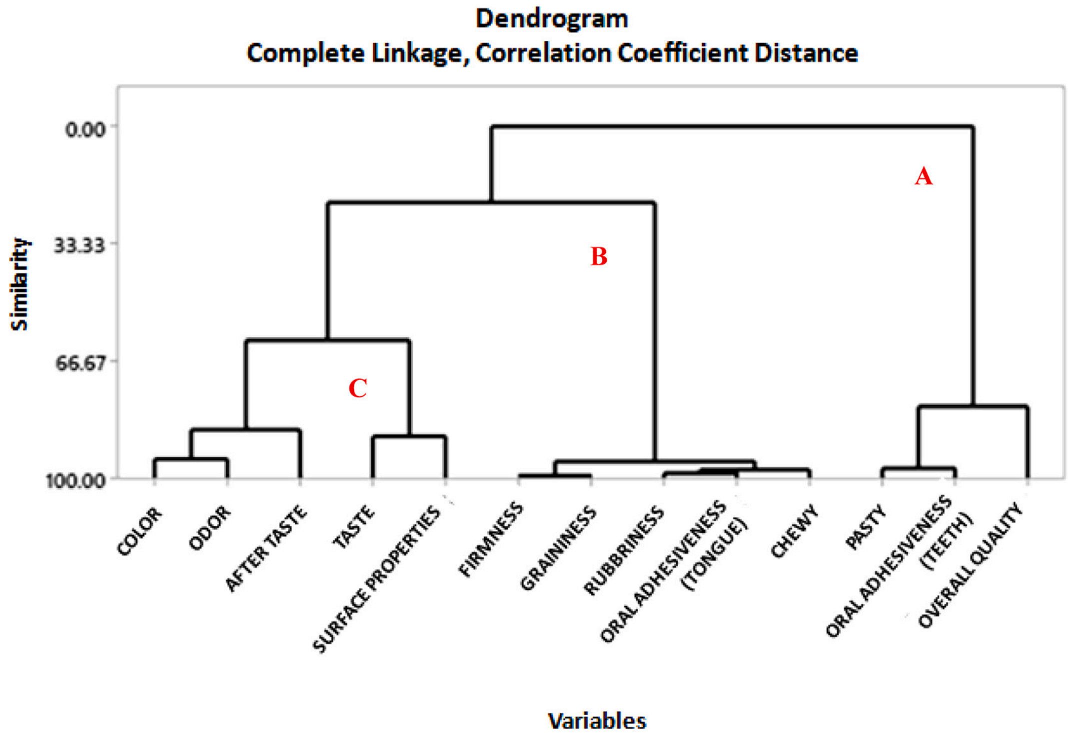

Fig. 4. Dendrogram of cluster variables showing the complete linkages and correlation coefficient distances between the variables along with similarity index; variables depict the mechanical and sensorial properties of the *chhana* samples.

casein with bigger size, harder milk fat due to larger proportion of high melting triglycerides in it and higher content of total and colloidal calcium. Development of typical rheological characteristics of *chhana* can be attributed to intensive heat-induced (β-LG-κ-CN) protein-protein interactions [30]. Elastic nature was dominant in the $MM_1$and BM samples as the G′ value was constantly higher when compared to CM sample. With decreasing the proportion of BM in mixed milk samples elasticity gradually diminished due to reduction in protein, fat and calcium contents. Lowering of elastic properties in the CM *chhana* may be due to weakening of the matrix caused by protein hydration and fat particles rearrangement in the *chhana* structure. This was observed in weak gel model factors where MM_1 sample had the highest A_F value which depicted the strong protein network in the matrix.

SEM images revealed that BM sample had more crumbly surface, larger particle size and larger pore size whereas CM sample had even surface with smaller particle size and smaller pores which were evenly distributed throughout the *chhana* matrix. In the mixed milk samples, as the proportion of CM was increased, the surface properties changed accordingly. When correlated with the sensory data, it was observed in PCA that MM_3 and CM had a positive factor score in case of pasty and adhesiveness (teeth) properties which can be correlated with the uniform and even surface of the CM sample.

3.5. Practical applications

Instrumental evaluation and consumer perception together form the backbone of superior product quality. Instrumental as well as descriptive sensory evaluations of five *chhana* samples of varying compositions were conducted in this paper. Sensory data were analyzed using principle component analysis and cluster analysis. Our approach could provide an insight on utilization of PCA and cluster analysis either singly or in association to extensively explore dairy product quality optimization and differentiation.

4. Conclusion

In our study, results demonstrated that BM can be added to CM up to 25:75 proportions (MM_3) to produce *chhana* with qualities comparable to that produced using CM only. MM_3 had superior textural, surface and sensory properties resulting in better overall acceptability. Through hedonic scale rating, PCA and cluster analysis it was observed that MM_3 sample was grouped along with CM based on the sensory attributes and overall acceptability. This can be explained through the fact that in instrumental analysis, CM and MM_3 had significantly similar stickiness and significantly different firmness. These two parameters affected the relative sensory scoring of the semi-trained panelists. On the contrary, BM and MM_1samples had lower overall acceptability and taste. Both finger and orally evaluated textural attributes (firmness, rubberiness, pasty, chewiness, adhesiveness, and graininess) of *chhana* had major effect on the overall sensory quality of these products. Hence, PCA and cluster analysis can be utilized singly or in association to extensively explore dairy product quality differentiation.

CRediT authorship contribution statement

Purba Chakraborty: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Writing - original draft,; **U.S. Shivhare:** Writing - review & editing, Validation; **Santanu Basu:** Conceptualization, Supervision, Visualization, Methodology, Project administration, Resources, Validation, Writing - review & editing

Declaration of Competing Interest

None.

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