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Characterization of physical attributes and texture profile analysis of Buffalo milk yogurt

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ABSTRACT

Yogurt is a fermented dairy product that is widely consumed and well-known for its distinct sensory qualities and numerous health benefits. Its textural and other physical properties are crucial for determining consumer acceptance and influencing their perception of its quality. This study provides a comprehensive analysis of the texture profile (firmness, work of adhesion, work of shear, time difference, and area under the force-time curve) and some other physical properties of buffalo milk yogurt, as buffalo milk yogurt is more likely accepted because of its high fat content as well as total solid contents, resulting in a creamier and thicker texture of yogurt. The primary objective of this scientific investigation was to expand the current understanding of the properties, viz., bulk density, moisture content, viscosity, and textural profile analysis (TPA), exhibited by yogurt. The research elements consist of the constituents used, the processing parameters implemented, and the microbial cultures incorporated during the manufacturing process. In addition, this paper explores the measurement techniques and methodologies used to assess these properties. The results demonstrate the significance of comprehending and optimizing these properties in order to improve the sensory perception and overall quality of yogurt.

1. Introduction

Yogurt, a cultured dairy product, is produced through the process of heating milk with lactic acid bacteria, specifically *Streptococcus thermophilus* and *Lactobacillus delbrueckii ssp. bulgaricus*. It is a widely consumed fermented dairy product on a global scale (Atik et al., 2023). India, being the largest milk-producing nation (Sain et al., 2020), has great potential to exhibit significant growth, indicating a promising outlook in the coming years in the probiotic market. Yogurt is made when thermophilic strains of *Lactobacillus bulgaricus* and *Streptococcus thermophilus* ferment milk. This causes lactic acid to be made, which causes the milk proteins to stick together (Fadela et al., 2009; Song and Aryana, 2014).

According to Kose and Ocak (2011), the process of lowering pH is achieved through the conversion of lactose into lactic acid. Yogurt exhibits superior nutritional properties compared to milk due to its higher content of milk solids, protein, calcium, phosphorus, and a diverse array of vitamins, in conjunction with the nutrients generated through the process of fermentation (Patel, 2011). Certain vitamins, such as pantothenic acid and vitamin B1, experience depletion as a result of their utilization by the bacterial culture. The three distinct physical states commonly observed in retail settings are as follows: set, stirred, and fluid. The set state refers to an undisturbed gel found in retail cups. The stirred state, on the other hand, pertains to an acid gel that is generated during incubation in large fermentation tanks and subsequently disrupted by stirring. Lastly, the fluid state denotes drinking yogurt, which is characterized by its liquid consistency (Prajapati et al., 2016). The reason behind the prevalence of stirred yogurts in fruit-flavored varieties lies in the necessity to effectively distribute flavors and fruit within the yogurt matrix subsequent to the fermentation process. Conversely, the majority of unadorned plain yogurts are classified as set yogurts, as they undergo fermentation directly within the containers in which they are ultimately retailed. The successful execution of various stages in the development of new products, such as processing, handling, process design, and quality assurance, is contingent upon a comprehensive comprehension of the rheological characteristics of the product. Yogurt is widely accepted by

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*Corresponding author: mukulsain95@gmail.com consumers based on various physical characteristics, including the absence of syneresis, perceived viscosity, acidity and scent perceptions, and textural features (Penna et al., 2006).

Yogurt varieties that exhibit thixotropic and viscoelastic properties demonstrate non-Newtonian flow behavior characterized by a strong temporal dependence. Besides, the type of milk utilized and the fat constituents during the production process has been found to have an influence on both the textural and rheological characteristics of yogurt (Prasanna, 2013). The investigation of altering the water retention capacity, viscosity, and mouthfeel of yogurt and its subsequent effects on texture and rheological properties has garnered considerable attention in scientific research. Based on that, research was undertaken to expand the current understanding of the properties, viz., bulk density, moisture content, viscosity, and textural profile analysis (TPA), exhibited by buffalo milk yogurt, as buffalo milk has greater amounts of total solids and fat content, which provides better textural attributes and consistency (FAO, 2023; Gursel et al., 2016).

2. Materials and Methods

Preparation of culture

Mixed cultures *(lactococcus lactis ssp lactis, lactococcus lactis ssp cremories, and lactococcus lactis ssp lactis var. diacetylactis)* from the dairy technology department at ICAR-NDRI Karnal, India were used to prepare yogurt, which makes milk easier to digest and gives it more nutrients. It is also known as a probiotic or functional food, as it possesses live lactic acid bacteria.

Preparation of yogurt

Buffalo milk, consisting of 5% fat was subjected to heating, reaching and maintaining a temperature of 90°C for 5 min and then cooled to 42°C. The starter culture was added to the milk at 2–3% and stirred properly. Then the milk with added culture was distributed into 8 different cups. Lids were added on top of the cups. The cups were arranged in the incubator. The temperature of the incubator was set to 42°C. The detailed production process has been shown in Fig. 1.

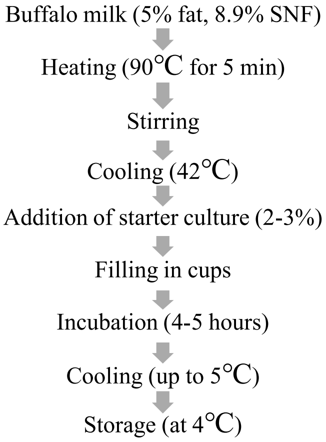

Figure 1. Procedure for yogurt preparation

Experimental setup

For temperature monitoring, 8 pt 100 sensors were provided to the 8 cups and were put inside the cabinet. A data logger was used to record the temperature data from the sensors. After the completion of time, cooling was started (Fig. 2a, 2b). Cups were taken out of the incubator and cooling cabinet, and different tests were carried out.

a) Controllers

b) Incubator cum cooling unit

Figure 2. Experimental setup

Viscosity Analysis

For measuring the rheology of the sample, "Haake Viscotester iQ" was used (Fig. 3a). 100 ml of yogurt was taken in a glass beaker. Readings were taken with increasing rotations per minute (RPM) of 10, 20, 30, and up to 100, and spindle RV4 was used to measure the viscosity of the samples. The viscosity of 3 samples at different temperatures (Sample 1 at 5 °C, Sample 2 at 10 °C, and Sample 3 at 20 °C) was studied.

Texture Profile Analysis (TPA) of Yogurt

For the analysis of the texture of prepared curd using a texture analyzer (Fig 3b). TPA tests were performed using a texture analyzer on a stable microsystem equipped with a 5-kg load cell. The analyzer was linked to a computer that records the data via a software program. Experiments were carried out using compression tests that generated a plot of force (g) vs. Time (s), from which texture values were obtained. A cylindrical probe was used to compress 100 mL of the yogurt sample. The speed of the probe was fixed at 5mm/sec during the compression and relaxation of the sample.

During the testing, the samples were held manually against the base plate. The data obtained in the compression test were used for the determination of the textural parameters.

Moisture content analysis

The method of oven (microwave) drying determined the yogurt's moisture content. Around 5 g of samples were taken, and they were spread over a circular plate. The sample was kept inside a hot oven for 30 seconds, then taken out. After a few times, it was again placed inside the oven for 30 seconds until the consecutive measurements gave a difference of 1 mg. This weight was taken as the final weight of the samples (Matela et al., 2019).

Then moisture content was calculated using some terms describe as follows: -

Initial weight of sample = $M1$

Final weight of sample = $M2$

Weight of moisture content = $M1 - M2 = M3$

Moisture content on wet basis (%) = $\frac{M3}{M1}\ x\ 100$

Moisture content on dry basis (%) = $M3/M2\ x\ 100$

Bulk density analysis

The bulk and tapped densities were determined as per the method adopted from Kalsi et al. (2023). Briefly, the powder was filled into a 100-mL graduated cylinder and weighed. The volume read directly from the cylinder was used to calculate the bulk density (qb) by dividing the mass by the volume.

3. Results and Discussion

Viscosity

Fig. 4 shows the analysis of viscosity with respect to strain rate and time for different samples. For sample 1, as the strain rate (ϒ) increased, the shear stress (Ʊ) also increased, indicating a positive correlation between strain rate and shear stress. The viscosity (ɳ) of Sample 1 ranged from 2.064698 Pa-s at the lowest strain rate to 0.301726 Pa-s at the highest strain rate (Fig. 4a). As the strain rate increased, the viscosity decreased, suggesting that the yogurt became less viscous at higher strain rates. Overall, Sample 1 exhibited typical non-Newtonian behavior, where the viscosity decreased with

a) Viscometer b) Texture analyzer

Figure 3. Instruments used for the experiments

increasing shear rate, as commonly observed in many viscoelastic fluids. Similarly, Kashaninejad et al. (2021) stated that yogurt exhibits viscoelastic behavior. Sample 2 was similar to sample 1, but there was a positive correlation between the strain rate (ϒ) and shear stress (ʊ) in sample 2. The viscosity (η) of sample 2 ranged from 3.88371 Pa-s at the lowest strain rate to 0.157019 Pa-s at the highest strain rate (Fig. 4b). Again, as the strain rate increased, the viscosity decreased, indicating shear-thinning behavior. Sample 2 also shows non-Newtonian behavior, characteristic of viscoelastic fluids. According to Saleh et al. (2020), linear viscoelastic behavior of non-fat set yogurt was observed from 0.1 to 10 Pa. In contrast, Sample 3 exhibited a negative correlation between strain rate (ϒ) and shear stress (ʊ) since the shear stress decreased as the strain rate increased. The viscosity (η) of Sample 3 ranged from 2.122539 Pa-s at the lowest strain rate to 0.188318 Pa-s at the highest strain rate, again indicating shear-thinning behavior with increasing strain rate (Fig. 4c). Sample 3 also displayed non-Newtonian behavior, consistent with the other samples. Osorio-Arias (2020) also stated in his study that yogurt shows shear-thinning behavior. For further detail and clear understanding, separate plots were drawn for viscosity vs time data. Similar curves are shown in viscosity vs. time plots, as shown in Figs. 4d, 4e, 4f.

By examining the relationship between strain rate (ϒ) and shear stress (ʊ) for each sample, a positive correlation was observed, indicating that as the strain rate increased, so did the shear stress. Additionally, the viscosity (η) values were analyzed for each sample across different strain rates. In all cases, the yogurt exhibited shear-thinning behavior, with the viscosity decreasing as the strain rate increased. This behavior was characteristic of viscoelastic fluids containing complex structures like proteins and polysaccharides, which was typical for yogurt. When Najgebauer-Lejko et al. (2020) conducted a similar study, they also discovered that shear rate had a complex impact on changes in apparent viscosity (the up-flow curve).

Furthermore, the effect of temperature on yogurt viscosity was evident from the data. As the temperature increased, the yogurt became more fluid-like, and its viscosity decreased. This trend was consistent across all three samples, supporting the understanding that temperature plays a significant role in the flow properties of yogurt. However, it was important to note that the viscosity-temperature relationship was not straightforward and may involve more complex interactions. Simultaneously, Guénard-Lampron et al. (2020) concluded in their study that viscosity of stirred yogurt increased as the temperature increased from 10 to 30 °C and then started to decrease at 35 °C.

Bulk density

The Fig. 5 shows the bulk density of different samples of buffalo milk yogurt. The average initial weight of the samples was 51.30 g, the average bulk volume was 50 ml, and the average density was 1.026 g/ml. The standard deviation of the initial weight was 0.12 g, the standard deviation of the bulk volume was 0.04 ml, and the standard deviation of the density was 0.002 g/ml.

The results of the data analysis suggest that the yogurt samples were relatively uniform in terms of their initial weight, bulk volume, and density. The standard deviations for all three measurements were relatively small, indicating that there was not a lot of variation between the samples.

Moisture content

The Fig. 6 depicts the moisture content of different samples of buffalo milk yogurt. The average initial weight of the samples was 5.58 g, the average final weight was 1.029 g, and the average moisture content was 79.41%. The standard deviation of the initial weight was 0.03 g, the standard deviation of the final weight was 0.01 g, and the standard deviation of the moisture content was 0.05%.

The results of the data analysis suggest that the yogurt samples were relatively uniform in terms of their initial weight, final weight, and moisture content. The standard deviations for all three measurements were relatively small, indicating that there was not a lot of variation between the samples. Matela et al. (2019) analyzed the moisture content of nine commercially available yogurt samples purchased from different places. The moisture content of the samples ranged from 76.08% to 80.07%.

Temperature profile

The Fig. 7 shows the temperature profile of different samples of buffalo milk yogurt during incubation. Sample 1 started at an initial temperature ranging from 34.9°C to 35.8°C in different cups. It took approximately 4 hours and 15 minutes for all cups for Sample 1 to reach 40°C in the incubator. The temperature rise in Sample 1 was relatively consistent across all cups, with minor variations. Sample 2 began at an initial temperature ranging from 32.1°C to 33.4°C in different cups. It took approximately 4 hours and 30 minutes for all cups in sample 2 to reach 40°C. Similar to Sample 1, the temperature rise in Sample 2 was relatively consistent among the cups. Sample 3 started at an initial temperature ranging from 29.1°C to 31.6°C in different cups. It took approximately 5 hours and 37 minutes for all cups in sample 3 to reach 40°C. The temperature rises in sample 3 showed slightly more variation among the cups compared to the other samples. Undugoda et al. (2019) did a similar study on yogurt. Each yogurt starter culture was added to the yogurt mixture, which was then filled into the yogurt cups, and finally, they were kept at 42 ºC for a 4-hour incubation period.

The observed data reveals interesting insights into the heating behavior of the yogurt samples during incubation. The time taken for each sample to reach the target temperature of 40°C varies among the different samples. Sample 1 demonstrated the shortest time to reach the target temperature, followed by Sample 2, and finally Sample 3, with the longest time. The variation in the initial temperatures of the yogurt cups in each sample could be attributed to natural variations in the production process or differences in heat transfer within the incubator. The uniformity in the time taken to reach the target temperature across all cups in each sample suggests a relatively consistent heating process. The longer time taken for Sample 3 to reach 40°C might indicate differences in the composition or structure of the yogurt, leading to altered heating behavior. Factors such as the type of bacterial cultures used, the milk source, and additives can influence the heat transfer properties and ultimately affect the time to reach the target temperature.

Texture profile analysis (TPA)

Firmness: The firmness values for all three samples were negative, indicating that the yogurt was soft and easily deformable. The average firmness was -0.025 N, with a relatively low standard deviation of 0.005 N, suggesting good consistency in firmness among the samples (Fig. 8a).

Work of Adhesion: The work of adhesion represented the energy required to pull apart the yogurt samples after compression. Sample 1 had the highest work of adhesion (0.185 N.s.), while Sample 2 had the lowest (0.130 N.s.). The average work of adhesion was 0.156 N.s., with a moderate standard deviation of 0.028 N.s., indicating moderate variation in this attribute among the samples (Fig. 8b).

Work of Shear: The work of shearing measured the energy needed to shear the yogurt samples. All three samples had comparable shear values, with an average of 3.169 N and a standard deviation of 0.166 N. This indicates consistent resistance to shearing across the samples (Fig. 8c).

Stickiness: Sample 3 exhibited a significantly higher stickiness value (2.890 g) compared to Samples 1 and 2 (around 0.3 g). This suggests that Sample 3 has a higher tendency to stick to surfaces. The average stickiness value was 1.162 g/s, with a relatively high standard deviation of 1.497 g/s, indicating considerable variation in stickiness among the samples (Fig. 8d).

Area under FT1:3: The area under the force-time curve for each sample (FT1:3) represented the energy absorbed during the compression process. The values for this attribute vary between the samples, with an average of 345.297 and a standard deviation of 19.245. This suggests differences in the rheological properties and elasticity of the yogurt samples (Fig. 9).

Time-difference (FT1:3) and Time-difference (FT4:6): The time-difference values represented the time taken for specific force-time curves to reach certain points. The average time difference for FT1:3 was 22.593 seconds, and for FT4:6, it was 0.513 seconds. These values showed the viscoelastic behavior of the yogurt samples during compression (Fig. 10).

The experimental samples exhibited typical yogurt-like properties, with soft and easily deformable textures (Kose et al., 2018). The relatively consistent firmness, work of adhesion, and work of shear suggest uniformity in the textural attributes among the samples. However, there were notable differences in stickiness and the area under the force-time curves, indicating variations in the yogurt samples' composition and structure.

4. Conclusion

The investigation of milk composition, encompassing the levels of fat and protein, assumes a pivotal role in the determination of firmness, viscosity, and gel formation during the process of fermentation. Additionally, this study aims to explore the various factors that influence the sensory attributes of yogurt. The results obtained from this investigation demonstrate significant potential for enhancing yogurt production methodologies. This would enable manufacturers to customize the product to align with the specific preferences and expectations of consumers, thereby enhancing consumer satisfaction and market competitiveness. Future research endeavors in this particular domain may prioritize the advancement of novel methodologies for assessing and manipulating the texture of yogurt. The primary objective of these endeavors is to facilitate the advancement of yogurts with exceptional sensory characteristics that are highly sought-after in the market.

5. Conflicts of Interest

The authors do not have any conflicts of interest in any manner.

6. Acknowledgment

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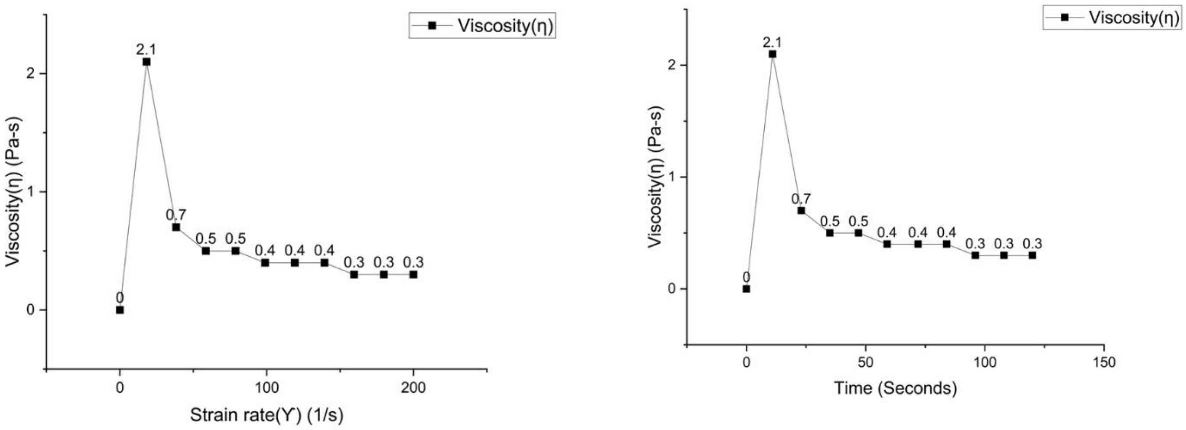
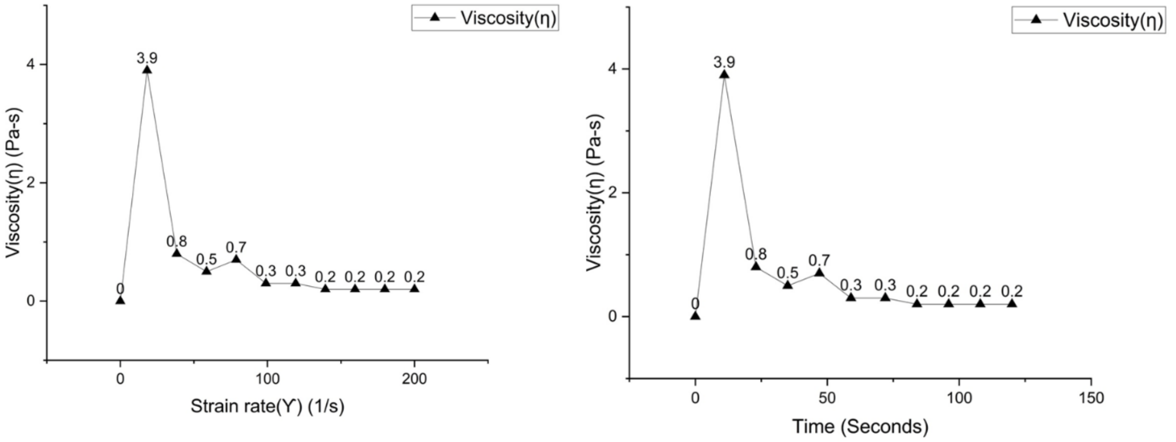


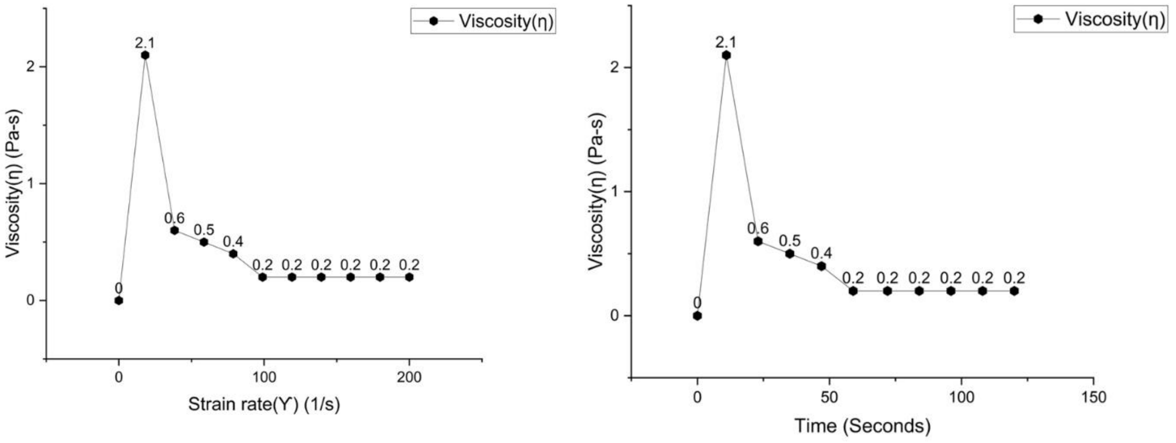
a) Viscosity vs strain rate (sample 1)

d) Viscosity vs time plot (sample 1)



b) Viscosity vs strain rate (sample 2)

e) Viscosity vs time plot (sample 2)



c) Viscosity vs strain rate (sample 3)

f) Viscosity vs time plot (sample 3)

Figure 4. Analysis of viscosity with respect to strain rate and time

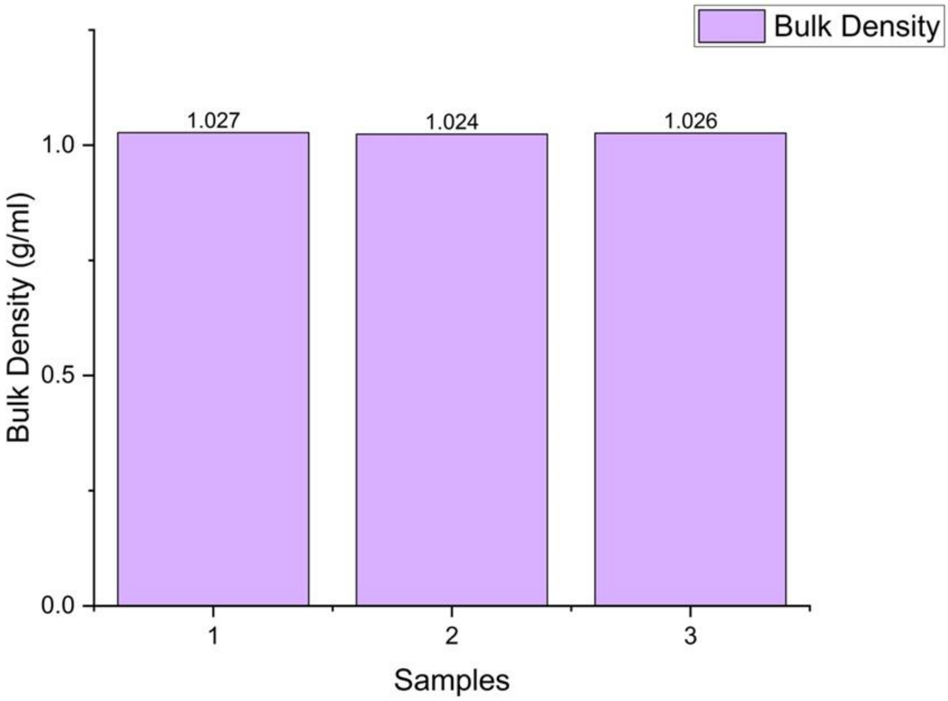
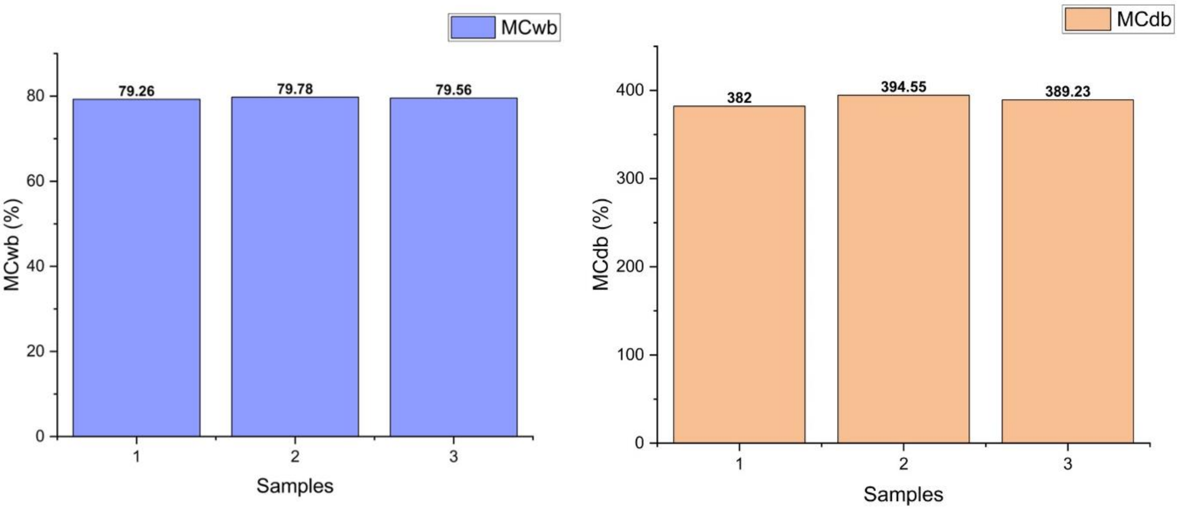


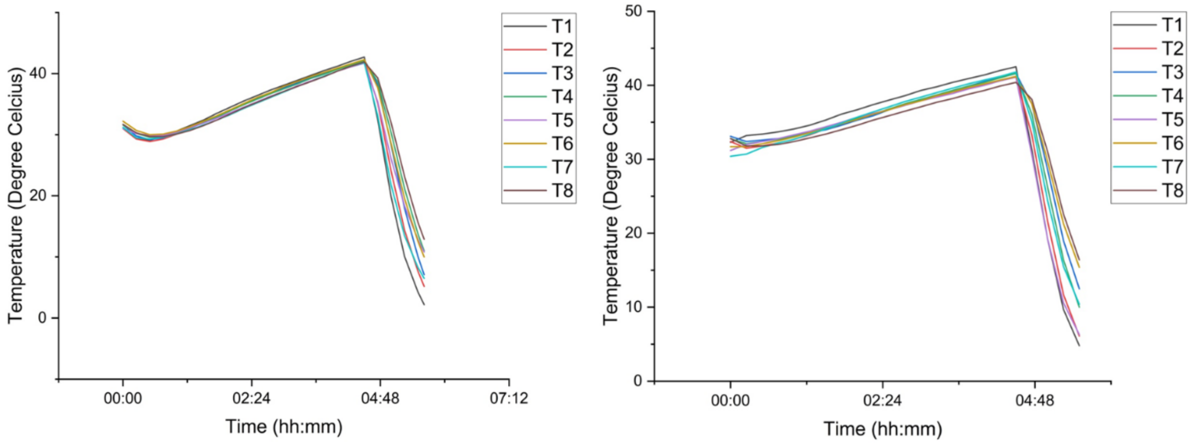
Figure 5. Bulk density of the samples (1, 2, 3)



a) Moisture content on wet basis

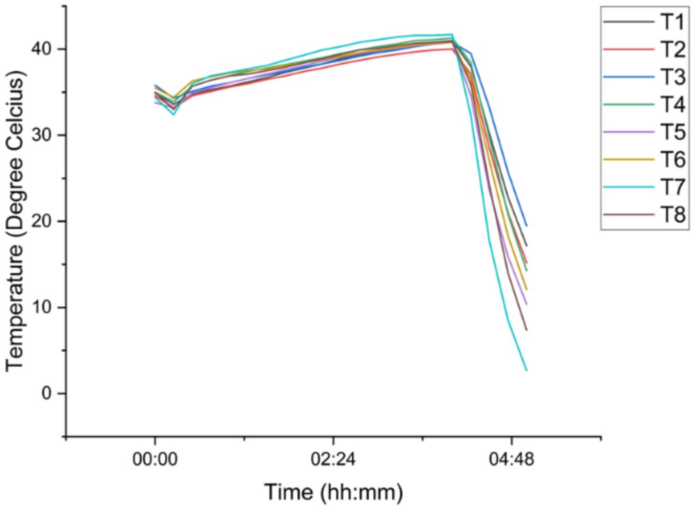
b) Moisture content on dry basis

Figure 6. Moisture content of the samples (1, 2, 3)



a) Temperature profile (sample 1)

b) Temperature profile (sample 2)



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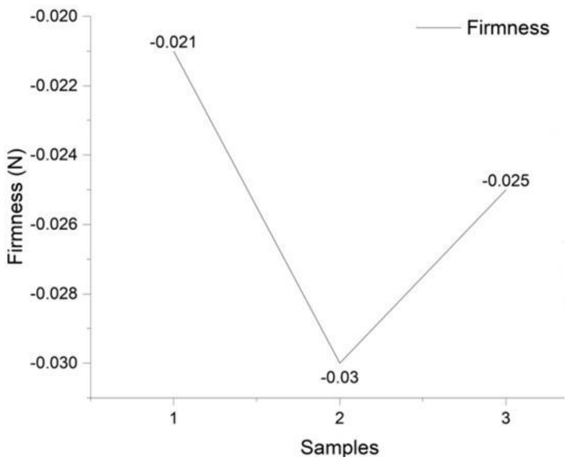
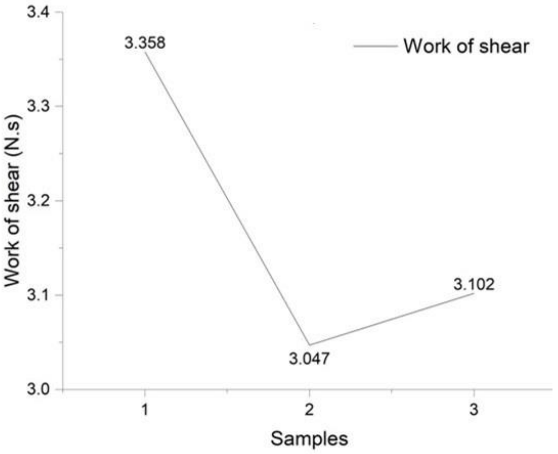
c) Temperature profile (sample 3)

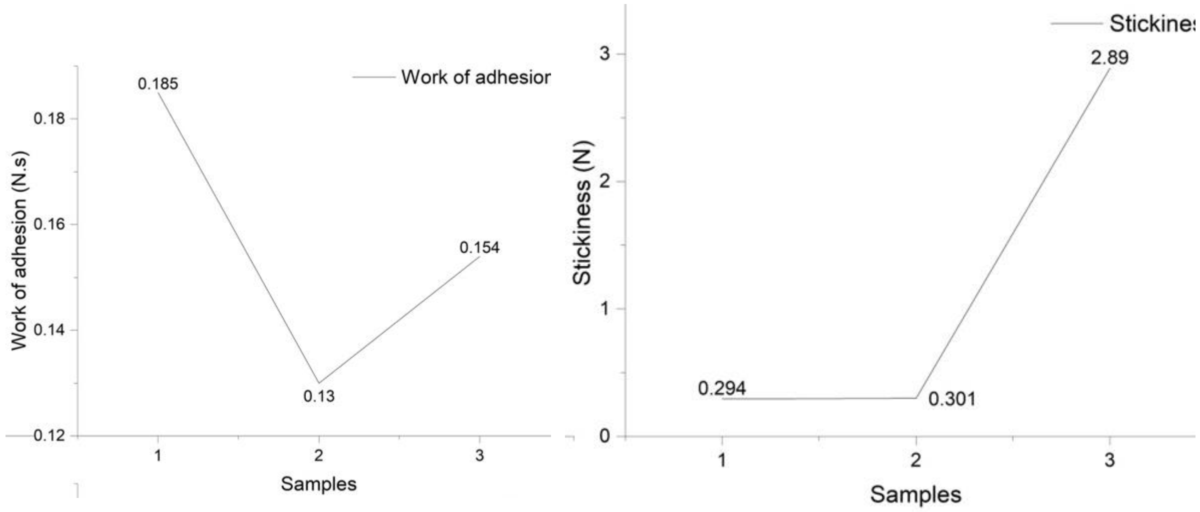
Figure 7. Temperature profile during incubation



a) Firmness

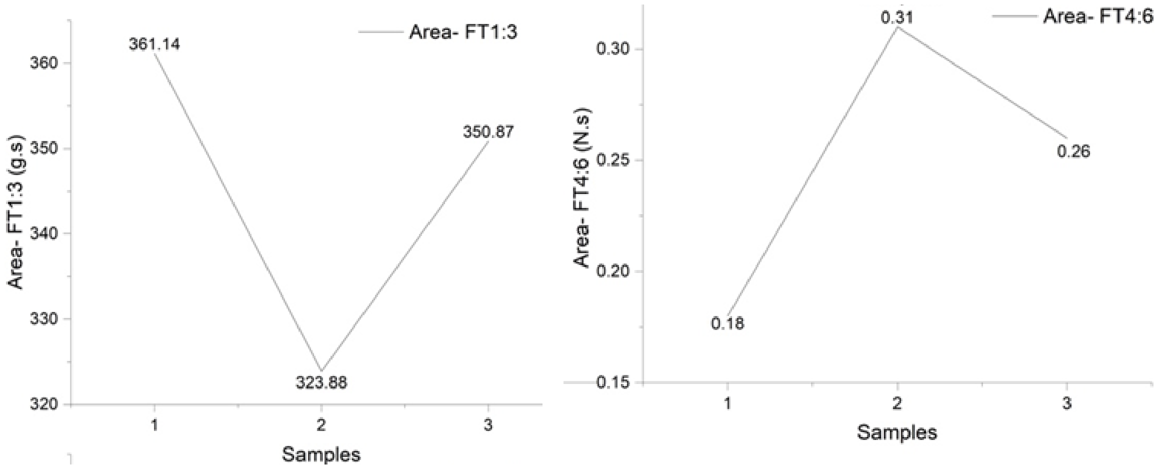


c) Work of shear



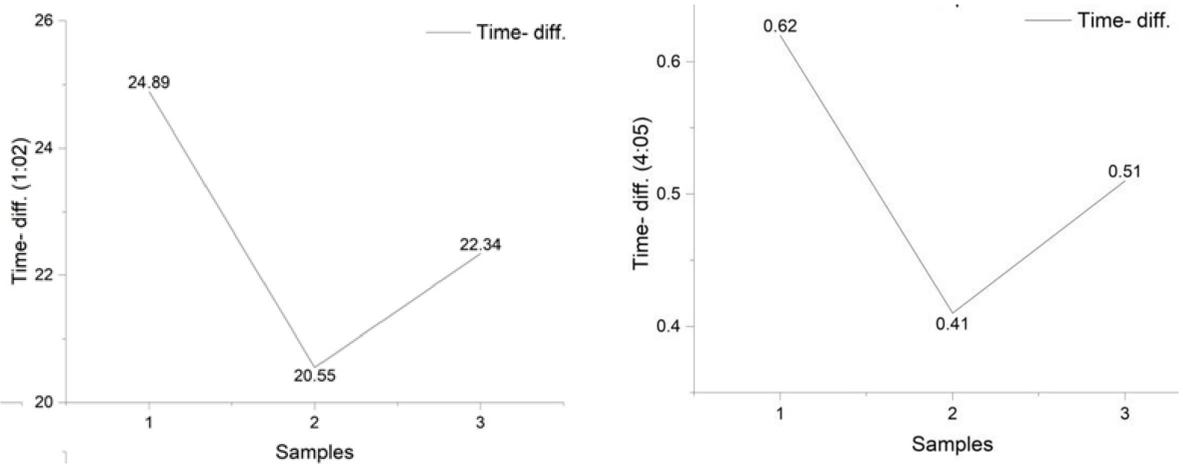
b) Work of adhesion d) Stickiness

Figure 8. Texture profile analysis for yogurt (Sample 1, 2, 3)



a) Area FT1:3 b) Area FT4:6

Figure 9. Texture profile analysis for yogurt (Sample 1, 2, 3)



a) Time difference (1:02) b) Time difference (4:05)

Figure 10. Time difference for the samples (Sample 1, 2, 3)

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