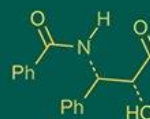


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Gitanjali Kumari
Department of Dairy Science
and Food Technology,
Institute of Agricultural
Sciences, Banaras Hindu
University, Uttar Pradesh
India

Priya Gupta
Department of Dairy Science
and Food Technology,
Institute of Agricultural
Sciences, Banaras Hindu
University, Uttar Pradesh
India

Adrija Chakraborty
Dairy Technology Division,
ICAR-National Dairy
Research Institute, Karnal,
Haryana, India

Saurabh Singh
Dairy Technology Division,
ICAR-National Dairy
Research Institute, Karnal,
Haryana, India

Durga Sankar Bunkar
Department of Dairy Science
and Food Technology,
Institute of Agricultural
Sciences, Banaras Hindu
University, Uttar Pradesh
India

Corresponding Author:
Durga Sankar Bunkar
Department of Dairy Science
and Food Technology,
Institute of Agricultural
Sciences, Banaras Hindu
University, Uttar Pradesh
India

Effect of dragon fruit (*Hylocereus* spp.) powder fortification on the physicochemical, microstructural and crystalline characteristics of dahi

Gitanjali Kumari, Priya Gupta, Adrija Chakraborty, Saurabh Singh and Durga Sankar Bunkar

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Abstract

The main objective of this research is to produce and characterization of dahi fortified with dragon fruit. The 4% dragon fruit dahi was determined to be the best formulation based on overall acceptance following a sensory study. Chemical analysis showed that, in comparison to the control, the fortified dahi had relatively higher carbohydrate content and a slightly lower fat and moisture content. FTIR, SEM, EDX, and XRD were used to further characterize the optimized sample and control. The O-H, C-H, C = O, and C-O functional groups were represented by distinctive absorption peaks in the FTIR spectra at 3393, 2922, 1747, 1460, 1160, and 719 cm^{-1} . At magnifications of 100x, 200x, 400x, 500x, 1000x, 2000x, and 5000x, SEM imaging showed a rough, spherical, spongy microstructure with voids. EDX confirmed the presence of major elements like carbon, oxygen, and nitrogen as well as trace minerals like calcium, magnesium, manganese, potassium, phosphorus, sulphur, Zinc, and iron. XRD analysis showed diffraction peaks at 18.57° , 19.47° , 20.339° , and 22.618° , with a crystallinity of 67.21% for the control dahi and 70.2% for the optimized dahi. The results demonstrate that adding dragon fruit powder to dahi enhances its nutritional profile and structural characteristics without adversely affecting its sensory attributes.

Keywords: Dragon fruit, crystallinity, fortification, elemental composition, fermentation, characterization

1. Introduction

For thousands of years, fermented foods have been prepared and consumed throughout India. It is believed that the Aryan-speaking people who came to India between 1500 and 1000 BC brought milk products like Ghee and Dahi, also known as curd. Dahi is consumed daily as part of a traditional diet, is particularly popular in India and its neighbouring nations. It is also used to make other culinary goods. It is a part of Panchamrita, a mixture of five meals used in Hindu devotion and puja. Mainly cow milk is used for Dahi making as cows are considered sacred creatures in India, and their milk and products are used in all religious and cultural ceremonies in addition to being eaten every day. (Mudgal *et al.*, 2017) ^[12]. The unique physicochemical properties of Dahi are a result of the combined impact of fermentation conditions and milk content. In addition to being aesthetically pleasing, Dahi has nutritional advantages as a source of fat, proteins, and other micronutrients (Das *et al.*, 2025) ^[4]. Dahi is composed of water (85-88%), fat (5-8%), lactose (4.6-5.2%), protein (3.2-3.4%), lactic acid (0.5-1.1%), ash (0.7-0.75%), and calcium (0.12-0.14%) (Anjum *et al.*, 2020) ^[1]. Lactic acid bacteria is added to Dahi and fermented at a specific temperature and duration to produce its unique flavor, creamy texture, and taste. Among the most prevalent bacterial cultures in Dahi are the beneficial starter bacteria (*Streptococcus thermophiles*, *Lactobacillus delbrueckii* spp. *bulgaricus*) needed in order to produce yogurt. In addition to the basic bacterial cultures mentioned above, Dahi contains a diverse range of microorganisms. Yogurt and dahi have comparable physico-chemical properties since they contain the same bacterial cultures (Qureshi *et al.*, 2025, Das *et al.*, 2025) ^[17, 4]. Dahi has long been believed to help with bone growth and avoid gastrointestinal issues. The lactic acid and the beneficial microbes in Dahi provide a healthy balance in the gut, and possibly improve the availability or digestion of particular nutrients.

It can be healthier for individuals with lactose intolerance to digest since fermentation reduces lactose and generates microbial β -galactosidase. It provides calcium, phosphorus, and protein essential for maintaining calcium levels in the bones and skeletal health (Pathania *et al.*, 2026, Pekhlui *et al.*, 2025) ^[15, 16].

Dragon fruit (*Hylocereus* spp.), often known as pitaya, has spread over the world due to its ability to adapt to tropical and subtropical environments. It is found in both northern South America and Mexico. Due to its abundance of bioactive phytochemicals that support its health advantages, such as flavonoids, phenols, anthocyanins, and betalains, dragon fruit has attracted a lot of attention (Chen *et al.*, 2024) ^[12]. Dragon fruit may enhance health since it contains bioactive substances that have several advantages, including anti-inflammatory, anti-diabetic, antioxidant, anti-cancer, and antibacterial properties (Nishikito *et al.*, 2023) ^[13].

Dragon fruit may be utilized in value addition of food products in a variety of ways, such as enhancing color, boosting nutritional content, and offering antibacterial properties (Kęska *et al.*, 2023) ^[9]. Dragon fruits may offer the further advantage of improving consumer health by adding essential components like vitamins, minerals, and natural antioxidants to food products. Therefore, In this study, dragon fruits were used to enhance the nutritional value to Dahi. The dragon fruit was added to Dahi to fortify it, and then the characterization of Dahi as well as the corresponding chemical parameters were evaluated.

2. Material and Methods

2.1 Raw Materials

Dragon fruits (*Hylocereus species*) purchased from the Sundarpur market, Varanasi. The cow milk containing a fat 4.0% and SNF 8.5% was purchased from Amul dairy shops. In addition, Masti Dahi of Amul brand is used as starter culture for the fermentation of Dahi. All chemicals are purchased from authorized chemical industry and are food grade.

2.2 Preparation of Dragon fruit powder (DFP)

The dragon powder was prepared using a modified method based Roppolo *et al.*, (2024) ^[18]. Initially, the dragon fruits were cleaned with reverse osmosis (RO) water to reduce microbiological and chemical contamination. After washing, the fruits were put on sterile trays and the peels were manually removed. In order to ensure even heat distribution and shorten the drying time, the pulp was then chopped into small, uniform pieces. Following that, the sliced dragon fruit was equally placed on drying trays and allowed to dry at the 48 °C for 36 hours. For the production of a powder with a consistent particle size, the product was ground up in a grinder after drying and then sieved.

2.3 Preparation of dragon fruit incorporated Dahi

Cow milk was adequately pasteurized by heating it to 85 °C for 15 minutes. Following that, the temperature lowered and was kept between 37°-38 °C. Then, the curd added to milk at a 1.0% (v/v) concentration. A control dahi along with three dragon fruits powder incorporated dahi samples were carefully produced in order to determine the optimal sample. A control dahi along with three dragon fruits powder incorporated dahi samples were carefully produced in order

to determine the optimal sample. Three different proportions of dragon fruit powder (2%, 4%, and 6% (w/v)) were added to determine the effect of dragon fruits powder on the nutritional and sensory attribute of the final products. The mixture was incubated for sixteen hours at 37-38 °C to promote desirable fermentation. After incubation, the product was moved to a 4 °C refrigerator for further analysis.

2.4 Sensory evaluation of Control and Dragon Fruit Powder Added Dahi

A sensory evaluation panel, consisting of both professors and students from the Dairy Science and Food Technology Department, were assembled to evaluate the sensory attributes of the Dahi samples. Panel members were informed about all four dahi samples before the evaluation commenced to ensure that they had a complete knowledge of the products under review. Body and texture, flavor, color and appearance, and overall acceptability were the four major aspects that were the focus of the sensory assessment. Each sample was evaluated by the panel members using a nine-point hedonic scale, where point 1 representing "very poor" and 9 indicating "excellent."

2.5 Physico-Chemical analysis of Control and Dragon Fruit Powder Added Dahi

The Rose-Gottlieb procedure, drying oven (100 ± 2 °C), muffle furnace ignition method (550 °C) and standard alkali neutralization method of Food Safety & Standards Authority of India (FSSAI, 2022) ^[5] was employed to determine the fat (%), moisture (%), ash (%) and titrable acidity (%) of dahi, respectively. The Kjeldahl digestion and distillation method was used to analyze the protein content (Goyal *et al.*, 2022) ^[6]. The carbohydrate content of dahi sample was obtained by difference.

$$\text{Carbohydrate (\%)} = 100 - (\text{Protein\%} + \text{Fat\%} + \text{Ash\%} + \text{Moisture \%})$$

2.6 Characterization of Control and Dragon Fruit Powder Added Dahi

2.6.1 Fourier transform infrared (FTIR) spectroscopy Analysis of Control and Dragon Fruit Powder Added Dahi

FTIR (Bruker Alpha, Germany) was used to determine the functional groups of the control sample and optimized sample. The sample combined with KBr (potassium bromide) at a 1:20 ratio. The combination was compacted into a pellet and analyzed using FTIR in the wave number range of 4000 to 400 cm⁻¹.

2.6.2 Scanning electron microscopy-Energy disperse x-ray (SEM-EDX) spectroscopy Analysis of Control and Dragon Fruit Powder Added Dahi

EDX (APOLLO X, AMETEK) microanalysis is based on a generation of distinctive x-rays that indicate the existence of certain elements present in the sample. SEM (D8374, Quanta 200, Thermo Fisher,) microanalysis used to determine the morphological structure of sample. It shows the micrograph at different magnification such as; 100x, 200x, 400x, 500x, 1000x, 2000x and 5000x.

2.6.3 X-Ray Diffraction (XRD) Analysis of Control and Dragon Fruit Powder Added Dahi

The crystal structure was analyzed using X-ray diffraction (DY 1688, Empyrean, Malvern Panalytical, Netherlands). The X-ray patterns were collected within a 10-60° scanning range, at a speed of 4°/min and a step size of 0.0130°, with a voltage of 45 kV and an accelerating current of 40 mA (Zheng *et al.*, 2025, Chen *et al.*, 2025) [20, 3].

2.7 Statistical analysis

A one-way Analysis of Variance (ANOVA) was implemented to examine the significance of differences between the optimized and control dahi, with a confidence interval set at 95%. Results were considered statistically significant at $p < 0.05$.

3. Results and Discussion

3.1 Sensory attributes of Control and Dragon Fruit Powder Added Dahi

On the basis of sensory analysis of all four dahi sample, the dahi sample containing 4% dragon fruit (D₂) scored significantly better than the other dahi samples ($p < 0.05$) in every aspect. It obtained scores of 7.3 ± 0.83 for appearance and color, 7.1 ± 1.05 for body and texture, 7.2 ± 0.96 for flavor, and 7.2 ± 0.82 for overall acceptability. On that basis, dragon fruit fortified dahi (D₂) and control dahi (D₀) was selected for further analysis.

3.2 Physico-Chemical Composition of Control and Dragon Fruit Powder Added Dahi

The chemical composition of the control and optimized dahi is presented in Table 1. The optimized dahi exhibited a higher protein (3.5%), ash (0.74%), carbohydrate (6.26%) and acidity (0.90%) content compared with the control dahi, which recorded 3.4%, 0.70%, 4.7% and 0.88%, respectively. In contrast, the moisture and fat contents decreased from 87.1% and 4.1% in the control dahi to 85.60% and 3.9%, respectively, in the optimized dahi. The observed changes are in agreement with the findings of Yeasmin *et al.* (2023) [19], who reported that incorporation of red dragon fruit peel powder into yogurt influenced its physicochemical composition, with increases in ash content and decreases in fat and protein contents with increasing levels of fortification. Overall, incorporation of dragon fruit powder resulted in an improvement in the nutritional composition of dahi, particularly with respect to protein, ash, carbohydrate and acidity, accompanied by a reduction in moisture and fat content.

3.3 Characterization of Control and Dragon Fruit Powder Added Dahi

3.3.1 Molecular Conformation and Functional group of Control and Dragon Fruit Powder Added Dahi By FTIR

FTIR was employed to elucidate the molecular conformation and functional group composition of the Dahi sample. The FTIR spectrum was presented in figure 1. A significant absorption peak observed at around 3393 cm⁻¹ corresponding to the O-H stretching vibration characteristic of hydroxyl (-OH) groups, indicating the presence of hydroxyl-rich substances in the dahi sample. Kurhade *et al.*, (2023) [11] observed a similar peak between 3365-3250 cm⁻¹, linked to O-H stretching from amides, carboxylic, or phenolic groups. An absorption peaks at 2922 cm⁻¹ were linked to the C-H stretching vibrations in alkane groups,

suggesting presence of alkaloids. The presence of conjugated alkene and α , β -unsaturated ketone functionalities was indicated by a peak at 1747 cm⁻¹, attributed to the double carbon bond stretching. Kozłowicz *et al.*, (2020) [10] revealed the presence of ketone and alkene of carbonyl group at a peak of 1735 cm⁻¹ in a study of honey powder. The FTIR spectrum exhibited a series of absorption peaks associated with CO-O-CO stretching vibrations, specifically at peaks of 1460 cm⁻¹, 1166cm⁻¹, and 719 cm⁻¹, suggesting the presence of sulfonyl chloride, alkyl aryl ether, and anhydride groups, respectively.

3.3.2 Result of Elemental Composition and Microstructural Morphology of Control and Dragon Fruit Powder Added Dahi by SEM-EDX

SEM combined with EDX evaluation was carried out in order to discover the elemental composition and microstructural morphology of dahi sample. EDX was performed across multiple regions, yielding spectra that identified key elements (table 2). The X-ray spectra, plotted as count rate versus energy (keV), revealed significant amounts of carbon, oxygen, and nitrogen with smaller quantities of calcium, magnesium, manganese, fluorine, potassium, phosphorus, copper, iron, sulphur, and zinc. Quantitative analysis reported the elemental composition in both weight percentage (% wt) and atomic percentage (% at) basis. The results revealed that the optimized dahi is primarily composed of carbon (21.20%), nitrogen (5.55%), and oxygen (72.60%) on a weight basis, and, carbon (26.25%), nitrogen (5.89%), and oxygen (72.60%), on an atomic basis. Goyi *et al.*, (2024) [7] also revealed the similar report in study on potato peel powder and hydrochar when compared with of EDX analysis of dahi, reported that the presence of oxygen and carbon, indicating the presence of the organic composition of the biomass materials.

The surface morphology of dahi was displayed via SEM analysis, with the corresponding micrograph presented in figure 3. The SEM images were captured at magnifications of 100x, 200x, 400x, 500x, 1000x, 2000x and 5000x, with scan areas of 500µm, 300µm, 100µm, 50µm, 40µm, 20µm and 10µm, at an accelerated voltage of 20 kV. The SEM analysis of dahi revealed a complex surface morphology with rough, spherical particles, irregularities, voids, holes, and cracks along with an open, and spongy structure. Casein particles would cling to chains and clusters during acidification, creating a three-dimensional network. The observed surface features suggest that processing treatment, significantly influenced particle morphology, leading to surface roughness and structural heterogeneity (Zheng *et al.*, 2025) [20]. A similar finding was revealed by Parvare *et al.*, (2017) [14] in the SEM analysis of the yoghurt revealed casein and denatured proteins aggregation on the micelle surface, forming clusters and ultimately a three-dimensional network.

3.3.3 Crystalline of Control and Dragon Fruit Powder Added Dahi by XRD

An amorphous matrix with organized crystalline mineral domains and a high protein content can be observed in XRD structure of Figure 3. The graph shows a rather abrupt peak, primarily centred around 16 and 23° (18.578°, 19.479°, 20.339° and 22.618°), and a broad baseline that covers the 2θ range of roughly 10-60°. These acute reflections suggest the presence of moderately ordered crystalline domains,

which could be related fractions of milk, particularly the calcium and phosphate-containing phases associated with casein micelles (Han *et al.*, 2025, Chen *et al.*, 2025) [8, 3]. This baseline is anticipated in both optimized and control dahi because the main structural elements, such as water, whey proteins, casein proteins, and other non-crystalline components, do not create distinct diffraction peaks. During dahi fermentation, casein micelles group together to create a three-dimensional protein gel network when the pH approaches the isoelectric region of casein. The average crystalline size of control and optimized dahi was 30.49 nm and 45.29 nm, respectively, with relative crystallinity (%) of 67.21% and 70.2%.

Table 1: Physicochemical Composition of Optimized and Control Dahi

Chemical composition	Control Dahi	Optimized Dahi
Moisture (%)	87.1 ± 0.1	85.60 ± 0.25
Fat (%)	4.1 ± 0.02	3.9 ± 0.16
Protein (%)	3.4 ± 0.2	3.5 ± 0.30
Ash (%)	0.70 ± 0.03	0.74 ± 0.01
Carbohydrate (%)	4.7 ± 0.66	6.26 ± 0.3
Acidity (%)	0.88 ± 0.2	0.90 ± 0.1

The mean and standard error are used to express the values at $p < 0.05$ for triplicate samples

Table 2: Elemental composition of Optimized and Control Dahi

Elemental composition	Optimized Dahi		Control Dahi	
	Weight (%)	Atomic (%)	Weight (%)	Atomic (%)
C	21.20	26.25	20.59	25.53
N	5.55	5.89	6.20	6.59
F	0.30	0.23	-	-
Mg	0.01	0.01	0.00	0.00
P	0.04	0.02	0.05	0.03
S	0.01	0.00	-	-
K	0.10	0.04	0.07	0.03
Ca	0.16	0.06	0.23	0.09
Mn	0.01	0.00	-	-
Fe	0.01	0.00	0.03	0.01
Cu	0.01	0.00	0.01	0.00
Zn	0.01	0.00	0.01	0.00
Oxygen	72.60	67.49	72.76	67.71

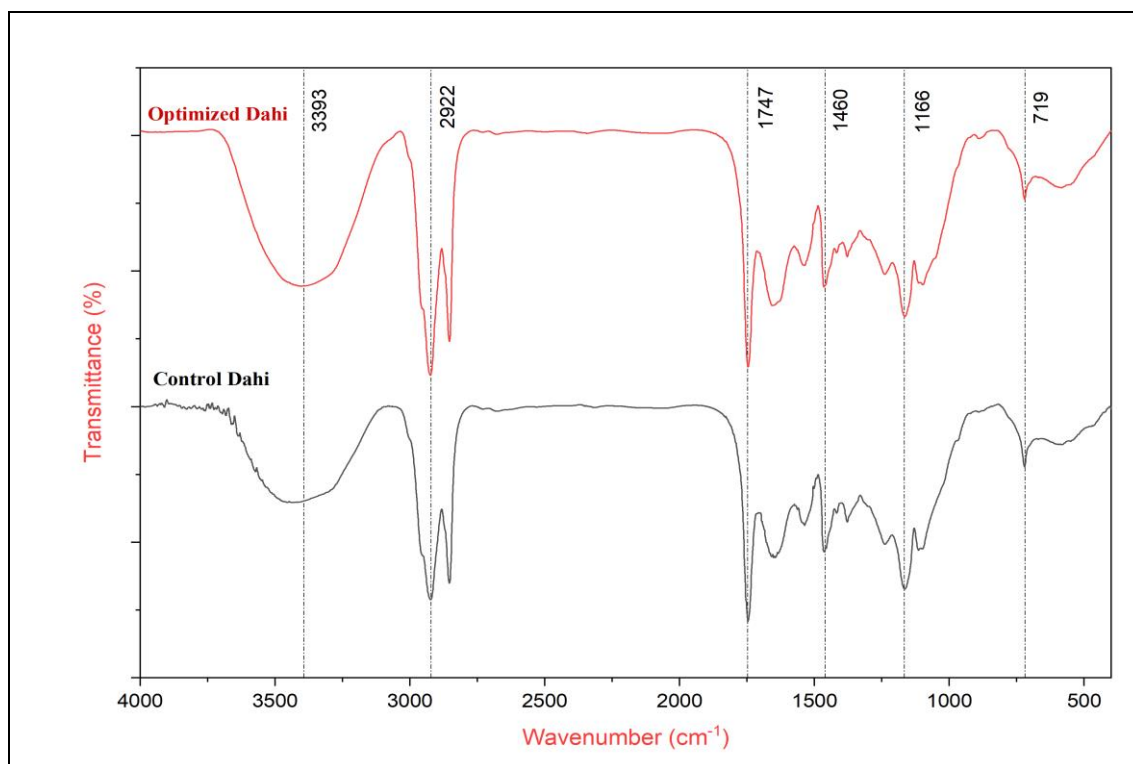


Fig 1: FTIR analysis of Optimized and Control Dahi

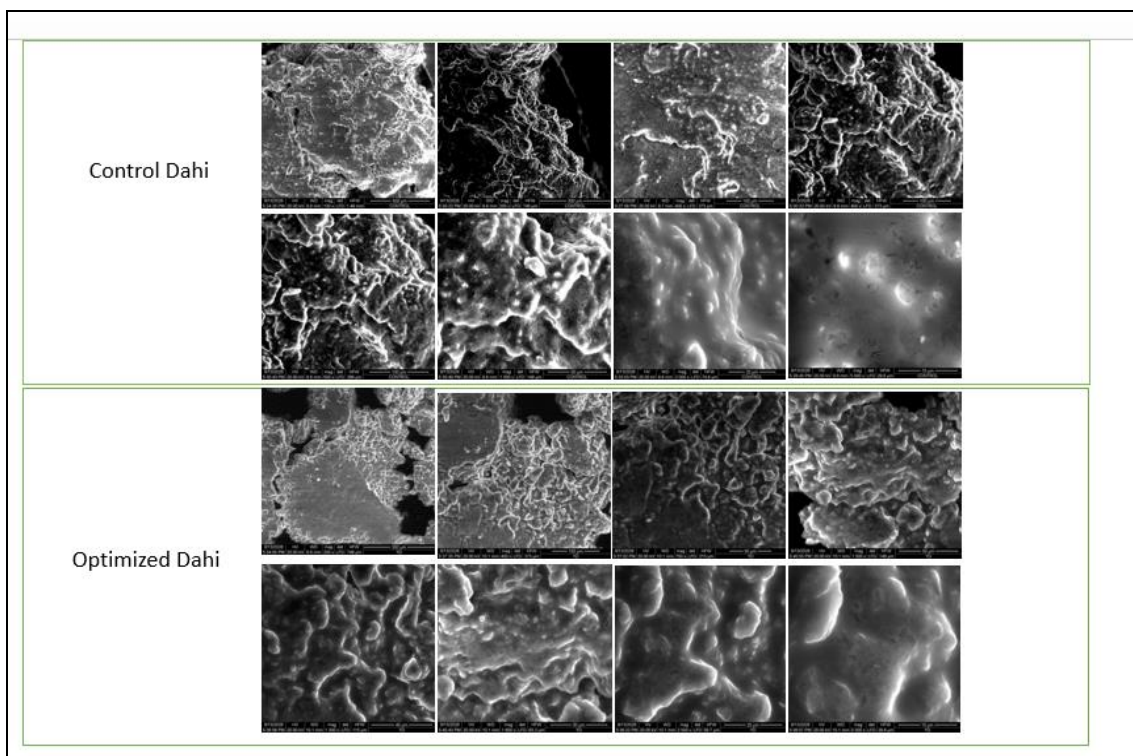


Fig 2: SEM analysis of Optimized and Control Dahi

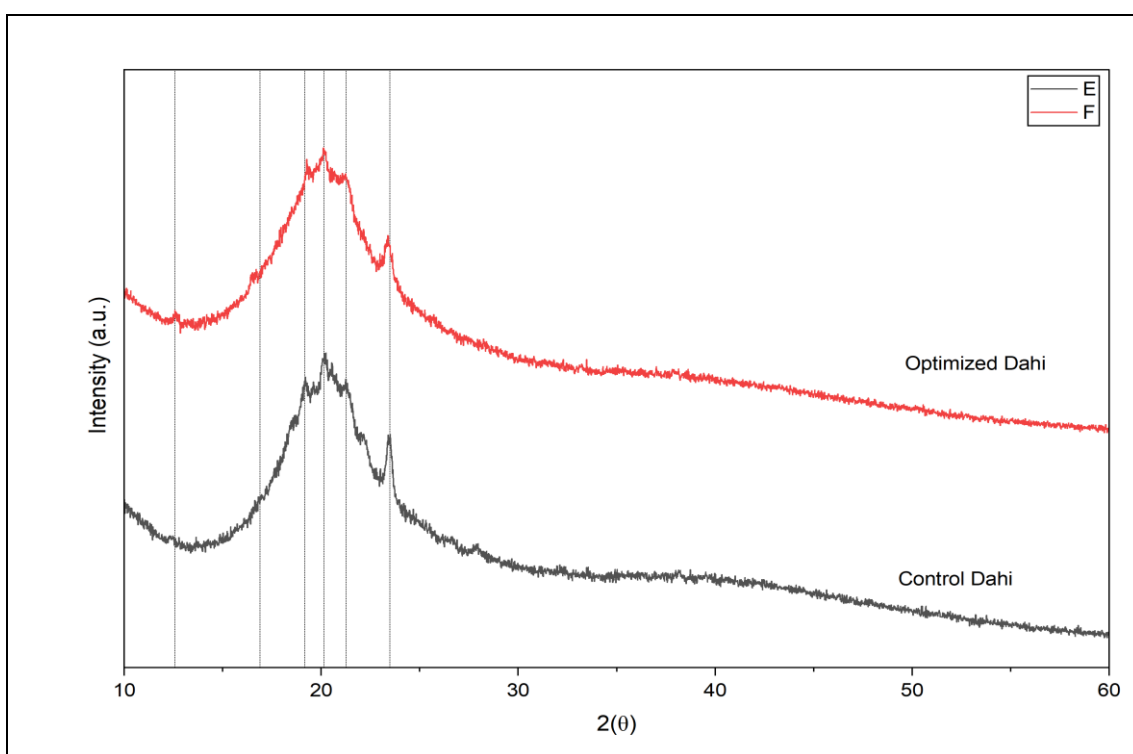


Fig 3: XRD analysis of Optimized and Control Dahi

4. Conclusion

The current study shows that adding dragon fruit powder as a functional element to dahi is feasible. Based on sensory analysis, the 4% fortified dahi was determined to be the most palatable product among the evaluated concentrations of 2%, 4%, and 6%. When comparing the fortified dahi to the control, proximate analysis revealed a comparable change in moisture, fat, ash, and carbohydrate. Different functional groups were identified by FTIR structural characterisation at 3393, 2922, 1747, 1460, 1160, and 719 cm^{-1} . SEM micrographs revealed a porous, spherical, and

aggregation network structure at different magnifications. Elemental analysis using EDX confirmed the presence of the fundamental elements C, O, and N as well as the trace minerals Ca, Mg, Mn, K, P, S, Zn, and Fe. The findings imply that using dragon fruit in the production of dahi can improve the product's nutritional profile while offering consumer a unique and tempting sensation. Therefore, dragon fruit powder may be utilized as a potential nutraceutical ingredient in the production of dairy products with additional value.

This research emphasizes the importance of exploring utilization of dragon fruits in food products, which can provide novel solutions for promoting human health and well-being. Future investigations should focus on elucidating the powder's bioavailability, bioaccessibility, and *in vivo* effectiveness to further unlock its therapeutic potential.

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