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Formulation, and sensory acceptability of a non-dairy Synbiotic functional Kulfi incorporating Bael leaves and banana peel powder with *Streptococcus thermophilus* BURD PB4

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Abstract
The increasing consumer demand for functional and plant-based foods has led to innovations in non-dairy probiotic desserts that combine health benefits with sensory satisfaction. The present study aimed to develop and evaluate a non-dairy synbiotic functional kulfi formulated using oats milk, Bael leaves powder, banana peel powder, herbal sugar, soy lecithin, and probiotic culture *Streptococcus thermophilus* BURD PB4 (Accession No. MN121714). Four formulations were prepared: a control (T_0) using 100% concentrated cow's milk and three experimental treatments (T_1-T_3) with varying concentrations of Bael and banana peel powders (2%, 4%, and 6%) in an oat milk base. Sensory evaluation was conducted by a panel of 50 semi-trained judges using a 9-point hedonic scale to assess colour, flavour, texture, taste, and overall acceptability. The results revealed that T_1 (Oats milk 85%, Herbal sugar 10%, Bael 2%, Banana peel 2%, Probiotic 1%) achieved the highest mean sensory scores across all parameters, followed by T_3 and T_2, while the control recorded the lowest scores. The improved sensory attributes of T_1 can be attributed to the balanced incorporation of prebiotic-rich Bael leaves and banana peel powders, which enhanced flavour complexity, texture smoothness, and colour appeal without imparting bitterness or excessive firmness. The findings were supported by earlier studies indicating that moderate inclusion of plant-based bioactive ingredients enhances both sensory and functional qualities of frozen desserts. The oat milk base provided a creamy consistency comparable to traditional dairy formulations, making it suitable for lactose-intolerant and vegan consumers. Overall, this study demonstrates that the optimized formulation (T_1) successfully combines probiotic functionality, prebiotic enrichment, and sensory acceptability, establishing non-dairy synbiotic kulfi as a promising health-oriented alternative to conventional dairy desserts.

Keywords: Non-dairy synbiotic kulfi, Functional frozen dessert, Bael (*Aegle marmelos*) leaves powder, Banana (*Musa acuminata*) peel powder, Oat milk, Probiotics, *Streptococcus thermophilus* BURD PB4, Prebiotic enrichment, Sensory evaluation, Plant-based functional foods

1. Introduction

Functional foods have gained substantial attention due to their ability to provide health benefits beyond basic nutrition (Verschuren, 2002) [22]. Non-dairy probiotic desserts, such as plant-based kulfi, represent a novel approach to combining sensory satisfaction with nutritional functionality (Akalın *et al*., 2024) [1]. Conventional kulfi formulations rely heavily on dairy, posing challenges for lactose-intolerant individuals and those following vegan diets (Rathod *et al*., 2025) [17]. Hence, developing non-dairy probiotic desserts using natural and functional ingredients is of current scientific and industrial interest.

In recent years, there has been a paradigm shift in food research towards the development of functional foods that not only meet sensory expectations but also deliver targeted health benefits (Birch and Bonwick, 2019) [6]. The incorporation of plant-based bioactive ingredients into novel food matrices has emerged as an effective strategy to enhance nutritional value while addressing specific dietary needs (Gomes and Sobral, 2021) [9]. Such innovations are particularly relevant in the context of non-dairy formulations, where natural functional components can compensate for the absence of dairy-derived nutrients and bioactives (Dey, 2018) [7]. In this regard, the exploration of medicinal plants and agro-industrial by-products as functional ingredients offers a sustainable and health-oriented approach to product development (Ingallina *et al*., 2025) [11]. Bael (*Aegle marmelos*) is a traditional medicinal plant known for its antidiabetic, antioxidant, and hepatoprotective properties (Baliga *et al*., 2011) [4]. Its leaves contain polyphenols, flavonoids, and essential micronutrients, which can act as functional bioactive compounds in foods. Similarly, banana peel powder is rich in carbohydrates, dietary fibre, minerals (iron, zinc, calcium), and antioxidants, making it an ideal ingredient for food fortification and reducing food waste (Padam *et al*., 2014; Zaini *et al*., 2022) [14, 23].

Functional foods have gained substantial attention due to their ability to provide health benefits beyond basic nutrition (Hasler, 2002) [10]. In recent years, research has increasingly focused on the incorporation of bioactive components such as probiotics, prebiotics, and synbiotics into food matrices to promote gut health and overall well-being (Sharifi-Rad *et al*., 2020) [19]. Among these, probiotics have emerged as a key functional ingredient owing to their proven role in modulating intestinal microbiota and enhancing host health (Sánchez *et al*., 2017) [18]. Non-dairy probiotic desserts, such as plant-based kulfi, represent a novel approach to combining sensory satisfaction with nutritional functionality (Akalın *et al*., 2024) [1]. Conventional kulfi formulations rely heavily on dairy, posing challenges for lactose-intolerant individuals and those following vegan diets (Rathod *et al*., 2025) [17]. Hence, developing non-dairy probiotic desserts using natural and functional ingredients is of current scientific and industrial interest. Probiotics such as *Streptococcus thermophilus* BURD PB4 (Accession No. MN121714) are known for their role in improving gut health, modulating immunity, and exerting anti-obesity effects. When combined with prebiotic substrates like Bael leaves and banana peel powders, they form a synbiotic system that enhances probiotic viability and functionality (Gibson *et al*., 2017) [8].

Therefore, this study aims to optimize the levels of Bael leaves powder, banana peel powder, and probiotic culture for the development of a non-dairy synbiotic functional kulfi based on sensory evaluation.

2. Materials and Methods

2.1 Raw Materials

Fresh Bael leaves and banana peels were collected from local markets in Barrackpore, West Bengal, India. Oats milk and herbal sugar were procured from commercial sources. Soy lecithin and probiotic cultures were obtained from the Microbiology Laboratory, Department of Food and Nutrition, Swami Vivekananda University.

2.2 Preparation of Bael Leaves and Banana Peels Powder

Fresh bael leaves and banana peels have chopped up into tiny bits, then Bael leaves have dehydrated at 40 °C for 4-6 hour and Banana peels have also dehydrated at 50 ^{o}C for 72 hours in a hot air-circulating oven after being rinsed with tap water. After properly removed free water from the sample, mixer grinder has used to prepare powder form (Pandey *et al*., 2020) [15].

2.3 Inoculation of Probiotic Culture

Freeze-dried *Streptococcus thermophilus* BURD PB4 (Accession No. MN121714) was taken from the Oriental Institute of Science and Technology, Burdwan, W.B.) The cultures were sub-cultured and maintained under aseptic conditions at the Microbiology Laboratory, Swami Vivekananda University, Barrackpore, West Bengal.

2.4 Treatment combination of Non-dairy Synbiotic functional kulfi

The experimental design included one control and three treatments, as shown in

- T_0 (100 parts concentrated cow milk (control) (Sontakke *et al.*, 2023) [20].
- T_1 (Oats milk-85%, Herbal sugar- 10%, Bael leaves powder- 2%, Banana peels powder 2%, Probiotic 1%, soy lecithin 0.50g).
- T_2 (Oats milk-80%, Herbal sugar- 11%, Bael leaves powder- 4%, Banana peels powder 4%, Probiotic 1%, soy lecithin 0.50g).
- T_3 (Oats milk-75%, Herbal sugar- 12%, Bael leaves powder- 6%, Banana peels powder 6%, Probiotic 1%, soy lecithin 0.50g).

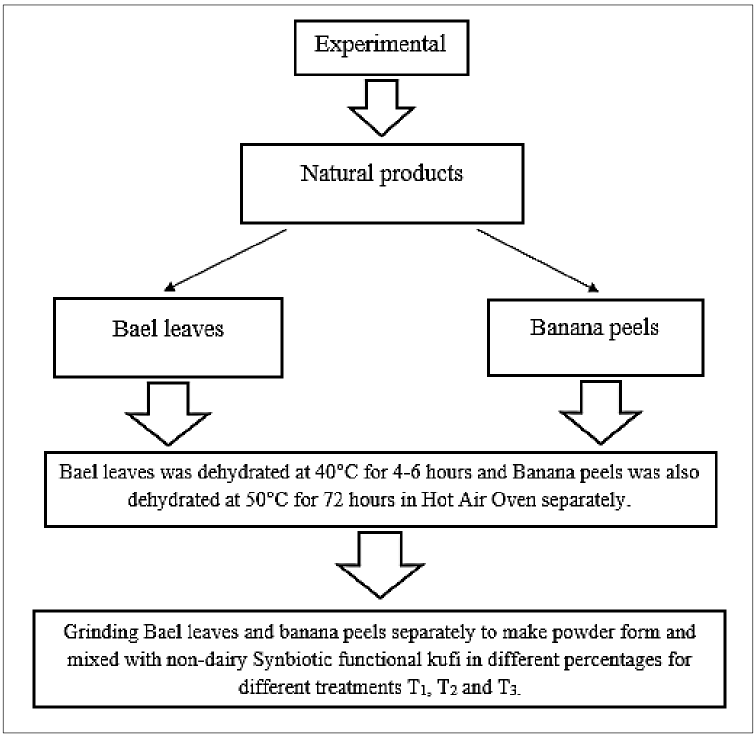

Fig 1: Flow chart for development of raw materials

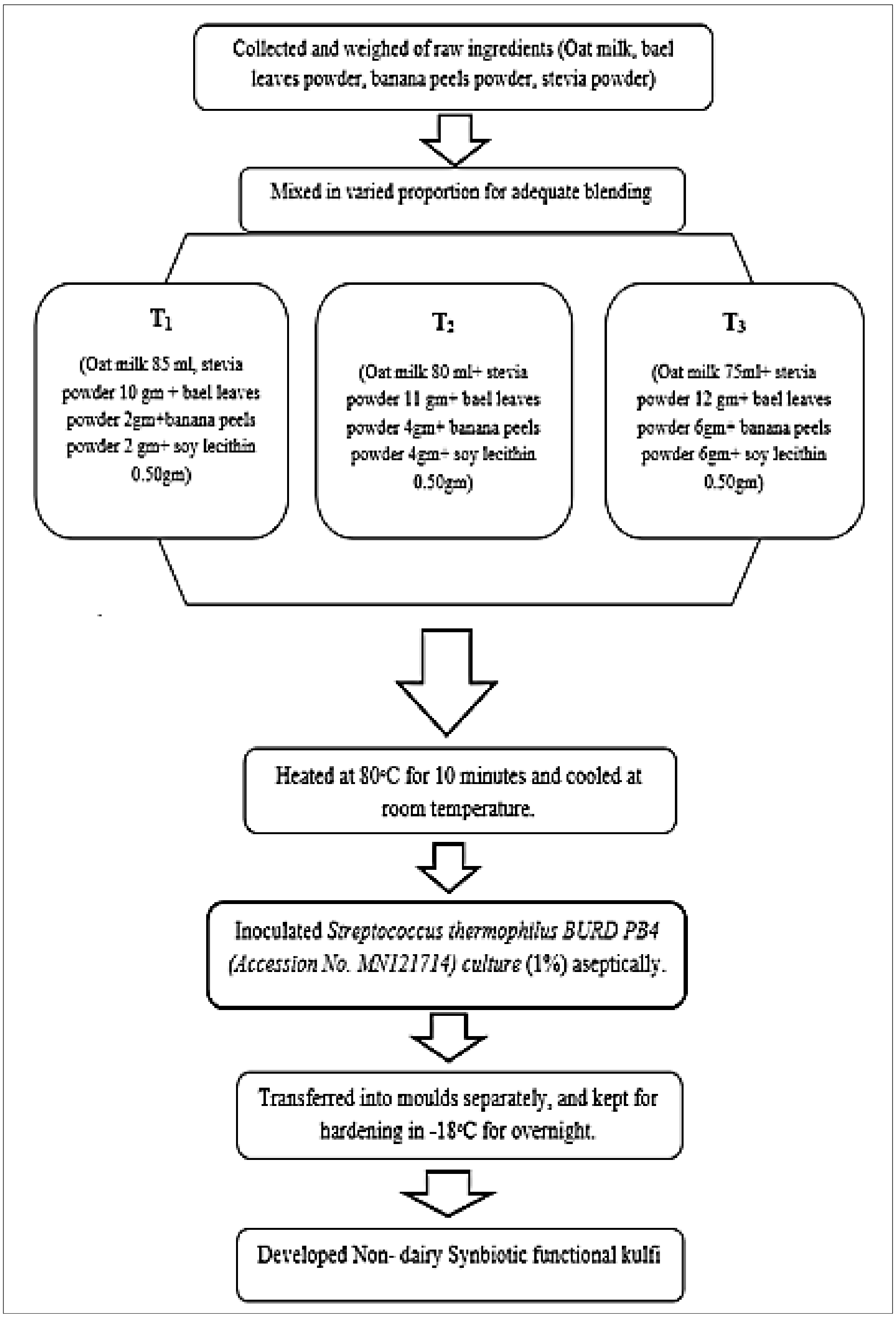

Fig 2: Flow chart for development of experimental Kulfi

Preparation of Non-Dairy Synbiotic Functional Kulfi

Oats milk was heated at 80 °C for 10 minutes with constant stirring. Herbal sugar was added gradually, followed by Bael leaves and banana peel powders. Soy lecithin was then incorporated as an emulsifier. After cooling to 40 °C, *Streptococcus thermophilus* BURD PB4 (Accession No. MN121714) culture (1%) was added aseptically. The mixture was poured into molds and stored at -18 °C overnight to set (Tewari *et al*., 2021) [21].

Sensory Evaluation

A sensory panel of 50 semi-trained judges evaluated the kulfi samples for colour, flavour, texture, and overall acceptability using a 9-point hedonic scale. The evaluation was conducted in triplicate at three-day intervals. To minimize bias, the panelists were seated separately, and samples were coded and served randomly as per the standard sensory evaluation procedures.

Statistical Analysis

To determine the statistical significance of the research data, One-Way Analysis of Variance (ANOVA) technique and Critical difference (C.D) were used. All values are expressed as mean and standard deviation of three parallel measurements.

Results and Discussion

Table 1: Sensory Evaluation of Non-Dairy Synbiotic Functional Kulfi Formulations

Treatment	Colour	Flavour	Texture	Taste	Overall Acceptability
T_0 (Control) (100% concentrated cow's milk)	7.20±0.12^a	7.10±0.15^a	7.30±0.10^a	7.00±0.14^a	7.15±0.11^a
T_1(Oats milk 85%, Herbal sugar 10%, Bael leaves 2%, Banana peel 2%, Probiotic 1%)	8.35±0.08^c	8.45±0.09^c	8.50±0.07^c	8.60±0.06^c	8.47±0.07^c
T_2(Oats milk 80%, Herbal sugar 11%, Bael leaves 4%, Banana peel 4%, Probiotic 1%)	7.60±0.11^{ab}	7.50±0.12^b	7.55±0.09^b	7.45±0.13^b	7.53±0.10^b
T_3(Oats milk 75%, Herbal sugar 12%, Bael leaves 6%, Banana peel 6%, Probiotic 1%)	7.80±0.10^b	7.60±0.13^b	7.65±0.12^b	7.55±0.11^b	7.65±0.09^b

All the test were performed in triplets. Different letter in the same column indicates statistical significance level of $p<0.0001$.

The sensory evaluation data presented in Table 1 reveal significant differences among the four formulations of non-dairy synbiotic functional kulfi, indicating that the incorporation of bael (*Aegle marmelos*) leaves powder and banana peel powder notably influenced the sensory quality of the developed product. The five key sensory parameters assessed colour, flavour, texture, taste, and overall acceptability demonstrated that the experimental treatments (T_1, T_2, and T_3) formulated with oats milk and functional ingredients performed comparably or superiorly to the control (T_0), which was prepared using 100% concentrated cow's milk. Among the formulations, T_1 (Oats milk 85%, Herbal sugar 10%, Bael leaves 2%, Banana peel 2%, Probiotic 1%) received the highest mean sensory scores across all attributes, suggesting that the moderate incorporation of plant-based powders enhanced the visual appeal, flavour complexity, and overall palatability of the synbiotic kulfi.

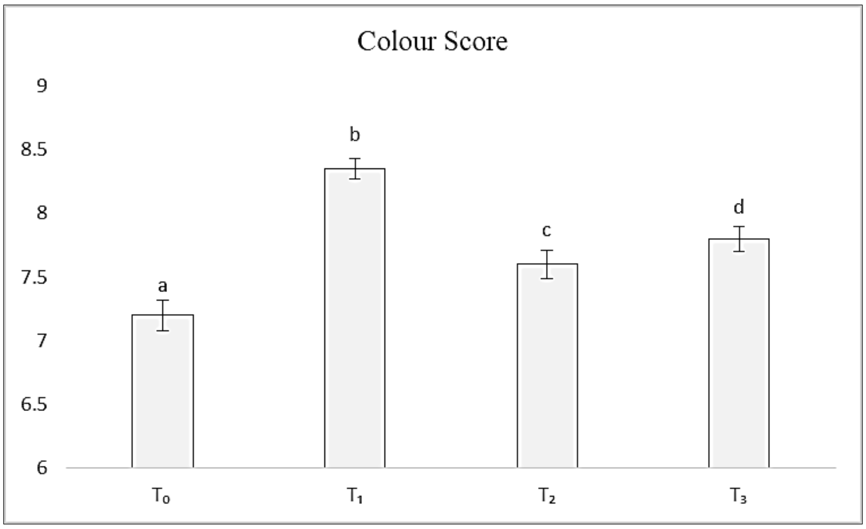

Fig 3: Colour score of newly developed non-dairy synbiotic kulfi after sensory evaluation

The colour of kulfi is a key sensory indicator that influences consumer perception and acceptability. The T_1 sample exhibited the highest colour score (8.35±0.08^c) compared to the control (7.20±0.12^a). This improvement may be attributed to the subtle greenish hue imparted by Bael leaves powder and the light brown tint from banana peel powder, providing a natural and appealing colour. In contrast, higher concentrations of Bael leaves and banana peel powders (T_3, 6% each) slightly darkened the product, which may have reduced consumer preference. Similar findings were reported by Ji (2024) [12], who observed that the incorporation of malted quinoa flour in functional kulfi enhanced colour appeal up to an optimal concentration but resulted in undesirable darkness beyond that threshold. Likewise, Puttasiddaiah *et al*. (2022) [16] reported that the inclusion of natural bioactive ingredients improved the overall appearance of kulfi but excessive addition could lead to visual changes perceived as less appealing.

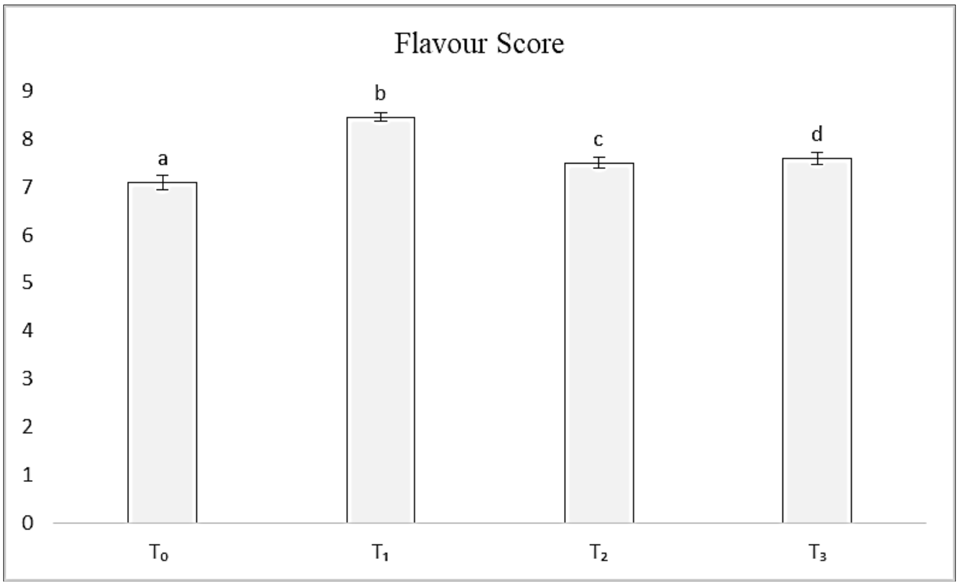

Fig 4: Flavour score of newly developed non-dairy synbiotic kulfi after sensory evaluation

The flavour score followed a similar trend, with T_1 (8.45±0.09^c) rated significantly higher than the control (7.10±0.15^a) and other treatments. The enhancement in flavour could be due to the synergistic effect of Bael and banana peel powders, which contain aromatic compounds and natural sweetness that complement the herbal sugar and oats base. Moreover, the presence of prebiotic fibres may have contributed to improved mouthfeel and flavour retention. However, the T_3 sample with higher levels of Bael leaves and banana peel powders (6% each) exhibited slightly lower flavour scores (7.60±0.13^b), likely due to the development of a mild astringent aftertaste caused by excess polyphenols and tannins from Bael leaves. These results align with the findings Akalın (2024) [1], who reported that the inclusion of herbal or fruit-based powders in probiotic frozen desserts enhances flavour up to an optimal concentration but excessive incorporation may lead to off-flavours and reduced consumer liking. Furthermore, the oat milk base contributed a mild and creamy flavour comparable to dairy milk, supporting its suitability as a plant-based milk alternative in frozen desserts, as previously discussed by Nedele *et al*. (2023) [13] in their evaluation of oat-based functional beverages.

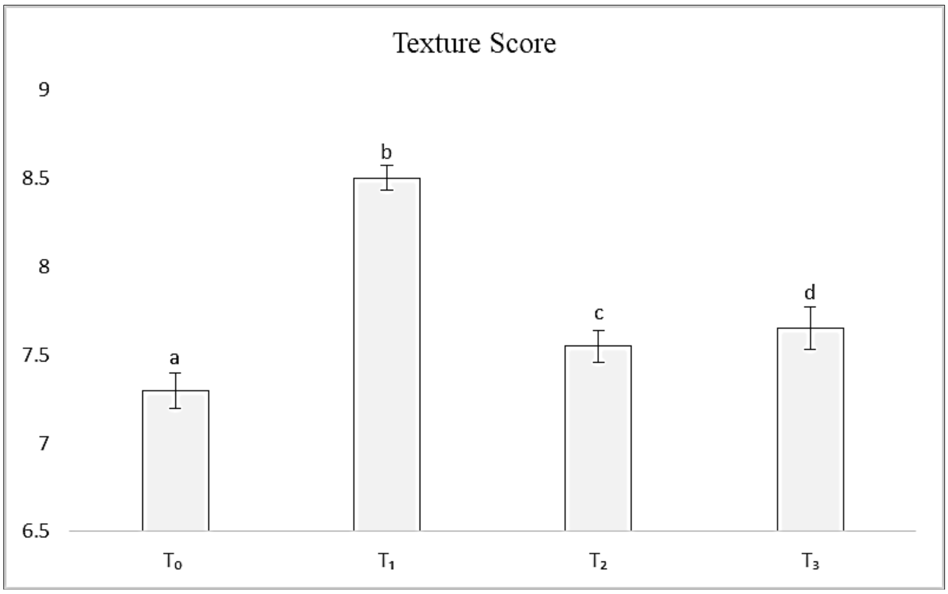

Fig 5: Texture score of newly developed non-dairy synbiotic kulfi after sensory evaluation

In terms of texture, T_1 again achieved the highest score (8.50±0.07^c), followed by T_3 (7.65±0.12^b) and T_2 (7.55±0.09^b), while the control recorded the lowest (7.30±0.10^a). The improved texture in oat-based formulations can be attributed to the natural viscosity and emulsifying properties of oats milk, as well as the dietary fibre and pectin present in banana peel powder, which enhanced body and creaminess while minimizing ice crystal formation during freezing. The moderate inclusion levels in T_1 provided optimal smoothness and mouthfeel, whereas higher levels in T_3 slightly increased firmness due to excess fibre, leading to a denser texture. Similar textural improvements in fibre-enriched frozen desserts were documented by Park *et al*. (2015) [25], who found that dietary fibres help stabilize air cells and moisture content, resulting in finer ice crystal structures. Padam *et al*. (2014) [14] also highlighted the functional potential of banana peel powder as a stabilizer due to its high soluble fibre content, which contributes to smoother consistency and better water-holding capacity in dairy and non-dairy desserts.

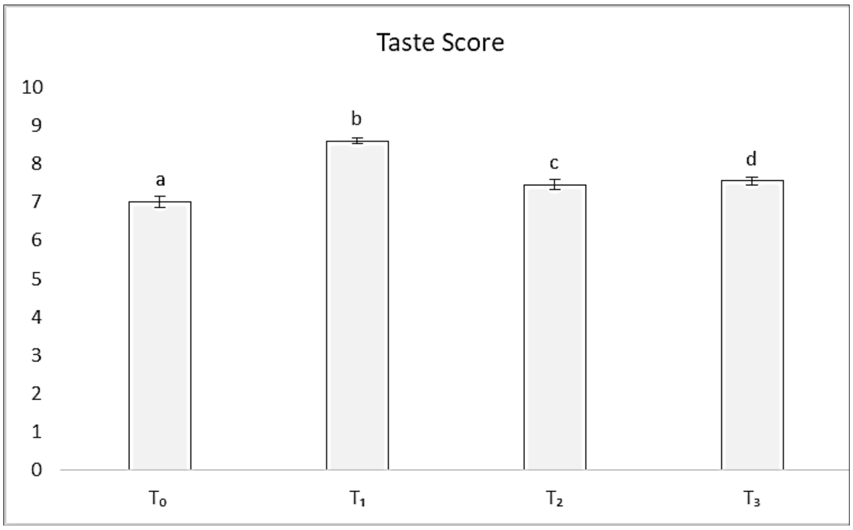

Fig 6: Taste score of newly developed non-dairy synbiotic kulfi after sensory evaluation

The taste attribute showed a consistent trend, with T_1 achieving the highest score (8.60 ± 0.06^c). The combination of herbal sugar (stevia-based), Bael leaves, and banana peel powders in moderate amounts provided a naturally sweet and mildly herbal taste that was preferred by the sensory panel. Conversely, the higher concentration in T_3 (6% each) resulted in a slightly bitter and earthy flavour profile, reducing taste acceptability (7.55 ± 0.11^b). The control (T_0) was rated lowest (7.00 ± 0.14^a), possibly due to the absence of functional ingredients contributing to flavour complexity. These findings are in agreement with Puttasiddaiah *et al*. (2022) [16], who observed that the inclusion of natural antioxidants such as plant extracts improved taste and flavour in kulfi, and Ji (2024) [12], who demonstrated that plant-based fortification up to moderate levels enhances sensory satisfaction without imparting bitterness.

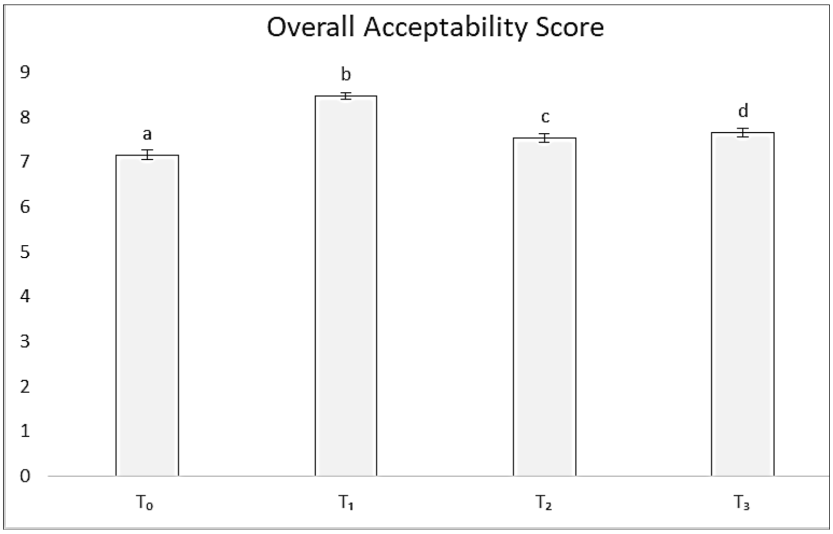

Fig 7: Overall acceptability score of newly developed non-dairy synbiotic kulfi after sensory evaluation

For overall acceptability, T_1 recorded the highest mean score (8.47 ± 0.07^c), significantly surpassing the control (7.15 ± 0.11^a) and other treatments (T_2 and T_3). This indicates that the formulation with 2% bael leaves and 2% banana peel powders achieved a balance between nutritional enhancement and sensory desirability. The results suggest that a moderate inclusion level of prebiotic ingredients can improve both the sensory and functional quality of the product without compromising consumer acceptance. In comparison, the control kulfi prepared solely from cow milk was perceived as rich but lacked the functional appeal and subtle flavour diversity introduced by the plant-based ingredients. Similarly, Ji (2024) [12] concluded that the optimal incorporation of plant powders in kulfi improved sensory scores while maintaining texture and flavour harmony.

Overall, the sensory results emphasize that the incorporation of bael leaves and banana peel powders into an oat milk-based synbiotic kulfi formulation significantly enhances consumer-perceived quality attributes. The findings align with previous research demonstrating that plant-based ingredients can improve the nutritional and sensory characteristics of dairy alternatives through their bioactive components, natural colourants, and texture-modifying properties. Importantly, the study highlights that moderate levels (2-4%) of such functional additives optimize sensory performance, whereas higher concentrations may adversely affect taste and appearance due to excessive fibre and phenolic compounds (Akalın *et al*., 2024) [1]. Therefore, formulation optimization is essential to balance functional enrichment with consumer preference. The superior performance of T_1 across all sensory parameters establishes it as the most acceptable and nutritionally advantageous formulation, supporting the feasibility of developing a non-dairy synbiotic kulfi that caters to modern health trends while preserving the traditional sensory appeal of this beloved frozen dessert.

Conclusion

The development and sensory evaluation of non-dairy synbiotic functional kulfi formulated with bael leaves and banana peel powders demonstrated that plant-based ingredients can significantly enhance the nutritional and sensory properties of traditional frozen desserts. Among all formulations, the treatment T_1 containing 2% bael leaves and 2% banana peel powders in an oat milk base was identified as the most acceptable based on its superior sensory attributes of colour, flavour, texture, taste, and overall acceptability. The balanced combination of prebiotic-rich powders and probiotic culture (*Streptococcus thermophilus* BURD PB4) not only improved sensory appeal but also contributed to the product's functional value, providing a potential synbiotic benefit. The oat milk-based system effectively replaced dairy without compromising the desirable mouthfeel or creaminess associated with conventional kulfi. Higher inclusion levels (4-6%) of bael leaves and banana peels powders, however, resulted in slightly lower acceptability due to increased astringency and fibre-related firmness, underscoring the importance of optimization in functional product formulation. The results align with previous studies on functional frozen desserts fortified with plant ingredients, which emphasize that moderate incorporation enhances overall palatability and nutritional worth. In conclusion, the optimized formulation offers an innovative, nutritionally enriched, and consumer-acceptable alternative suitable for individuals with lactose intolerance or vegan dietary preferences. Future studies should focus on the shelf-life stability, probiotic viability during storage, and biochemical characterization of bioactive retention to further substantiate its potential as a commercial non-dairy synbiotic dessert.

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