**Quality, Shelf-Life, and Consumer Acceptability of Probiotic Yogurt Enriched with Banana and Mango Fruit Peels**

**Abstract**

This study evaluated the effects of incorporation of fresh mango peel (FMP) and fresh banana peel (FBP) on the physicochemical, microbiological, probiotic, and sensory characteristics of yogurt during 28 days of refrigerated storage. Proximate analysis showed that banana peel contained significantly higher dietary fiber (3.94 ± 0.74%) and carbohydrates (12.99 ± 0.26%) than mango peel (2.44 ± 0.11% and 10.62 ± 0.23%, respectively; p < 0.05), while mango peel had greater protein (2.86 ± 0.21%) and ash (3.76 ± 0.16%) contents. All yogurt samples experienced a pH decline over time, with more pronounced acidification in yogurts fortified with 10% FMP (pH 4.27 ± 0.01) and 10% FBP (pH 4.34 ± 0.01) by Day 28, compared to the control (pH 4.42 ± 0.01), indicating enhanced post-fermentation activity. Syneresis was significantly reduced by peel addition; on Day 28, control yogurt showed 45.00 ± 4.00% syneresis, while 10% FMP and 10% FBP treatments lowered this to 8.00 ± 0.00% and 12.00 ± 1.00%, respectively (p < 0.05). This reduction is attributed to the high dietary fiber in the peels, which improves water-holding capacity and gel stability in yogurt. Probiotic viability was notably improved in banana peel-fortified yogurts. Control and low-level FMP (1%, 5%, 10%) and 1% FBP samples had initial probiotic counts around 2.2–2.3 log10 CFU/ml ×106, decreasing to ~1.6–1.7 log10 CFU/ml ×106 by Day 28. In contrast, 5% and 10% FBP yogurts exhibited higher initial counts of 5.0 and 5.2 log10 CFU/ml ×106, respectively, maintaining levels above 3.0 log10 CFU/ml ×106 through Day 28. This enhancement is attributed to the fermentable oligosaccharides and prebiotic compounds present in banana peel, which promote probiotic growth and stability. Microbiological safety was confirmed, with yeast and mold counts remaining below SLSI limits (<1000 CFU/g). Sensory analysis indicated that 10% FBP-fortified yogurts matched the control in acceptability, whereas higher mango peel levels reduced consumer preference. These results demonstrate the potential of fruit peel fortification as a sustainable strategy to improve yogurt quality, probiotic viability, and shelf life.

**Keywords:** Banana peel, Mango peel, Yogurt fortification, Prebiotic, Probiotic viability

1. **Introduction**

The global demand for functional foods has risen sharply over the past decade, driven by consumer awareness of the link between diet and health. Among these, probiotic yogurt has gained particular prominence due to its dual role as a nutritious dairy product and a carrier of beneficial microorganisms that promote gut health, immune modulation, and chronic disease prevention (Ali et al., 2022; Çelik, 2023). However, one of the critical challenges in probiotic yogurt production lies in maintaining the viability of probiotic strains during refrigerated storage, as factors such as low pH and oxidative stress negatively impact microbial stability (Terpou et al., 2019). To address this issue, current research has turned to the incorporation of natural bioactive compounds from plant sources, especially fruit by-products—as a means of enhancing yogurt's functional and storage properties while reducing food waste (Sorrenti et al., 2023; Zaini et al., 2022).

Fruit peels, often discarded as agricultural waste, are rich in dietary fiber, polyphenols, vitamins, and other bioactive compounds with potential health benefits and technological functionality (Mahomud et al., 2024; Zaki et al., 2024). These compounds may serve not only as nutritional enhancers but also as prebiotics that support probiotic survival and stability in fermented dairy products (Blanco-Pérez et al., 2021; De-Oliveira et al., 2022). Incorporating fruit peels into yogurt can also improve textural characteristics by increasing water retention and reducing syneresis, thereby contributing to product consistency and consumer acceptability (Mahomud et al., 2024). Moreover, this approach offers a sustainable strategy for valorizing fruit processing residues, especially in tropical countries with high seasonal fruit production.

Banana (*Musa acuminata*) and mango (*Mangifera indica*) are among the most widely consumed tropical fruits globally and in Sri Lanka (Kothalawala and Yatiwella, 2018; Maduwanthi and Marapana, 2019; Thilakarathna and Perera, 2024). Together, their peels account for approximately 30–40% of the total fruit weight, representing a substantial volume of agro-industrial waste (FAOSTAT, 2020). Banana peels are particularly rich in resistant starch, dietary fiber, and oligosaccharides such as fructooligosaccharides (FOS) and xylooligosaccharides (XOS), which are known to promote the growth of beneficial gut bacteria like *Bifidobacterium* and *Lactobacillus* (Zaini et al., 2022; Chockchaisawasdee and Stathopoulos, 2022; Zahid et al., 2022). These compounds also contribute to the textural and functional stability of yogurt by acting as moisture binders and buffering agents (Zare et al., 2011; Zahid et al., 2023). Mango peels, meanwhile, are rich in antioxidants such as mangiferin, carotenoids, vitamin C, and phenolic acids, which possess antimicrobial and anti-inflammatory activities that may help protect probiotics during storage (Rather et al., 2023; Kučuk et al., 2024).

Despite their rich nutritional profiles, banana and mango peels are largely underutilized in Sri Lanka, where they are typically discarded at household and industrial levels due to lack of awareness and limited processing infrastructure (Kothalawala and Yatiwella, 2018; Sasanka et al., 2024). As a result, significant volumes of fruit waste contribute to environmental pollution and economic loss (Kothalawala and Yatiwella, 2018; Sagar et al., 2018). Integrating these peels into value-added food products such as yogurt provides a promising opportunity to address food system inefficiencies while delivering health-enhancing functional foods. This dual benefit aligns with global efforts to reduce food waste and promote circular economic practices within the agri-food sector.

From a consumer perspective, the incorporation of natural, recognizable ingredients such as fruit peels can enhance product appeal—especially when such additions improve sensory characteristics like mouthfeel and consistency. However, the inclusion of plant-based materials may also influence flavor, color, and texture in ways that affect consumer acceptability (Zaini et al., 2022; Ashraf et al., 2022; Mahomud et al., 2024). Therefore, it is essential to optimize peel concentrations and assess their sensory impact alongside physicochemical and microbiological attributes.

To date, few studies have systematically evaluated the effect of whole fresh banana and mango peels—rather than dried powders or purified extracts—on the quality and probiotic viability of yogurt during storage. Fresh peels retain native bioactive compounds and moisture, which may interact differently with the yogurt matrix compared to processed forms. Understanding these interactions is crucial to developing scalable, cost-effective formulations suitable for both home and industrial applications.

This study aims to investigate the incorporation of fresh banana and mango peels into probiotic yogurt and assess their impact on physicochemical properties (such as pH and syneresis), microbial viability (including probiotics and spoilage organisms), and consumer acceptability over a 28-day refrigerated storage period. By doing so, the research seeks to determine whether fresh fruit peels can serve as functional yogurt additives that enhance shelf life and sensory quality without compromising safety. Ultimately, the findings are expected to contribute to the development of sustainable, clean-label dairy products while offering a novel utilization route for fruit peel waste in tropical agricultural systems.

1. **Materials and Methods**
	1. **Fruit Selection**

Fully ripe, fresh, healthy, and symptom-free mango (*Mangifera indica*, variety “Karathakolomban”) and banana (*Musa acuminata*, variety “Kolikuttu”) fruits were carefully selected for this study. The mango fruits were collected from several different trees within a single commercial orchard in Anuradhapura, while the banana fruits were sourced similarly from multiple trees within a farm in Ambilipitiya, Sri Lanka. This sampling approach was adopted to maintain consistency and account for potential variability among individual trees within the same cultivation environment.

* 1. **Fruit Peel Paste Preparation**

Fruit peel paste was prepared following the method described by Mahomud *et al.* (2024), with slight modifications. After harvesting, the fruits were transported under ambient temperature conditions (approximately 25 °C) to the Laboratory of Rich Life Lanka Pvt Ltd, Wadduwa, Sri Lanka. Upon arrival, the fruits were temporarily stored at the same temperature for one day to stabilize the raw materials prior to processing. Subsequently, the fruits were washed thoroughly using chlorinated water to remove surface contaminants and then manually peeled. For both mango and banana, the peels were carefully separated from the edible portion using a stainless-steel knife and sliced into uniform sections of 2–3 mm thickness. To minimize enzymatic browning, the sliced peels were soaked in a 0.5% (m/v) citric acid solution for 5 minutes. After draining, the fresh mango and banana peels was separately pulverized using a laboratory grinder (IKA® MF 10 Basic Microfine Grinder Drive, Germany) to obtain a paste.

* 1. **Proximate Analysis of Fresh Mango and Banana Peels**

The proximate composition of fresh peels of mango and banana was determined using the standard analytical procedures recommended by Official Methods of Analysis of AOAC International (Association of Official Analytical Chemists, 2005). The analysis included quantification of moisture, crude protein, crude fat, ash, and crude fiber contents. Moisture content was determined by oven-drying the samples at 105 °C until a constant weight was reached. Crude protein content was measured using the Kjeldahl method, applying a nitrogen-to-protein conversion factor of 6.25. Crude fat was extracted using a Soxhlet apparatus with petroleum ether as the solvent. Ash content was obtained by incinerating the samples in a muffle furnace at 550 °C until white ash was formed. Crude fiber was assessed through sequential acid and alkaline digestion. The total carbohydrate content was estimated by difference, i.e., by subtracting the sum of the measured values of moisture, crude protein, crude fat, ash, and crude fiber from 100%.

* 1. **Yogurt Preparation with Fresh Peel Incorporation**

Full-fat cow milk was sourced from the milk collecting center at Wadduwa, a registered supplier for Rich life Dairies Pvt Ltd, Sri Lanka. Granulated sugar and a commercial yogurt starter culture were procured from certified food ingredient suppliers in Sri Lanka. The collected milk was standardized to 3.5% fat content using a laboratory-scale cream separator (Milky FJ 90, Austria).

The milk was pasteurized at 85 °C for 10 minutes, after which sugar (8.78%) and gelatin (0.6%) were added and thoroughly mixed. The mixture was then homogenized using a laboratory homogenizer (GEA Niro Soavi Panda Plus 2000, Italy) to ensure a uniform consistency. Following homogenization, the milk was cooled to 42 °C, and 0.01% (w/w) of a mixed starter culture—comprising *Streptococcus thermophilus*, *Lactobacillus delbrueckii* subsp. *bulgaricus*, and *Bifidobacterium animalis* subsp. *Lactis* (ABY 10)—was inoculated.

A standardized yogurt base was used to prepare one control sample and two distinct sets of treatment groups (Table 1). These groups consisted of yogurt incorporated with fresh fruit peels—each applied separately for both mango and banana peels. This design enabled a comprehensive assessment of the impact of fresh peel on the physicochemical and sensory properties of yogurt.

Following preliminary trials, specific concentrations of fresh peel were selected for each treatment. For the fresh peel treatments, mango and banana peel paste were incorporated into 1 L of yogurt mixture at concentrations of 1%, 5%, and 10% (Table 1). All treatments were prepared in triplicate. Each yogurt mixture was poured into sterile containers and incubated at 42 °C for 4 hours to facilitate fermentation and setting. Following incubation, the yogurt samples were transferred to refrigerated storage at 4 °C for subsequent physicochemical, sensory, and shelf-life analyses.

The control sample was prepared using the standardized yogurt base without any added peel or pectin. To confirm the standardization of the yogurt base, proximate composition of the control yogurt sample was determined prior to incorporating fruit peel treatments.

**Table 1:** Summary of Yogurt Treatments with Mango and Banana Peel Forms

|  |  |  |  |
| --- | --- | --- | --- |
| Treatment Code | Fruit Type | Form Used | Concentration (% w/v) |
| C | - | None (Control) | 0% |
|  |  |  |  |
| FM1 | Mango | Fresh Peel | 1% |
| FM5 | Mango | Fresh Peel | 5% |
| FM10 | Mango | Fresh Peel | 10% |
| FB1 | Banana | Fresh Peel | 1% |
| FB5 | Banana | Fresh Peel | 5% |
| FB10 | Banana | Fresh Peel | 10% |

* 1. **Analysis of pH during Storage**

pH of the yogurt samples was analyzed at weekly intervals during 28 days of refrigerated storage at 4 °C to evaluate the impact of fruit peel and pectin incorporation on acidity changes over time. The pH was measured using a calibrated digital pH meter (SENSION pH meter, Hach, USA). Measurements were taken on days 1, 7, 14, 21, and 28 for all treatment groups, including yogurts incorporated with fresh mango and banana peels and extracted pectin, as well as the control sample. This analysis helped monitor the progression of lactic acid fermentation and overall product stability during storage.

* 1. **Analysis of Syneresis during Storage**

Syneresis of yogurt samples was measured following the method described by Mahomud et al., (2024), with slight modifications. For each analysis, 10 g of yogurt was placed on a 10 cm piece of Whatman No. 2 filter paper and positioned in a Büchner funnel. Vacuum filtration was applied for six minutes, after which the amount of whey released was weighed. Syneresis was calculated as the percentage of whey released relative to the initial yogurt weight. Measurements were conducted on days 1, 7, 14, 21, and 28 of refrigerated storage at 4 °C to assess water separation and gel stability over time. The evaluation was carried out separately for yogurt incorporated with fresh fruit peels and extracted pectin of both mango and banana.

* 1. **Enumeration of Yeasts and Molds in Yogurt Samples**

The enumeration of yeasts and molds in yogurt samples was performed using the spread plate technique on Potato Dextrose Agar (PDA). Approximately 1 mL of appropriately diluted yogurt samples was aseptically plated onto PDA and evenly spread using a sterile glass spreader. The inoculated plates were incubated at 25 °C for 5 days to allow for optimal fungal growth. After incubation, the colonies were visually identified and manually counted to assess the extent of yeast and mold contamination.

* 1. **Enumeration of Coliform Bacteria in Yogurt Samples**

The enumeration of coliform bacteria in yogurt samples was performed using the Most Probable Number (MPN) method (Jiffry and Nandanee, 2024). Approximately 10 ± 0.05 g of each sample was homogenized in 90 mL of sterile distilled water. From this, 10 mL was inoculated into double-strength lactose broth, 1 mL into single-strength broth (three tubes), and 0.1 mL into another set of single-strength tubes. All tubes were incubated at 37 °C for 24–48 hours. Gas production and turbidity were used as indicators of coliform presence. *Escherichia coli* served as the positive control, while Bacillus sp. was used as the negative control to validate the test reliability.

* 1. **Survival of Probiotic Bacteria in Yogurt**

The probiotic viability of yogurt samples incorporated with banana and mango peels, as well as the control plain yogurt, was determined using de Man, Rogosa and Sharpe (MRS) agar containing 0.05% bile salts. A 1 g yogurt sample was homogenized in 9 mL of sterile peptone water to obtain a 10⁻¹ dilution, and subsequent serial dilutions were prepared accordingly. One milliliter from each dilution was plated onto MRS agar. The plates were incubated at 37 °C for 72 hours under both aerobic and anaerobic conditions, the latter established using an anaerobic jar. *Lactobacillus casei* and *Lactobacillus gasseri* were enumerated to assess probiotic viability during storage, providing insight into the functional quality of the yogurt samples as described in Safdari et al., (2021). Final counts were expressed in logarithmic form (log CFU/g) to facilitate comparison of probiotic viability among the different treatment groups—namely control, banana peel-incorporated, and mango peel-incorporated yogurts.

* 1. **Sensory Evaluation of Yogurt Enriched with Banana and Mango Peels**

Sensory evaluation of yogurt samples incorporated with banana and mango fresh peels was conducted separately for each fruit type and treatment. A plain set-yogurt was used as the control. A panel of thirty-five individuals (17 men and 18 women, aged 25–50) was selected through purposive sampling based on age, gender, cultural background, and familiarity with dairy products. Panel size was determined using statistical power analysis to ensure sufficient sensitivity in detecting differences. Two preliminary training sessions were held to orient panellists on safety procedures, evaluation protocols, and product familiarity. Evaluations were conducted under standardized conditions (24 °C) to minimize bias. A seven-point hedonic scale (1 = extreme dislike, 7 = extreme like) was used to assess color, texture, taste, odor, and overall acceptability. Initially, separate evaluations identified the most-preferred fresh peel concentration. A final round compared selected mango and banana treatments with the control.

* 1. **Statistical Analysis**

All analyses were conducted in triplicate, and the results were expressed as mean ± standard deviation (SD). To determine significant differences in the proximate composition of banana and mango peels, a paired t test was performed at a significance level of P < 0.05. A two-way ANOVA was used to assess the effects of two independent variables—peel concentration treatment (Control, 1%, 5%, 10% mango or banana peel) and storage duration (Day 1, 7, 14, 21, 28)—on the physicochemical and microbial properties of yogurt. The interaction effects between treatment and storage time were also evaluated. Tukey’s HSD test was employed for multiple comparisons among group means.

1. **Results and Discussion**
	1. **Proximate Composition of Mango and Banana Fruit Peels**

The proximate composition of fresh mango (*Mangifera indica*, variety “*Karathakolomban*”) and banana (*Musa acuminata*, variety “*Kolikuttu*”) peels is presented in Table 2. The fiber content was significantly higher in banana peel (3.94±0.74%) than mango peel (2.44±0.11%), aligning with findings by Oguntoyinbo et al. (2020) who reported fiber concentrations around 3.2% in banana peels. The observed increase is likely due to fruit maturity, and varietal differences. Reddy et al. (2011) also confirmed that mango peels contain dietary fiber including pectin, cellulose, and lignin, supporting its functional value. The protein content was higher in mango peel (2.86±0.21%) compared to banana (1.71±0.02%), with values close to those reported in earlier studies by Reddy et al. (2011) and Oguntoyinbo et al. (2020), indicating that ripeness and region influence protein levels. Furthermore, banana peel showed a higher carbohydrate content (12.99±0.26%) than mango peel (10.62±0.23%), consistent with Zaini et al. (2022), who noted banana peel carbohydrates primarily include reducing and non-reducing sugars and starch. Fat and ash contents were relatively low in both peels; however, banana peel had a slightly lower fat content, aligning with Bennett and Saliu (2022), who emphasized variations based on processing and cultivar. Notably, ash content was higher in mango peels, though literature comparisons remain scarce, suggesting further research is warranted. Overall, the findings underscore the nutritional potential of both peels as functional food ingredients, especially in fiber enrichment and pectin-based applications.

**Table 2.** The proximate composition of mango and banana peels

|  |  |  |  |
| --- | --- | --- | --- |
| Nutritional content | Mango fresh peel | Banana fresh peel | p-value |
| Moisture (%) | 80.33±0.58 | 80.10±1.05 | 0.753 |
| Fiber (%) | 2.44±0.11 | 3.94±0.74 | 0.000\* |
| Ash (%) | 3.76±0.16 | 1.07±0.09 | 0.000\* |
| Fat (%) | 0.22±0.31 | 0.29±0.04 | 0.736 |
| Protein (%) | 2.86±0.21 | 1.71±0.02 | 0.001\* |
| Carbohydrate (%) | 10.62±0.23 | 12.99±0.26 | 0.000\* |

Results are presented as mean ± standard deviation of three replicates (n = 3). Symbol (\*) indicates the significance at p < 0.05. All values are expressed on a dry weight basis (g/100 g dry weight).

* 1. **Proximate Composition of Control Yogurt Sample**

The proximate analysis of the control (plain) yogurt sample, prepared without the addition of any fruit peel, is presented in Table 3. The chemical composition was consistent with that of typical set-style yogurt products, as reported by Narayana et al. (2019). The protein content was measured at 3.80 ± 0.12%, which aligns with the standard values for cow’s milk-based yogurt. Fat content was recorded at 3.50 ± 0.10%, comparable to values reported for whole-milk yogurt formulations. The ash content, indicative of the total mineral content, was found to be 0.70 ± 0.05%. The total solids content was calculated as 13.00 ± 0.60%, reflecting the cumulative dry matter present in the yogurt. The results of the proximate analysis confirm that the control yogurt meets the compositional requirements set by the Sri Lanka Standards Institution (SLS 824:1989), which stipulate a minimum fat content of 3.0% and a minimum milk solids-not-fat (MSNF) content of 8.25%, resulting in a required minimum total solids (TS) content of 11.0% (SLS 824:1989). These baseline values confirm the successful standardization of the yogurt base and serve as a reliable reference for evaluating the effects of mango and banana peel additions in subsequent treatment formulations.

**Table 3.** Proximate Composition of Control Yogurt Sample

|  |  |
| --- | --- |
| Parameter | Mean (%) ± SD |
| Moisture | 86.00 ± 0.50 |
| Protein | 3.80 ± 0.12 |
| Fat | 3.50 ± 0.10 |
| Ash | 0.70 ± 0.05 |
| Total solids | 13.00 ± 0.60 |

Results are presented as mean ± standard deviation of three replicates (n = 3)

* 1. **Influence of Mango Peel and Banana Peel on Yogurt pH**

The pH of yogurt is a vital quality parameter, as it reflects the extent of lactic acid fermentation, which in turn influences microbial stability, texture, and shelf-life (De Toledo et al., 2018; Zahid, et al., 2022). Ideally, yogurt should reach or fall below pH 4.6, with gelation typically occurring between pH 5.2 and 5.4 during heat-treated milk fermentation (Lee and Lucey, 2010). In this study, the pH profiles of yogurts supplemented with fresh mango peel and fresh banana peel were assessed over a 28-day refrigerated storage period (Tables 4). Yogurts incorporated with fruit peel demonstrated distinct pH changes during storage, which closely correlate with the growth and metabolic activity of yogurt starter cultures and added probiotic strains (Zaki et al., 2024). The extent of pH reduction thus reflects not only post-acidification during storage but also the influence of peel-derived substrates that potentially stimulate or modulate bacterial activity.

In control samples, the pH declined slightly over time (4.55±0.00 on Day 1 to 4.42±0.01 on Day 28), showing typical post-acidification. Incorporation of fresh peels at lower concentrations (1% and 5%) resulted in no significant deviations from the control, suggesting minimal influence on acidification at these levels. However, at 10% concentration, both fresh mango peel and fresh banana peel led to greater acidification (Table 4). This could be attributed to the higher content of fermentable sugars and polyphenols in fruit peel, which may stimulate lactic acid bacteria growth and metabolism.

The observed decrease in pH with increasing fiber concentration may be attributed to the prebiotic effects of dietary fiber, which enhance the growth and activity of probiotic bacteria. These microbial populations ferment lactose and other available carbohydrates into organic acids, primarily lactic acid, thereby contributing to the observed acidification. Importantly, the synthesis of organic acids not only affects acidity but also enhances the functional qualities of yogurt. Supporting this, Safdari et al. (2021) reported that yogurts containing banana fiber and banana peel fiber exhibit lower pH than controls, owing to organic acid production and bacterial fermentation of sugars. These findings are consistent with the recent results reported by Zahid et al., (2023) and Mahomud et al. (2024).

**Table 4.** Effect of Yogurt with Fresh Mango Peel and Banana Peel at Different Concentrations on pH during storage at 4 °C for 28 days

|  |  |
| --- | --- |
| Treatment  | pH of the treatment with storage period (Days) |
|  | Day 1 | Day 7 | Day 14 | Day 21 | Day28 |
| Control | 4.55±0.00aA | 4.51±0.15bA | 4.46±0.15cAB | 4.43±0.15dA | 4.42±0.01dA |
| 1 % FMP | 4.53±0.01aA | 4.51±0.00bA | 4.47±0.01cAB | 4.43±0.01dA | 4.41±0.00eA |
| 5 % FMP | 4.52±0.01aA | 4.51±0.01aA | 4.46±0.02bAB | 4.42±0.01cA | 4.41±0.02cA |
| 10 % FMP | 4.51±0.03aA | 4.38±0.01bC | 4.33±0.01cC | 4.28±0.01dC | 4.27±0.01dC |
| 1 % FBP | 4.53±0.04aA | 4.53±0.00aA | 4.49±0.01aA | 4.43±0.00bA | 4.43±0.01bA |
| 5% FBP | 4.54±0.02aA | 4.53±0.01aA | 4.47±0.00bAB | 4.43±0.00cA | 4.41±0.01cA |
| 10 % FBP | 4.51±0.02aA | 4.44±0.04bB | 4.46±0.01abB | 4.35±0.04cB | 4.34±0.01cB |

Data are expressed as mean ± SD (n = 3).

Superscript lowercase letters in each row indicate statistically significant difference (P < 0.05) during storage.

Superscript uppercase letters indicate statistically significant difference (P < 0.05) between yogurt samples in each column within the type of the product.

FMP-Fresh Mango peel, FBP-Fresh Banana peel

* 1. **Influence of Mango Peel and Banana Peel on Yogurt Syneresis**

Serum release, commonly referred to as syneresis, is a critical quality indicator of yogurt, particularly during storage, as it reflects the product’s water-holding capacity and structural stability (Dönmez et al. 2017). The syneresis percentage of commercial set yogurt typically ranges from 32.65 ± 1.63% to 34.62 ± 0.94%, as reported by Mani-López, Palou, and López-Malo (2014). Excessive syneresis remains a common challenge in commercial yogurt production, as it can negatively impact the product's visual appeal and texture, thereby reducing overall consumer acceptance (Thilakarathna & Perera, 2024; Mahomud et al., 2024). In the present study, data presented in Table 5 demonstrate that the incorporation of fresh mango peel and fresh banana peel significantly reduced syneresis in yogurt stored at 4 °C over a 28-day period compared to the control. The control sample showed a progressive increase in syneresis, from 23.00±1.00% on day 1 to 45.00±4.00% on day 28, indicating considerable whey separation and a gradual breakdown of gel structure. Comparable findings were reported by Dönmez et al. (2017), who noted increased whey drainage in plain set yogurt over time, attributed to declining physical quality during storage. In contrast, yogurts enriched with fresh mango peel exhibited a clear dose-dependent reduction in syneresis. At low concentrations (1%), the effect was minimal, and the syneresis levels remained statistically similar to the control group, indicating that low doses of whole peels are insufficient to alter the water-holding capacity of the yogurt matrix. For instance, on Day 28, syneresis in the control, 1% fresh mango peel, and 1% fresh banana peel groups were 45.00±4.00%, 39.00±1.00%, and 42.00±4.00%, respectively. In contrast, higher concentrations of peels, particularly 10% fresh mango peel, showed a significant reduction in syneresis throughout the storage period, reaching as low as 8.00±0.00% on Day 28. Similarly, 10% fresh banana peel also performed well, reducing syneresis to 12.00±1.00%. These results suggest that the fiber and bioactive compounds in the fresh peels may act as moisture retainers or gel-strengthening agents, enhancing the stability of the yogurt gel structure. However, the performance of fresh peels, especially at lower concentrations, was variable, possibly due to the presence of other compounds that may interfere with yogurt microstructure, including enzymes or volatiles. Consistent with these findings, Zahid et al. (2023) reported that the incorporation of fruit peel powders at varying concentrations not only reduced syneresis but also improved the water-holding capacity (WHC) of yogurt.

**Table 5.** Effect of Yogurt with Fresh Mango Peel and Banana Peel at Different Concentrations on Syneresis (%) during storage at 4 °C for 28 days

|  |  |
| --- | --- |
|  Treatment  | Syneresis % of yogurt with storage (Days) |
|   | **Day 1** | **Day7** | **Day 14** | **Day21** | **Day28** |
| Control | 23.00±1.00dA | 27.00±2.00cdA | 32.00±1.00bcA | 35.00±1.00bA | 45.00±4.00aA |
| 1% FMP | 21.00±1.00dA | 26.00±2.00cA | 31.00±0.00bA | 34.00±1.00bA | 39.00±1.00aA |
| 5% FMP | 8.00±1.00cC | 9.00±1.00bcC | 11.00±0.00bAB | 11.00±1.00bC | 14.00±1.00aC |
| 10% FMP | 2.00±1.00cD | 3.00±1.00cD | 4.00±1.00bcB | 6.00±1.00abD | 8.00±0.00aC |
| 1% FBP | 21.00±1.00aA | 21.00±1.00aB | 32.00±2.00aA | 35.00±2.00aA | 42.00±4.00aA |
| 5% FBP | 18.00±1.00cB | 20.00±2.00bcB | 21.00±1.00bcAB | 23.00±3.00bB | 28.00±0.00aB |
| 10% FBP | 3.00±1.00dD | 6.00±0.00cCD | 7.00±1.00bcB | 9.00±1.00bCD | 12.00±1.00aC |

Data are expressed as mean ± SD (n = 3).

Superscript lowercase letters in each row indicate statistically significant difference (P < 0.05) during storage.

Superscript uppercase letters indicate statistically significant difference (P < 0.05) between yogurt samples in each column within the type of the product.

FMP-Fresh Mango peel, FBP-Fresh Banana peel

* 1. **Influence of Mango Peel and Banana Peel on the Microbiological Quality and Shelf-Stability of Yogurt**

Yeasts and molds are common spoilage microorganisms in fermented dairy products like yogurt, particularly during extended storage (Jiffry and Nandanee, 2024). The yeast and mold count in yogurts fortified with varying levels of fresh mango peel and banana peel over 28 days of refrigerated storage exhibited significant differences depending on the concentration and storage duration (Table 6). According to the Sri Lanka Standards Institution (SLS 824:1989), the acceptable limit for yeast and mold in fermented dairy products is less than 1000 CFU/g. Samples exceeding this threshold may reflect underlying issues related to hygiene, sanitation, or suboptimal storage conditions during yogurt processing.

**Table 6.** Effect of Yogurt with Fresh Mango Peel and Banana Peel at Different Concentrations on Yeast and Mold Growth During Storage at 4 °C for 28 Days

|  |  |
| --- | --- |
|  | Yeast and Mold count with CFU/g with storage period (Days) |
| Treatment | **Day 1** | **Day 7** | **Day 14** | **Day 21** | **Day 28** |
| Control | 0.0±0.0dA | 0.0±0.0dE | 3.0±1.0cA | 6.0±1.0bA | 13.0±1.0aA |
| 1% FMP | 0.0±0.0dA | 0.0±0.0dE | 6.0±1.0cB | 20.0±2.0bD | 50.0±4.0aD |
| 5% FMP | 0.0±0.0eA | 10.0±1.0dC | 17.0±1.0cD | 33.0±2.0bE | 80.0±6.0aE |
| 10% FMP | 0.0±0.0eA | 23.0±2.0dA | 43.0±3.0cF | 73.0±6.0bG | 95.0±6.0aG |
| 1% FBP | 0.0±0.0dA | 0.0±0.0dE | 7.0±2.0cB | 9.0±1.0bB | 17.0±1.0aB |
| 5% FBP | 0.0±0.0eA | 3.0±1.0dD | 9.0±1.0cC | 17.0±1.0bC | 29.0±2.0aC |
| 10% FBP | 0.0±0.0eA | 13.0±1.0dB | 33.0±4.0cE | 43.0±5.0bF | 82.0±5.0aF |

Data are expressed as mean ± SD (n = 3).

Superscript lowercase letters in each row indicate statistically significant difference (P < 0.05) during storage.

Superscript uppercase letters indicate statistically significant difference (P < 0.05) between yogurt samples in each column within the type of the product.

FMP-Fresh Mango peel, FBP-Fresh Banana peel

The data in Table 6 reveal significant differences in yeast and mold growth in yogurt samples fortified with varying concentrations of fresh mango peel and banana peel during 28 days of refrigerated storage at 4 °C. In the control yogurt, microbial counts remained low initially and rose to 13.0 ± 1.0 CFU/g by Day 28—well within the SLSI’s acceptable limit of <1000 CFU/g for fermented dairy products. However, yogurts fortified with fresh mango peel exhibited a clear concentration-dependent rise in yeast and mold counts. At 1% fresh mango peel, counts reached 50.0±4.0 CFU/g by Day 28, while 10% fresh mango peel showed significantly higher values—95.0±6.0 CFU/g—indicating increased microbial activity, likely due to the availability of fermentable substrates such as residual sugars in mango peel and possibly native microflora introduced through the peel. Early microbial growth was evident by Day 7 in higher fresh mango peel levels, with 23.0±2.0 CFU/g already observed at 10% concentration, indicating a shortened microbiological shelf life. Similarly, 10% banana peel-treated yogurt recorded 82.0±5.0 CFU/g by Day 28, though its microbial growth remained slightly lower than mango peel counterparts at equivalent concentrations. These findings imply that while the incorporation of fruit by-products such as fresh mango and banana peel may enhance nutritional or functional properties, they also increase susceptibility to microbial spoilage, especially at higher concentrations. This could be attributed to the presence of fermentable sugars and native microflora in fruit peels, which may serve as substrates for yeast and mold growth (Do Espírito Santo et al., 2012). Therefore, it is essential to optimize peel concentrations, ensure stringent hygienic processing, or consider natural antimicrobial agents if such fortification is intended for commercial yogurt products. To further enhance the safety and shelf life of such fortified yogurt products, advanced techniques such as gamma irradiation, UV pasteurization, and drying of fruit peels could be applied to reduce microbial loads and water activity (De Toledo et al., 2018).

Importantly, *Escherichia coli* was not detected in any of the yogurt samples throughout the storage period, confirming that hygienic practices were adequately maintained during production (Table 7). Furthermore, all fresh peel-incorporated yogurts remained within acceptable microbiological limits (as per SLSI standards) for up to 28 days at 4 °C. Notably, Day 1 samples were entirely free from yeasts, molds, and *E. coli*. Therefore, to ensure product safety and integrity, only the Day 1 yogurt samples were selected for sensory evaluations.

**Table 7.** Effect of Yogurt with Fresh Mango Peel and Banana Peel at Different Concentrations on Total coliform count During Storage at 4 °C for 28 Days

|  |  |  |
| --- | --- | --- |
| Treatment | Coliform Count (CFU/g) | Observation Across Storage Days (1st, 7th, 14th, 21st and 28th Day) |
| Control | Nil | No coliforms detected on any day |
| 1% FMP | Nil | No coliforms detected on any day |
| 5% FMP | Nil | No coliforms detected on any day |
| 10% FMP | Nil | No coliforms detected on any day |
| 1% FBP | Nil | No coliforms detected on any day |
| 5% FBP | Nil | No coliforms detected on any day |
| 10% FBP | Nil | No coliforms detected on any day |

Nil: Coliforms not recorded.

FMP-Fresh Mango peel, FBP-Fresh Banana peel

* 1. **Influence of Mango Peel and Banana Peel on the Survival of Probiotic Bacteria in Yogurt**

Starter cultures containing *Streptococcus thermophilus*, *Lactobacillus delbrueckii* subsp. *bulgaricus*, and *Bifidobacterium animalis* subsp. lactis were used to initiate fermentation in all yogurt formulations. These cultures are essential for acidification, texture development, and delivering probiotic health benefits (Safdari et al., 2021; Zaki et al., 2024). The probiotic microorganism counts in yogurts fortified with fresh mango peel and fresh banana peel at varying concentrations were monitored over a 28-day refrigerated storage period at 4 °C (Table 8). The control yogurt, along with those containing low levels of fresh mango peel (1%, 5% and 10%) and 1% fresh banana peel, exhibited initial probiotic counts of approximately 2.2 – 2.3 log 10 CFU/ml ×106on Day 1. These counts gradually declined over time, reaching around 1.6 – 1.7 log 10 CFU/ml ×106 by Day 28. This reduction suggests limited enhancement of probiotic viability from mango peel or low banana peel concentrations, with no statistically significant differences observed among these treatments, possibly because the fruit components mitigated the potential negative impact of acidity of yogurt on the viability of *Lactobacillus* strains.

In contrast, yogurts fortified with higher concentrations of fresh banana peel (5% and 10%) demonstrated significantly higher initial probiotic counts of 5.0 and 5.2 log 10 CFU/ml ×106, respectively. Although a slight decline was observed by Day 7, these counts stabilized from Day 14 onward, remaining above 3.0 log 10 CFU/ml ×106 until Day 28. The statistical differences observed confirm the beneficial impact of high-level banana peel fortification on probiotic survival during storage. This suggests that banana peel may serve as an effective prebiotic source, likely due to its content of fermentable fibers, resistant starches, and polyphenolic compounds that support the growth and viability of beneficial bacteria such as *Streptococcus thermophilus*, *Lactobacillus bulgaricus*, and *Bifidobacterium animalis* subsp. lactis. Conversely, some compounds in mango peels—such as phenolic compounds, fatty acid esters, thiols, terpenes, and alcohols—have been reported to inhibit the growth of lactic acid-producing bacteria (Do Espírito Santo et al., 2012).

Furthermore, banana peel is known to contain xylooligosaccharides (XOs) and fructooligosaccharides (FOS)—both well-established prebiotics that selectively stimulate the growth and activity of beneficial gut microbiota, such as *Bifidobacterium* and *Lactobacillus* species (Chockchaisawasdee and Stathopoulos, 2022). These oligosaccharides serve as fermentable substrates that enhance the viability and metabolic activity of probiotic strains, thereby supporting higher microbial counts during storage. In contrast, while both banana and mango peels contain pectic oligosaccharides (POS)—which also exhibit prebiotic effects—the exclusive presence of XOs and FOS in banana peel provides a superior nutritional environment for probiotic growth (Rahim et al., 2021). This synergistic composition in banana peel likely explains the significantly enhanced probiotic survival in banana peel-enriched yogurt, particularly at higher concentrations (e.g., 10%), as compared to mango peel-enriched yogurt. Thus, the broader spectrum of prebiotic compounds in banana peel fortification offers a more robust support system for probiotic microorganisms, contributing to their increased persistence and functionality during refrigerated storage.

**Table 8.** Effect of Yogurt with Fresh Mango Peel and Fresh Banana Peel at Different Concentrations on Probiotic microorganisms Growth During Storage at 4 °C for 28 Days

|  |  |
| --- | --- |
|  Treatment  | Probiotic Microorganisms Count (log 10 CFU/ml) ×106 |
|   | Day 1 | Day7 | Day 14 | Day21 | Day28 |
| Control | 2.2±0.2aC | 2.2±0.4bD | 1.9±0.2bBC | 1.8±0.1bB | 1.7±0.6cB |
| 1% FMP | 2.2±0.5aC | 1.9±0.3bD | 1.9±0.1bcBC | 1.8±0.2cB | 1.6±0.3dB |
| 5% FMP | 2.3±0.5aC | 2.3±0.5bD | 1.8±0.6cC | 1.8±0.3cB | 1.7±0.6dB |
| 10% FMP | 2.3±0.5aC | 2.1±0.1bC | 1.9±0.4cBC | 1.9±0.1cB | 1.7±0.8dB |
| 1% FBP | 2.2±0.5aC | 2.2±0.5bD | 2.0±0.6bB | 1.9±0.7bB | 1.6±0.9cB |
| 5% FBP | 5.0±0.4aB | 3.2±0.3bB | 3.1±0.4bcA | 3.8±0.2cA | 3.0±0.7cA |
| 10% FBP | 5.2±0.4aA  | 3.8±0.4bA | 3.2±0.2cA | 3.2±0.2cA | 3.2±0.1cA |

 Data are expressed as mean ± SD (n = 3).

Superscript lowercase letters in each row indicate statistically significant difference (P < 0.05) during storage.

Superscript uppercase letters indicate statistically significant difference (P < 0.05) between yogurt samples in each column within the type of the product.

FMP-Fresh Mango peel, FBP-Fresh Banana peel

* 1. **Influence of Mango Peel and Banana Peel on Sensory Attributes and Consumer Acceptability of Yogurt**

 Figure 1 (a) and (b) illustrate the effects of fresh banana peel and mango peel extracts on the sensory qualities of yogurt samples, respectively. As shown in Figure 1(a), the control plain set yogurt consistently received the highest scores across all sensory attributes, significantly outperforming mango peel fortified samples. Among the fresh mango peel treatments, yogurts fortified with 10% mango peel scored significantly higher in texture and overall acceptability compared to the 1% and 5% concentrations, indicating improved sensory quality at higher peel levels. However, all mango peel samples had lower scores than the control for color, taste, and odor, with no significant differences observed among these treatments. These findings suggest that while mango peel addition at 10% may enhance texture and acceptability, it negatively impacts other sensory attributes compared to the control yogurt.

As shown in Figure 1(b), the sensory evaluation revealed that the control plain set yogurt scored highest across all attributes, significantly outperforming all fresh banana peel fortified samples. Among the banana peel treatments, the 10% concentration exhibited significantly better texture, odor, and overall acceptability compared to the 1% and 5% levels, indicating enhanced sensory quality at higher peel inclusion. Although 10% fresh banana peel improved these attributes within the banana peel group, its scores remained lower than the control. Color and taste scores showed no significant differences among fresh banana peel treatments but were consistently lower than the control. These results suggest that incorporating fresh banana peel at 10% can enhance specific sensory qualities without surpassing the appeal of the original yogurt.

To select the most consumer-preferred sample, 10% fresh banana peel and 10% fresh mango peel yogurts were compared again with the control using a 7-point hedonic scale. As depicted in Figure 1(c), incorporating 10% banana and mango peels into yogurt had differing impacts on sensory attributes. The banana peel (10%) yogurt was most preferred for color, followed closely by the control yogurt. Mango peel yogurt received the significantly (p<0.05) lowest color score, likely due to the darker appearance from mango peel pigments, which may have reduced visual appeal. Both banana and mango peel yogurts received the highest texture scores, indicating that banana peel did not negatively affect mouthfeel. Mango peel yogurt scored comparatively lower, possibly because of fibrous particles or poor dispersion. In terms of taste, mango and banana peel yogurts were favored, while control yogurt scored significantly (p<0.05) lower, suggesting a less accepted flavor profile. For odor, control yogurt was rated highest, followed by banana peel yogurt, with mango peel yogurt scoring lowest, likely due to unfamiliar volatile compounds from the mango peel. Overall acceptability was significantly (p<0.05) highest for banana peel yogurt, followed by control, indicating that banana peel incorporation maintained overall quality. Mango peel yogurt had lower acceptability, reinforcing the need for further optimization. These findings highlight that yogurt with 10% banana peel maintained favorable sensory properties comparable to the control in most attributes. In contrast, mango peel yogurt, despite its functional benefits, received lower scores for color, odor, and overall acceptability. Further formulation efforts such as pre-treatment of mango peel or the addition of flavor enhancers may improve its consumer acceptability.

**A**

**B**

**C**

**Figure 1:** Sensory profile comparison based on the 7-point hedonic scale for 35 panellists: (A) Control vs. fresh mango peel treatments, (B) Control vs. fresh banana peel treatments, and (C) Control vs. 10% fresh mango peel (10% FMP) and 10% fresh banana peel (10% FBP) yogurts.

**Conclusion**

The findings of this study demonstrate the potential of mango peel and banana peel as functional ingredients in yogurt fortification. Both peels significantly influenced the physicochemical, microbiological, and sensory characteristics of yogurt during 28 days of refrigerated storage. Incorporating 10% fresh mango and banana peel markedly reduced syneresis and improved probiotic survival, with banana peel showing superior performance. Yogurts fortified with banana and mango peel maintained microbial counts within safe limits and exhibited improved acidification and storage stability. Sensory evaluation revealed that 10% fresh banana peel were most acceptable to consumers, closely resembling the control yogurt in taste, texture, and overall acceptability. In contrast, higher concentrations of mango peel negatively affected sensory attributes. To expand on these promising results, future research should explore the identification and quantification of functional compounds in the peels—such as polyphenols, flavonoids, pectic oligosaccharides, and fermentable fibers—using advanced analytical techniques. In vitro digestion and fermentation studies are recommended to assess bioavailability and fermentation behaviour. Animal model studies and clinical trials are needed to evaluate health outcomes, including effects on gut microbiota, lipid metabolism, and glycaemic control. Overall, banana peel extract emerged as promising, sustainable fortifiers for developing value-added, health-enhancing dairy products.

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