



RESEARCH

Physicochemical, Microbiological, and Sensory Attributes of Probiotic Yoghurt Enriched with Pectin Derived from Banana and Mango Peel

S.M.D.S.C. Senaratne^{1*}, G.M. Somaratne^{1,2}, L.U. Athukorala² and D. Roy³

¹Postgraduate Institute of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka

²Department of Food Science and Technology, Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka

³Riddet Institute, Massey University, 4472, New Zealand

ARTICLE INFO

Article history:

Received: 10 November 2025

Revised version received: 19 December 2025

Accepted: 20 December 2025

Available online: 01 January 2026

Keywords:

Banana peel

Mango peel

Pectin

Yoghurt fortification

Prebiotic

Probiotic viability

Citation:

Senaratne, S.M.D.S.C. Somaratne, G.M. Athukorala, L.U. and Roy, D.(2026). Physicochemical, Microbiological, and Sensory Attributes of Probiotic Yoghurt Enriched with Pectin Derived from Banana and Mango Peel. *Tropical Agricultural Research*, 37(1): 34-54.

DOI: <https://doi.org/10.4038/tar.v37i1.9015>

Senaratne, S.M.D.S.C. 
<https://orcid.org/0009-0006-3120-4171>

ABSTRACT

This study investigated the potential of banana (*Musa acuminata*) and mango (*Mangifera indica*) peel pectin as a functional ingredient in probiotic yoghurt. Pectin was extracted, characterised, and incorporated at concentrations of 0.1–10% (w/v) to evaluate effects on physicochemical, microbiological, and sensory properties during 28 days of refrigerated storage. Banana peels contain a higher pectin content (15.87%) than mango peel (13.32%), both of which met international standards for food-grade pectin. Yoghurts fortified with peel-derived pectin exhibited improved water-holding capacity, reduced syneresis, and enhanced acidity development relative to controls, with banana pectin exerting greater gel-strengthening effects. Probiotic viability remained above the recommended therapeutic threshold of 10⁶ CFU/g in formulations containing 5–10% pectin, confirming its prebiotic contribution. Microbiological analyses verified the absence of *E. coli* and coliforms, while yeast and mold counts remained within acceptable safety limits throughout storage. Sensory evaluation indicated that 1% banana peel pectin produced the most favorable yoghurt, receiving higher taste and overall acceptability scores compared with both mango peel and control samples. These results suggest that banana and mango peel pectin can enhance yoghurt quality, extend probiotic viability, and improve consumer preference, while simultaneously valorizing fruit-processing by-products. The integration of peel-derived pectin into dairy systems highlights its potential as a cost-effective, natural stabilizer and prebiotic fortifier, contributing both to functional food innovation and to sustainable waste reduction in the food industry.

* Corresponding Author: senaratnesuraj5@gmail.com

INTRODUCTION

Fermented milk products are widely consumed worldwide for their distinctive sensory attributes, nutritional value, and health-promoting potential. Yoghurt, in particular, represents one of the largest segments of the fermented dairy market, with set-style yoghurt, where fermentation occurs directly in the final packaging being especially popular in many Asian and European countries (Chandan *et al.*, 2017; Naik, 2023). Global yogurt production is steadily rising, reaching approximately 292,000 tons in 2019 compared to 269,000 tons in 2018, representing a 4% growth rate. Asia leads production in both years, driven by increasing consumer demand for functional and probiotic foods (Rashwan *et al.*, 2023; Abdi-Moghadam *et al.*, 2023). Yoghurt is produced through lactic acid fermentation of milk by *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus*, which converts lactose to lactic acid, lowering pH to about 4.6 and causing casein coagulation into a smooth, creamy gel (Siddiqi *et al.*, 2024). According to international standards, the final product should contain at least 10^6 viable cells of these lactic acid bacteria per millilitre at the time of consumption (Ospanov *et al.*, 2023; Kazemi *et al.*, 2024).

In recent years, probiotic yoghurt has gained substantial attention as a functional dairy product. Probiotics are defined as “live microorganisms which, when administered in adequate amounts, confer a health benefit on the host”, which are incorporated to improve gut health, immune function, and metabolic balance (Parichat & Pongsak, 2023; Siddiqi *et al.*, 2024). However, probiotic survival and stability during storage are influenced by factors such as yoghurt matrix composition, pH fluctuations, and environmental stress, necessitating formulation strategies to improve both microbial viability and overall product quality (Rutella *et al.*, 2016; Yang *et al.*, 2023).

Texture and stability are among the most critical physicochemical and sensory attributes of yoghurt (Abdi-Moghadam *et al.*, 2023; Kazemi *et al.*, 2024). Hydrocolloids such as pectin are commonly used in dairy

systems to enhance viscosity, reduce syneresis, and improve mouthfeel (Alam *et al.*, 2025). Pectin is a plant-derived, water-soluble heteropolysaccharide primarily composed of partially methoxylated galacturonic acid residues, along with L-rhamnose and neutral sugars (Halahlah *et al.*, 2023). Traditionally extracted from apple pomace and citrus peel, pectin forms gel networks that bind water and interact with milk proteins, making it valuable for set-style yoghurt production (Said *et al.*, 2023).

In recent years, there has been growing interest in alternative pectin sources from agro-industrial by-products to promote sustainable food production. In tropical countries such as Sri Lanka, banana (*Musa acuminata*) and mango (*Mangifera indica*) are widely consumed fruits, whose peels account for roughly 30–40% of total fruit weight. These peels are rich in pectin, dietary fiber, and bioactive compounds but are often discarded, contributing to environmental waste and economic loss (Sagar *et al.*, 2018; Zahid *et al.*, 2021; Sasanka *et al.*, 2024).

Fruit peel-derived pectin offers multiple functional properties relevant to yoghurt production. Its strong gelling capacity and ability to form stable protein-polysaccharide networks enhance viscosity, water-holding capacity, and textural stability (Zahid *et al.*, 2022). As a soluble dietary fiber, it can modulate digestion and serve as a prebiotic substrate, promoting the growth of beneficial gut microbiota (Halahlah *et al.*, 2023). Moreover, pectin from banana and mango peels often retains phenolic compounds and flavonoids with antioxidant, antimicrobial, and anti-inflammatory activities, potentially improving probiotic survival and extending product shelf life (Zahid *et al.*, 2021).

Despite their potential, banana and mango peels remain underutilized in Sri Lanka due to limited processing capacity and low public awareness (Kothalawala & Yatiwella, 2018; Sasanka *et al.*, 2024). Valorizing these peels as pectin sources aligns with circular economy principles by reducing food waste and enabling the creation of nutrient-rich, value-added dairy products. Therefore, the present study aimed to develop probiotic yoghurt

formulations enriched with pectin extracted from banana and mango peel powders. The physicochemical parameters (pH, titratable acidity, syneresis, viscosity), microbiological quality (probiotic viability), and sensory attributes were assessed during fermentation and refrigerated storage to evaluate the functional potential of fruit peel-derived pectin in improving yoghurt quality and shelf life.

METHODOLOGY

Fruit selection

Fresh, fully ripe, healthy, and disease-free mango (*Mangifera indica*, variety "Karathakolomban") and banana (*Musa acuminata*, variety "Kolikuttu") fruits were selected for the study. Mangoes were harvested from several trees within a single commercial orchard in Anuradhapura, while bananas were obtained from multiple trees on a farm in Ambilipitiya, Sri Lanka. This collection strategy was designed to ensure uniformity while also capturing natural variability among trees grown under the same cultivation conditions.

Fruit peel paste preparation

The preparation of fruit peel paste was carried out according to the procedure outlined by Mahomud *et al.* (2024), with minor modifications. Freshly harvested mango and banana fruits were transported at ambient temperature (~25 °C) to the Laboratory of Rich Life Dairies Pvt. Ltd., Wadduwa, Sri Lanka. The fruits were held under the same conditions for 24 hours to allow stabilisation prior to processing. Thereafter, they were thoroughly washed with chlorinated water to eliminate surface impurities and manually peeled. The mango and banana peels were carefully separated from the pulp using a stainless-steel knife and cut into slices of 2–3 mm thickness. To reduce enzymatic browning, the peel slices were immersed in a 0.5% (w/v) citric acid solution for 5 minutes. Following draining, the fresh mango and banana peels were individually ground using a laboratory grinder (IKA® MF 10 Basic Microfine Grinder Drive, Germany) until a uniform paste was obtained. The

resulting peel pastes were packed in polythene bags and stored for subsequent pectin extraction.

Pectin Extraction from Banana and Mango Peels

The dried peel powders were sieved to obtain a uniform particle size of 0.18 mm prior to extraction. Pectin was extracted following the procedure of Ahsan *et al.* (2024) and Gemechu *et al.* (2024), with slight modifications. Based on literature evidence, several preliminary trials were conducted to optimize pectin yield, after which the appropriate pH, extraction time, and temperature for the extraction process were selected. For each extraction, 50 g of peel powder was dispersed in 500 mL of distilled water, and the pH was adjusted to 2.0 using food-grade concentrated citric acid. The suspension was stirred until the powder was uniformly wetted and evenly dispersed in the acidified medium. Extraction was then carried out by heating the mixture at 60±5 °C for 60 minutes on a swirling hot plate.

After cooling, the slurry was filtered through a 1 mm standard mesh screen lined with two layers of cheesecloth. The filtrate obtained was mixed with twice its volume of food-grade ethanol to precipitate the pectin. The precipitate was subsequently centrifuged at 5000 rpm for 10 minutes to recover the pectin fraction. The recovered pectin was dried in a hot-air oven at 65 °C for 18 hours until a constant weight was achieved. The dried pectin was then ground into fine powder and stored in airtight containers for further use.

Characterisation of pectin derived from mango and banana peels

The characterization of pectin was carried out following standard protocols described by Ahsan *et al.* (2024) and Gemechu *et al.* (2024). The parameters analysed included yield estimation, moisture and ash content, equivalent weight, methoxyl content, total anhydrouronic acid content, and degree of esterification.

Yield estimation

Pectin yield was calculated as the ratio of the weight of dried pectin to the mass of the powdered fruit peel, expressed as a percentage (Eq. 1):

$$Pectin\ Yield\ (\%) = \frac{\text{Extracted Pectin (g)}}{\text{Dried Fruit Powder (g)}} \times 100 \quad (\text{Eq. 1})$$

Moisture and total ash content

The moisture and ash of pectin derived from mango and banana was determined using the standard analytical procedures recommended by Official Methods of Analysis of AOAC International, 15th Edition (Association of Official Analytical Chemists, 2005). Moisture content was determined by oven-drying the samples at 105 °C until a constant weight was reached. Ash content was obtained by incinerating the samples in a muffle furnace at 550 °C until white ash was formed.

Equivalent weight

To determine the equivalent weight, 0.5 g of pectin was dispersed in 5 mL of 96% ethanol, followed by 1.0 g of sodium chloride and 100 mL of distilled water. After adding phenol red indicator, the solution was titrated with 0.1 N NaOH until a stable pink endpoint was reached. Equivalent weight was calculated using Eq. (2):

$$\text{Equivalent Weight (mg)} = \frac{\text{Weight of Sample} \times 1000}{\text{Volume of Alkali} \times \text{Normality of Alkali}} \quad (\text{Eq. 2})$$

Methoxyl content

The neutralised solution from equivalent weight determination was treated with 25 mL of 0.25 N NaOH and allowed to stand for 30 minutes at room temperature. After addition of 25 mL of 0.25 N HCl, the mixture was titrated with 0.1 N NaOH. Methoxyl content was calculated using Eq. (3):

$$\text{Methoxyl Content (\%)} =$$

$$\frac{\text{Volume of Alkali} \times \text{Normality of Alkali} \times 31}{\text{Weight of Sample (mg)} \times 1000} \times 100 \quad (\text{Eq. 3})$$

Where, 31 is the molecular mass of methoxyl (CH₃O-).

Total anhydrouronic acid content

The anhydrouronic acid content, an indicator of pectin purity, was determined using Eq. (4):

$$\text{Total Anhydrouronic Acid (\%)} = \frac{176 \times 0.1z \times 100}{w \times 1000} + \frac{176 \times 0.1y \times 100}{w \times 1000} \quad (\text{Eq. 4})$$

where,

z = mL of NaOH used for determination of equivalent weight.

y = mL of NaOH used in methoxyl content determination.

w = weight of sample (g).

Degree of esterification

The degree of esterification was estimated based on the relationship between methoxyl content and AUA, using Eq. (5).

$$\text{Degree of Esterification} = \frac{176 \times \text{MeC}(\%) \times 100}{31 \times \text{AUA}(\%)} \quad (\text{Eq. 5})$$

where MeC = methoxyl content and AUA = anhydrouronic acid content.

Yoghurt preparation with fruit peel derived pectin incorporation

Full-fat cow's milk was obtained from the Wadduwa milk collection center, a registered supplier for Rich Life Dairies Pvt. Ltd., Sri Lanka. Granulated sugar and a commercial yoghurt starter culture were purchased from certified 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 incorporated and thoroughly mixed. The mixture was homogenized with a laboratory homogenizer (GEA Niro Soavi Panda Plus 2000, Italy) to ensure uniform consistency, then cooled to 42 °C. A mixed starter culture (0.01% w/w) containing *Streptococcus thermophilus*, *Lactobacillus delbrueckii* subsp. *bulgaricus*, and *Bifidobacterium animalis* subsp. *lactis* (ABY 10) was inoculated.

A standardised yoghurt base was prepared and used to formulate one control group and two sets of treatment groups (Table 1). The treatments consisted of yoghurt incorporated separately with mango peel-derived pectin and banana peel-derived pectin. This design enabled evaluation of the effects of fruit peel pectin on yoghurt's physicochemical, sensory, and storage stability characteristics.

Based on preliminary trials, mango and banana pectin were incorporated into 1 L of yoghurt mixture at concentrations of 0.1%, 0.5%, 1%, 5%, and 10% (w/v) (Table 1). All treatments were prepared in triplicate. Each yoghurt mixture was dispensed into sterile containers, incubated at 42 °C for 4 hours to allow fermentation and setting, and subsequently stored at 4 °C for further analyses.

The control yoghurt sample was prepared using the standardized base without added pectin. To ensure uniformity of the base formulation, the proximate composition of the control was determined prior to applying the fruit peel pectin treatments.

Analysis of pH during storage

The pH of yoghurt samples was monitored at weekly intervals throughout 28 days of refrigerated storage (4 °C) to assess the effect of fruit peel-derived pectin on acidity development and product stability. Measurements were carried out using a calibrated digital pH meter (SENSION, Hach, USA). For each treatment group including control yoghurt and samples incorporated with mango and banana peel-derived pectin, pH values were recorded on days 1, 7, 14, 21, and 28. This analysis provided insights into

the progression of lactic acid fermentation and the influence of peel-derived pectin on the stability of yoghurt during storage.

Analysis of syneresis during storage

Syneresis of yoghurt samples was determined following the procedure of Mahomud *et al.* (2024) with slight modifications. For each measurement, 10 g of yogurt was placed on a 10 cm disc of Whatman No. 2 filter paper and positioned in a Büchner funnel. Vacuum filtration was applied for 6 minutes, and the volume of whey released was collected and weighed. Syneresis (%) was calculated as the weight of whey released relative to the initial sample weight, expressed as a percentage. Measurements were performed on days 1, 7, 14, 21, and 28 of refrigerated storage (4 °C) for all treatment groups, including control yoghurt and samples incorporated with mango and banana peel-derived pectin. This evaluation provided an indication of gel stability and water-holding capacity over storage time.

Enumeration of yeasts and molds in yoghurt samples

Yeasts and molds in yoghurt samples were enumerated using the spread plate method on Potato Dextrose Agar (PDA). Serial dilutions of each sample were prepared, and 1 mL of the appropriate dilution was transferred aseptically onto PDA plates. The inoculum was evenly distributed using a sterile glass spreader. Plates were incubated at 25 °C for 5 days to promote fungal growth. Following incubation, colonies were examined and counted, providing an estimate of yeast and mold load in the yogurt samples.

Enumeration of Coliform bacteria in yoghurt samples

Coliform bacteria were enumerated using the Most Probable Number (MPN) technique as described by Jiffry and Nandane (2024). Approximately 10±0.05 g of each yoghurt sample was homogenized in 90 mL of sterile distilled water to obtain the initial dilution. From this suspension, 10 mL was inoculated into double-strength lactose broth, while 1 mL and 0.1 mL aliquots were inoculated into separate sets of single-strength broth tubes

(three replicates per dilution). All tubes were incubated at 37 °C for 24–48 hours, and the development of gas and turbidity was taken as evidence of coliform growth. *Escherichia coli* was used as the positive control and *Bacillus* sp. as the negative control to ensure reliability of the test.

Survival of probiotic bacteria in yoghurt

The viability of probiotic bacteria in yoghurt samples (control, banana peel-incorporated, and mango peel-incorporated) was evaluated using de Man, Rogosa and Sharpe (MRS) agar supplemented with 0.05% bile salts, following the method of Safdari *et al.* (2021). For each assay, 1 g of yogurt was homogenized in 9 mL of sterile peptone water

to prepare a 10⁻¹ dilution. Subsequent tenfold serial dilutions were prepared, and 1 mL from each dilution was plated onto MRS agar. Plates were incubated at 37 °C for 72 hours under both aerobic and anaerobic conditions, with anaerobic conditions established in an anaerobic jar. Colonies of *Lactobacillus* spp. were enumerated to assess probiotic viability during storage. Counts were expressed as logarithmic values (log CFU/g) to facilitate comparison among treatments. Probiotic enumeration was performed for both yoghurt samples containing fresh banana and mango peel, and for those supplemented with peel-derived pectin, after 24 hours of refrigerated storage (4 °C).

Table 1: Experimental design for yoghurt preparation with mango and banana peel-derived pectin incorporation

Treatment Code	Fruit Type	Form Used	Concentration (% w/v)
C	-	None (Control)	0%
PM0.1	Mango	Extracted Pectin	0.1%
PM0.5	Mango	Extracted Pectin	0.5%
PM1	Mango	Extracted Pectin	1%
PM5	Mango	Extracted Pectin	5%
PM10	Mango	Extracted Pectin	10%
BM0.1	Banana	Extracted Pectin	0.1%
BM0.5	Banana	Extracted Pectin	0.5%
BM1	Banana	Extracted Pectin	1%
BM5	Banana	Extracted Pectin	5%
BM10	Banana	Extracted Pectin	10%

Sensory evaluation of yoghurt enriched with banana and mango peel-derived pectin

The sensory properties of yoghurt samples enriched with banana and mango peel-derived pectin were evaluated separately for each fruit type and treatment, using plain set yoghurt as the control. A panel of thirty-five individuals (17 men and 18 women, aged 25–50 years) was recruited through purposive sampling, considering age, gender, cultural background, and familiarity with dairy products. Panel size was determined using statistical power analysis to ensure adequate sensitivity in detecting differences among treatments. Two preliminary training sessions were conducted to familiarise panellists with product attributes, evaluation protocols, and safety procedures. Sensory evaluations were performed under standardised conditions (24 °C) to minimize external bias. A seven-point hedonic scale (1 = extreme dislike, 7 = extreme like) was used to assess key attributes: colour, texture, taste, odour, and overall acceptability. In the first stage, separate evaluations were carried out to identify the most-preferred concentration of pectin for each fruit type. In the final stage, the selected mango and banana pectin treatments were compared directly with the control yogurt to determine overall consumer preference.

Statistical analysis

All experiments were performed in triplicate, and results were expressed as mean \pm standard deviation (SD). To compare the properties of pectin extracted from banana and mango peels, paired t-tests were conducted at a significance level of $p < 0.05$. For yogurt analyses, a two-way analysis of variance (ANOVA) was applied to evaluate the effects of two independent variables: pectin concentration (control, 0.1%, 0.5%, 1%, 5%, and 10% w/v of either mango or banana peel pectin) and storage duration (Day 1, 7, 14, 21, and 28). Interaction effects between treatment and storage period were also examined. Post-hoc comparisons among group means were carried out using Tukey's Honest Significant Difference (HSD) test.

RESULTS AND DISCUSSION

Characterisation of pectin extracted from mango and banana fruit peels

The physicochemical properties of pectin extracted from mango and banana peels are presented in Table 2. Pectin yield was comparatively higher in banana peel ($15.87 \pm 1.20\%$) than mango peel ($13.32 \pm 0.00\%$). This agrees with previous findings where banana peels were reported as a rich source of pectin due to their high protopectin content and favourable cell wall polysaccharide structure (Khamsucharit *et al.*, 2018; Mada *et al.*, 2022). The lower yield from mango peels may be attributed to cultivar differences and the presence of phenolic compounds that interfere with efficient pectin solubilization during acid hydrolysis (Pacheco-Jiménez *et al.*, 2024).

Moisture content is an important quality parameter as it directly affects the stability, purity, and shelf life of pectin. In this study, mango peel pectin contained $7.77 \pm 2.91\%$ moisture, while banana peel pectin showed a slightly higher level of $9.62 \pm 2.56\%$. These values are consistent with the ranges reported by Ahsan *et al.* (2024) and Pacheco-Jiménez *et al.* (2024). Moisture contents below this threshold are desirable as they lower water activity, thereby restricting microbial proliferation and inhibiting the activity of endogenous enzymes such as pectinases that can deteriorate structural quality. Consequently, the observed low moisture values suggest that both mango and banana peel pectins possess good storage stability and retain functional properties suitable for diverse industrial applications, particularly in food and pharmaceutical formulations.

Ash content reflects the level of mineral residues and inorganic matter in pectin, serving as an indicator of its purity. In this study, mango peel pectin showed a higher ash content ($9.52 \pm 0.62\%$) than banana peel pectin ($8.92 \pm 2.44\%$). These findings are comparable with Ahsan *et al.* (2024), who reported ash values of 6–9% for ripe banana peel pectin. The relatively elevated ash content in mango peel pectin may arise from

its naturally higher mineral composition or the partial retention of acid extractant residues. Since premium-quality pectin requires ash levels below 10% (Chua *et al.*, 2020), the mango peel sample lies close to the maximum permissible threshold, highlighting the need for optimized purification methods to ensure better quality.

Equivalent weight, a measure of gel-forming capacity, was observed to be slightly higher in banana peel pectin (1495.31 ± 3.73) compared to mango peel (1433.10 ± 6.08). A higher equivalent weight generally reflects stronger gel strength, which is advantageous for food applications requiring thickening and gelling (Macias-Frotto *et al.*, 2025). Methoxy content values were similar for both mango ($7.76 \pm 0.84\%$) and banana peel ($7.86 \pm 1.94\%$) pectin, classifying them as high-methoxyl pectin

(HMP), since values exceed 7% (Ahsan *et al.*, 2024). HMPs are desirable for conventional jam and jelly production, as they readily form gels in the presence of high sugar and low pH (Gemechu *et al.*, 2024).

Anhydrouronic acid (AUA) content serves as a key indicator of pectin purity. In the present study, AUA levels were $56.32 \pm 1.34\%$ for mango peel pectin and $55.10 \pm 1.67\%$ for banana peel pectin. Both values exceed the minimum 50% threshold set by the Food Chemical Codex (FCC, 2019), thereby confirming acceptable purity. These findings are consistent with earlier reports, where banana peel pectin was found within 54–63% and mango peel pectin around 50% (Ahsan *et al.*, 2024; Gemechu *et al.*, 2024).

Table 2. Characterisation of pectin extracted from mango and banana peels

Parameter	Mango peel pectin	Banana peel pectin	p-value
Yield	13.32±0.00	15.87±1.20	0.021*
Moisture Content (%)	07.77±2.91	09.62±2.56	0.455
Ash (%)	09.57±0.62	08.91±2.44	0.673
Equivalent Weight	1433.10±6.08	1495.31±3.73	0.000*
Methoxy Content (%)	07.76±0.84	07.86±1.94	0.639
Anhydrouronic Acid (%)	56.32±1.34	55.10±1.67	0.376
Degree of Esterification (%)	78.16±2.56	80.00±2.70	0.442

Results are presented as mean ± standard deviation of three replicates (n = 3). Symbol (*) indicates the significance at $p < 0.05$.

Since AUA and methoxy content are closely associated with esterification, their variations were reflected in the degree of esterification (DE). The DE values observed in this study were $78.16 \pm 2.56\%$ for mango peel and $80.00 \pm 2.70\%$ for banana peel, placing both within the typical range of 60–90% for food-grade high methoxyl pectin (Macias-Frotto *et al.*, 2025). The slight difference between mango and banana peel pectin can be attributed to species-specific structural characteristics, tissue composition, and the maturity stage at which peels were harvested. A lower DE, as noted in some studies, is often linked to the conversion of soluble pectin into

protopectin during fruit maturation, accompanied by sugar accumulation and fruit softening (Gemechu *et al.*, 2024). Taken together, the results suggest that banana peel pectin exhibits slightly superior functional properties compared to mango peel pectin, particularly in terms of yield and equivalent weight, while both sources meet international quality standards. These findings reinforce the potential of fruit by-products as sustainable alternative sources of commercial pectin. Furthermore, the use of ethanol as an extractant is not only effective but also cost-efficient on an industrial scale, making the process economically viable and supporting a

circular economy approach by utilizing fruit by-products.

Proximate composition of control yoghurt sample

The proximate composition of the plain control yoghurt (formulated without any pectin enrichment) is summarised in Figure 1. The obtained values closely correspond to those reported for conventional set-type yoghurts in earlier studies (e.g., Narayana *et al.*, 2019). The protein content of the control was $3.82 \pm 0.15\%$, reflecting the contribution of milk proteins typically retained during fermentation. Fat content was measured at $3.48 \pm 0.08\%$, consistent with whole-milk yoghurt formulations. The mineral fraction, expressed as ash, accounted for $0.72 \pm 0.04\%$, while the total solids were $12.95 \pm 0.55\%$. The high moisture fraction ($86.05 \pm 0.45\%$) indicates the expected water-rich matrix of yogurt. These compositional values fulfill the regulatory requirements of the Sri Lanka Standards Institution (SLS 824:1989), which specifies a minimum of 3.0% fat and 8.25% milk solids-not-fat (MSNF), with a minimum 11.0% total solids for yoghurt. Therefore, the baseline formulation demonstrates acceptable nutritional quality and provides a valid control for subsequent treatments fortified with fruit-derived ingredients.

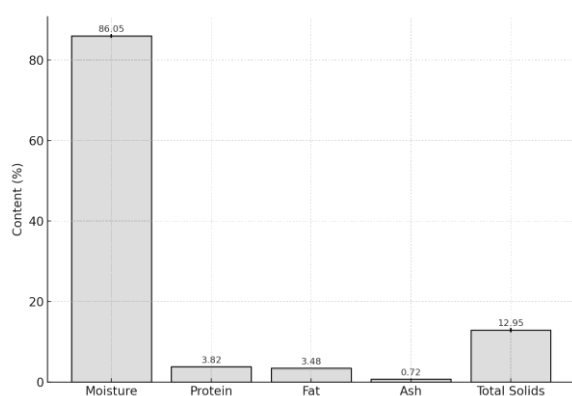


Figure 1. Proximate composition of the control yoghurt sample (mean \pm SD, $n = 3$), (Error bars indicate the standard deviation of three replicates).

Influence of mango peel pectin and banana peel pectin on yoghurt pH

Yoghurt pH serves as a key quality parameter, as it reflects the progression of lactic acid fermentation, which in turn governs microbial safety, product texture, and storage stability (De Toledo *et al.*, 2018; Zahid *et al.*, 2022). During the fermentation process, milk typically undergoes gelation when the pH falls within the range of 5.2–5.4, while the final product is expected to reach a pH of 4.6 or lower to achieve the required firmness and ensure microbiological safety (Lee & Lucey, 2010).

In this study, the pH profiles of yoghurts supplemented with mango peel pectin and banana peel pectin were monitored over a 28-day refrigerated storage period (Table 3). The control yogurt showed a gradual decline in pH from 4.55 ± 0.00 (Day 1) to 4.42 ± 0.01 (Day 28), reflecting normal post-acidification. In contrast, yoghurts fortified with either mango peel pectin or banana peel pectin exhibited significantly lower pH values than the control from the beginning of storage, with the extent of reduction depending on pectin concentration. For instance, yogurts with 10% mango peel pectin and banana peel pectin reached final pH values of 4.16 ± 0.01 and 4.10 ± 0.01 , respectively, on Day 28.

These findings indicate that fruit peel-derived pectin may act as a fermentable or prebiotic substrate, stimulating the growth and metabolic activity of yogurt starter cultures and added probiotics (Zaki *et al.*, 2024). The purified form of extracted pectin likely makes it easier for microbes to access and utilize, leading to stronger acidification in yogurt. This indicates that adding pectin can not only enhance the fermentation process but also provide additional functional benefits to yogurt formulations. However, further studies are needed to better understand how fruit-derived pectin influences microbial activity and acidification patterns in dairy systems.

Table 3. Effect of Yoghurt with Mango Peel Pectin (MPP) and Banana Peel Pectin (BPP) at Different Concentrations on pH during storage at 4 °C for 28 days

	Day 1	Day 7	Day 14	Day 21	Day28
Control	4.55±0.00 ^{aA}	4.51±0.02 ^{bA}	4.46±0.02 ^{cA}	4.43±0.02 ^{dA}	4.42±0.01 ^{dA}
0.1% MPP	4.49±0.01 ^{aB}	4.48±0.01 ^{aAB}	4.42±0.01 ^{bAB}	4.38±0.01 ^{cB}	4.33±0.03 ^{dB}
0.5% MPP	4.41±0.01 ^{aC}	4.43±0.06 ^{abBC}	4.38±0.02 ^{abBC}	4.32±0.02 ^{bcC}	4.27±0.02 ^{cC}
1% MPP	4.33±0.01 ^{aE}	4.30±0.01 ^{bcD}	4.26±0.02 ^{bD}	4.21±0.02 ^{cEF}	4.21±0.03 ^{cDE}
5% MPP	4.30±0.02 ^{aEF}	4.28±0.01 ^{aDE}	4.27±0.01 ^{aD}	4.23±0.01 ^{bE}	4.20±0.02 ^{cDE}
10% MPP	4.29±0.02 ^{aFG}	4.26±0.02 ^{abDE}	4.23±0.02 ^{bDE}	4.16±0.01 ^{cG}	4.16±0.01 ^{cE}
0.1% BPP	4.44±0.01 ^{aC}	4.43±0.01 ^{aABC}	4.37±0.01 ^{bC}	4.33±0.01 ^{cC}	4.28±0.03 ^{dB}
0.5% BPP	4.37±0.01 ^{aD}	4.39±0.06 ^{aC}	4.34±0.02 ^{abC}	4.28±0.02 ^{bcD}	4.23±0.02 ^{cCD}
1% BPP	4.28±0.01 ^{aFG}	4.24±0.01 ^{abDE}	4.21±0.02 ^{bEF}	4.16±0.02 ^{cG}	4.16±0.03 ^{cE}
5% BPP	4.26±0.02 ^{aGH}	4.24±0.01 ^{aDE}	4.23±0.01 ^{aDE}	4.19±0.01 ^{bFG}	4.16±0.02 ^{cE}
10% BPP	4.23±0.02 ^{aH}	4.20±0.02 ^{abE}	4.17±0.02 ^{bF}	4.10±0.01 ^{cH}	4.10±0.01 ^{cF}

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.

MPP - Mango Peel Pectin, BPP - Banana Peel Pectin

Influence of mango peel pectin and banana peel pectin on yoghurt syneresis

Serum release, or syneresis, is one of the most important quality parameters in yoghurt, as it reflects the water-holding capacity and structural integrity of the product during storage (Dönmez *et al.*, 2017; Mahomud *et al.*, 2024). Commercial set yoghurts generally show syneresis values ranging from 32.65±1.63% to 34.62±0.94% (Mani-López, Palou, & López-Malo, 2014). Excessive whey separation remains a persistent issue in yoghurt production because it reduces visual appeal, compromises texture, and ultimately lowers consumer acceptance (Thilakarathna & Perera, 2024; Mahomud *et al.*, 2024).

Table 4 illustrates that the incorporation of mango peel pectin and banana peel pectin significantly influenced yogurt syneresis (%) during 28 days of refrigerated storage at 4 °C. In the control samples, syneresis increased progressively from 2.3% on day 1 to 4.5% on day 28, reflecting gradual whey separation

and weakening of the gel network. In contrast, yoghurts enriched with either mango peel pectin or banana peel pectin exhibited markedly lower syneresis, confirming the positive role of pectin in improving water retention and structural stability.

A particularly strong effect was observed with banana peel pectin: as its concentration increased from 0.1% to 1.0%, syneresis decreased substantially, stabilizing between 2.97% and 1.89% by day 28 significantly below the control values. This indicates that banana peel pectin effectively reinforces the yogurt matrix by enhancing water-binding capacity and minimizing whey expulsion. Mango peel pectin also contributed to reduced syneresis, though its effect was generally less pronounced compared to banana peel pectin at higher inclusion levels. Overall, these findings underscore that pectin is efficient even at relatively low concentrations, but higher levels provide greater improvements in yogurt stability. At

0.1% and 0.5%, both pectin yielded syneresis values similar to or slightly higher than the control, suggesting that adequate concentration is critical for optimal stabilization.

These results are consistent with previous studies showing that functional ingredients such as inulin (Żbikowska, *et al.*, 2020), banana peel fiber (Safdari *et al.*, 2021), and pomegranate peel (Jany *et al.*, 2024) can effectively reduce syneresis by strengthening the gel structure and enhancing water-binding capacity. Fibers possess the ability to interact with water molecules and milk components particularly proteins thereby stabilizing the protein network, limiting water mobility, and ultimately reducing whey separation (Safdari *et al.*, 2021). Another mechanism proposed for the reduction of syneresis in prebiotic-enriched yoghurts is their ability to increase consistency and improve the water-holding index of the gel matrix, which enables prebiotic compounds to retain more water within the structure (Żbikowska, *et al.*, 2020). Similarly, increasing dry matter content contributes to greater gel stability, higher water retention, and reduced syneresis. Studies have further shown that yoghurts supplemented with prebiotics such as fructooligosaccharides and inulin display lower viscosity, reduced firmness, and comparatively less syneresis (Safdari *et al.*, 2021). From an application standpoint, standardized pectin extracts present a reliable option for large-scale industrial yoghurt production, whereas the direct incorporation of fruit peels may serve as a cost-effective and natural alternative in traditional or resource-limited settings. Overall, the incorporation of mango and banana peel pectin demonstrates considerable potential to improve yoghurt quality by minimizing syneresis, an essential attribute for consumer acceptance, while simultaneously supporting sustainable utilization of fruit-processing by-products.

Influence of mango peel and banana peel pectin on the microbiological quality and shelf-life of yoghurt

According to the Sri Lanka Standards Institution (SLSI 824: Part 2), the permissible limit of yeast and mold in fermented dairy products is <1000 CFU/g. Counts exceeding this threshold are generally indicative of lapses in hygienic practices, inadequate sanitation, or improper storage conditions during yoghurt processing and handling. Yeasts and molds are recognized as the main spoilage organisms in fermented dairy products like yoghurt, particularly during extended storage periods (Jiffry & Nandane, 2024). In the present study, yoghurts fortified with mango peel and banana peel pectin exhibited yeast and mold counts that varied with both concentration and storage duration (Table 5). These findings suggest that the incorporation of fruit peels may influence the microbial stability of yoghurt, with higher inclusion levels potentially providing protective effects against spoilage organisms during refrigerated storage.

The findings demonstrate that both the control yoghurt and those fortified with low concentrations (0.1% and 0.5%) of mango peel pectin (MPP) and banana peel pectin (BPP) maintained strong microbiological stability over 28 days of refrigerated storage. Yeast and mold counts consistently remained well below the SLSI safety limit of 10^3 CFU/g. Even at higher concentrations ($\geq 1\%$), MPP-fortified yogurts showed only modest increases in yeast and mold counts (20–30 CFU/g by Day 28), which were still within acceptable limits. In comparison, BPP-fortified yogurts exhibited superior stability, with counts remaining lower and comfortably within the safety threshold throughout the storage period. Although fruit peel fortification has been suggested to provide a protective effect against spoilage, our data showed slightly higher microbial counts in the fortified samples. This may be due to pectin acting as an additional carbon source, potentially supporting the growth of non-target microbes. These results highlight the importance of optimizing pectin concentration and ensuring rigorous hygienic

practices during processing. Additionally, the use of natural antimicrobial agents may be considered when formulating such fortified yogurts for commercial production. Advanced interventions, including gamma irradiation, UV pasteurization, or drying of fruit peels, may further enhance safety and extend shelf life by lowering microbial loads and reducing water activity (De Toledo *et al.*, 2018).

It is evident that, pectin fortification not only offers nutritional and functional benefits but also contributes to better microbiological safety and extended shelf life. Nevertheless, research on the microbiological impacts of fruit peel pectin in yogurt systems remains limited. Further studies are required to clarify the mechanisms involved, assess long-term stability, and investigate the combined effects of pectin with other natural antimicrobials or probiotic cultures to enhance its applicability in commercial yogurt production.

Microbiological analysis revealed that *Escherichia coli* was absent in all yogurt samples throughout the storage period, indicating that production was carried out under proper hygienic conditions (Table 6). In addition, yogurts containing peel pectin complied with the microbiological limits specified by SLSI standards for up to 28 days at 4 °C. On Day 1, all samples were completely free from yeasts, molds, and *E. coli*, confirming their safety and freshness at the beginning of storage. For this reason, only Day 1 samples were chosen for subsequent sensory evaluations to ensure the reliability of consumer acceptance testing.

Influence of mango peel and banana peel pectin on the survival of probiotic bacteria in yoghurt

The effect of fruit peel pectin on the survival of probiotic microorganisms in yoghurt was evaluated to understand their potential role in enhancing probiotic stability during storage. All yogurt formulations were fermented using starter cultures consisting of *Streptococcus thermophilus*, *Lactobacillus delbrueckii* subsp. *bulgaricus*, and *Bifidobacterium animalis* subsp. *lactis*. These microorganisms are essential for acid production, texture development, and delivering probiotic health benefits (Safdari

et al., 2021; Zaki *et al.*, 2024). The survival of probiotics in yogurts fortified with mango peel pectin (MPP) and banana peel pectin (BPP) during 28 days of refrigerated storage is presented in Table 7.

In yoghurts containing low mango peel pectin concentrations (0.1% and 0.5%), probiotic counts showed only a slight improvement compared to the control. Counts decreased steadily from 3.2×10^6 CFU/g on Day 1 to $<2.0 \times 10^6$ CFU/g by Day 28, indicating limited support for long-term probiotic viability. At 1% MPP, a modest increase was observed on Day 1 (4.10×10^6 CFU/g compared to 2.20 in the control), but numbers dropped sharply thereafter, stabilizing near 2.10×10^6 CFU/g at Day 28. At higher levels (5–10% MPP), the initial counts were significantly higher (4.60 – 5.17×10^6 CFU/g), but a sharp decline occurred during storage, with 10% MPP yogurt falling to just 1.20×10^6 CFU/g by Day 28. This suggests that although MPP boosts early probiotic counts, it provides weaker long-term protection. In contrast, yoghurts fortified with banana peel pectin demonstrated a more pronounced and sustained enhancement of probiotic survival. Even at low levels (0.5–1% BPP), probiotic counts remained above 3.0×10^6 CFU/g by Day 28, significantly higher than the control and MPP treatments. At higher concentrations, the effect was striking: 5% BPP increased counts to 6.70×10^6 CFU/g at Day 1 and maintained 3.94×10^6 CFU/g at Day 28, while 10% BPP produced the highest counts across all time points (7.30×10^6 CFU/g on Day 1 and 4.20×10^6 CFU/g on Day 28). These results highlight a clear dose-dependent prebiotic effect of BPP, which outperformed MPP in sustaining probiotic viability.

Table 4. Effect of Yoghurt with Mango Peel Pectin (MPP) and Banana Peel Pectin (BPP) at Different Concentrations on Syneresis (%) during storage at 4 °C for 28 days

Treatment	Syneresis % of yoghurt with storage (Days)				
	Day 1	Day 7	Day 14	Day 21	Day 28
Control	23.00±1.00 ^{dA}	27.00±2.00 ^{cdA}	32.00±1.00 ^{bcA}	35.00±1.00 ^{bA}	45.00±4.00 ^{aA}
0.1% MPP	22.33±0.58 ^{dA}	25.67±2.52 ^{cdA}	30.33±0.58 ^{bcAB}	33.67±1.53 ^{bA}	42.67±3.51 ^{aABC}
0.5% MPP	14.33±0.58 ^{dB}	17.67±2.52 ^{cdB}	22.33±0.58 ^{bcC}	25.67±1.53 ^{bB}	34.67±3.51 ^{aBCD}
1% MPP	11.00±1.00 ^{dC}	15.00±2.00 ^{cdBC}	20.00±1.00 ^{bcD}	23.00±1.00 ^{bBC}	33.00±4.00 ^{bD}
5% MPP	06.00±1.00 ^{cDE}	07.00±1.00 ^{bcDE}	09.00±0.00 ^{bF}	09.00±1.00 ^{bD}	12.00±1.00 ^{aE}
10% MPP	05.00±1.00 ^{cEF}	06.00±1.00 ^{bcE}	08.00±0.00 ^{bFG}	08.00±1.00 ^{bD}	11.00±1.00 ^{aE}
0.1% BPP	21.00±1.00 ^{dA}	25.00±2.00 ^{cdA}	30.00±1.00 ^{bcB}	33.00±1.00 ^{bA}	43.00±4.00 ^{aAB}
0.5% BPP	13.33±0.58 ^{dBC}	16.67±2.52 ^{cdBC}	21.33±0.58 ^{bcCD}	24.67±1.53 ^{bB}	33.67±3.51 ^{aCD}
1% BPP	08.00±1.00 ^{dD}	12.00±2.00 ^{cdCD}	17.00±1.00 ^{bcE}	20.00±1.00 ^{bC}	30.00±4.00 ^{aD}
5% BPP	04.00±1.00 ^{cEF}	05.00±1.00 ^{bcE}	07.00±0.00 ^{bGH}	07.00±1.00 ^{bD}	10.00±1.00 ^{aE}
10% BPP	03.00±1.00 ^{cF}	04.00±1.00 ^{bcE}	06.00±0.00 ^{bH}	06.00±1.00 ^{bD}	09.00±1.00 ^{aE}

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 yoghurt samples in each column within the type of the product.

MPP - Mango Peel Pectin, BPP - Banana Peel Pectin

The improved survival of probiotics in BPP and MPP-fortified yoghurts may be explained by the prebiotic fiber content of fruit peel pectins. Dietary fibers provide fermentable substrates, stabilize the protein matrix, and increase the buffering capacity of yogurt, thereby protecting probiotic cells under refrigerated conditions (Zare *et al.*, 2011; Safdari *et al.*, 2021). Additionally, peel-derived compounds may reduce the availability of free water and enhance nutrient exchange, creating a more favorable microenvironment for bacterial persistence.

As reported by Senaratne *et al.* (2025), yogurts fortified with 10% fresh mango or

banana peel maintained probiotic counts above the minimum effective threshold of 10⁶ CFU/g throughout 28 days of storage. Similarly, in the present study, yoghurts fortified with fruit peel pectin also maintained viable counts above the recommended 6 log CFU/g threshold (Zahid *et al.*, 2022), classifying them as probiotic products. Notably, BPP, particularly at 10%, provided the strongest protection, maintaining counts well above this threshold at all-time points.

Table 5. Effect of Yoghurt with Mango Peel Pectin (MPP) and Banana Peel Pectin (BPP) at Different Concentrations on Yeast and Mold Growth During Storage at 4 °C for 28 Days

Yeast and Mold Count (CFU/g) in Yoghurt Samples During Storage					
Treatment	Day 1	Day 7	Day 14	Day 21	Day 28
Control	00.00±0.00 ^{dA}	00.00±0.00 ^{dB}	03.33±0.58 ^{cD}	06.67±0.58 ^{bE}	13.33±0.58 ^{aEF}
0.1% MPP	00.00±0.00 ^{bA}	00.00±0.00 ^{bB}	05.33±1.15 ^{aD}	06.33±1.15 ^{aE}	07.66±1.53 ^{aF}
0.5% MPP	00.00±0.00 ^{dA}	01.33±1.15 ^{dB}	08.67±2.08 ^{cD}	15.00±3.00 ^{bCDE}	22.33±3.06 ^{aDE}
1% MPP	00.00±0.00 ^{dA}	09.33±2.08 ^{cB}	17.67±2.50 ^{bB}	23.67±3.70 ^{bC}	37.00±4.58 ^{aBC}
5% MPP	00.00±0.00 ^{dA}	24.00±5.57 ^{cA}	38.33±3.51 ^{bA}	45.00±3.60 ^{abAB}	51.00±4.58 ^{aB}
10% MPP	00.00±0.00 ^{dA}	27.67±4.51 ^{cA}	41.33±3.51 ^{bcA}	53.00±4.36 ^{bA}	67.67±9.30 ^{aA}
0.1% BPP	00.00±0.00 ^{bA}	00.33±0.57 ^{bB}	04.33±1.15 ^{aD}	05.33±1.15 ^{aE}	06.67±1.53 ^{aF}
0.5% BPP	00.00±0.00 ^{dA}	00.67±1.50 ^{dB}	06.67±2.08 ^{cD}	13.00±3.00 ^{bDE}	20.33±3.05 ^{aEF}
1% BPP	00.00±0.00 ^{dA}	09.33±3.06 ^{cB}	16.00±2.65 ^{bcBC}	22.67±3.80 ^{bCD}	36.00±4.58 ^{aCD}
5% BPP	00.00±0.00 ^{dA}	22.33±5.03 ^{cA}	36.33±3.51 ^{bA}	43.00±3.60 ^{abB}	49.00±4.58 ^{aBC}
10% BPP	00.00±0.00 ^{dA}	26.33±5.03 ^{cA}	41.33±3.78 ^{bA}	53.00±5.30 ^{abA}	65.67±8.62 ^{aA}

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.

MPP - Mango Peel Pectin, BPP - Banana Peel Pectin

When comparing extracted pectin with fresh peel fortification, previous reports suggest that fresh banana peel supported higher counts than extracted pectin (Senaratne *et al.*, 2025), likely due to the presence of additional natural prebiotic compounds. However, in the present study, extracted BPP at 10% still showed superior results compared to MPP, indicating that banana peel pectin is especially effective in enhancing probiotic survival. In summary, both mango and

banana peel pectins improved the survival of probiotics in yoghurt, but banana peel pectin exhibited a stronger and more consistent prebiotic effect, particularly at higher concentrations. These findings confirm that fruit peel pectins, especially BPP, can serve as effective functional ingredients to enhance the health-promoting properties and shelf life of probiotic-enriched dairy products.

Table 6. Effect of Yoghurt with Mango Peel Pectin (MPP) and Banana Peel Pectin (BPP) at Different Concentrations on Total coliform count During Storage at 4 °C for 28 Days

Treatment	Coliform Count (CFU/g)	Observation Across Storage Days (1 st , 7 th , 14 th , 21 st and 28 th Day)
Control	Nil	No coliforms detected on any day
0.1% MPP	Nil	No coliforms detected on any day
0.5% MPP	Nil	No coliforms detected on any day
1% MPP	Nil	No coliforms detected on any day
5% MPP	Nil	No coliforms detected on any day
10% MPP	Nil	No coliforms detected on any day
0.1%BPP	Nil	No coliforms detected on any day
0.5% BPP	Nil	No coliforms detected on any day
1 % BPP	Nil	No coliforms detected on any day
5% BPP	Nil	No coliforms detected on any day
10 % BPP	Nil	No coliforms detected on any day

Data are expressed as mean \pm SD (n = 3). Nil: Coliforms not recorded.
MPP - Mango Peel Pectin, BPP - Banana Peel Pectin

Influence of mango peel and banana peel pectin on sensory attributes and consumer acceptability of yoghurt

The impact of mango peel pectin and banana peel pectin on yogurt sensory qualities was assessed using a 7-point hedonic scale, and the results are summarized in Figure 2. Figure 2 (A) and (B) illustrate the effects of mango peel pectin and banana peel pectin on the sensory qualities of yogurt samples, respectively. As shown in Figure 2(A), the control plain set yogurt consistently received the highest scores across all sensory

attributes, significantly outperforming mango peel pectin-fortified samples. Among the mango peel pectin treatments, yogurt fortified with 1% mango peel pectin showed the most favorable sensory profile, particularly for odor and overall acceptability, with scores significantly higher than those of other mango peel pectin concentrations. While 0.1% and 0.5% mango peel pectin had moderate acceptability, higher concentrations (5% and 10%) scored significantly lower in all sensory attributes, likely due to negative impacts on taste, texture, and appearance. These findings suggest that 1% mango peel

pectin is an acceptable formulation following the control.

Table 7. Effect of Yoghurt with Mango Peel Pectin (MPP) and Banana Peel Pectin (BPP) at Different Concentrations on Probiotic microorganisms Growth during Storage at 4 °C for 28 Days

Treatment	Probiotic Microorganisms Count (CFU/g) ×10 ⁶				
	Day 1	Day7	Day 14	Day21	Day28
Control	2.20±0.00 ^{aE}	2.03±0.06 ^{bD}	1.90±0.00 ^{bF}	1.90±0.10 ^{bDE}	1.67±0.58 ^{cDE}
0.1% MPP	2.50±0.00 ^{aE}	2.33±0.06 ^{bD}	2.20±0.00 ^{bEF}	2.20±0.10 ^{bDE}	1.97±0.58 ^{cCD}
0.5% MPP	3.17±0.58 ^{aCDE}	3.20±0.00 ^{aBCD}	2.83±0.38 ^{aDE}	2.07±0.58 ^{bDE}	1.83±0.31 ^{bCD}
1% MPP	4.10±0.10 ^{aBCD}	3.17±0.72 ^{abBCD}	2.30±0.35 ^{bcEF}	2.10±0.00 ^{cDE}	2.10±0.00 ^{cCD}
5% MPP	4.60±1.04 ^{aBC}	3.10±0.36 ^{bBCD}	2.40±0.10 ^{bEF}	1.77±0.25 ^{bE}	1.90±0.10 ^{bCD}
10% MPP	5.17±1.20 ^{aB}	3.70±0.52 ^{abBC}	4.13±0.42 ^{aC}	2.17±0.35 ^{cDE}	1.20±0.20 ^{cE}
0.1%BPP	2.80±0.00 ^{aDE}	2.63±0.06 ^{bCD}	2.50±0.00 ^{bEF}	2.50±0.01 ^{bCD}	2.27±0.58 ^{cC}
0.5% BPP	4.10±0.17 ^{aBCD}	4.20±0.00 ^{aB}	3.83±0.38 ^{aC}	3.07±0.58 ^{bBC}	2.83±0.31 ^{bB}
1 % BPP	5.17±0.06 ^{aB}	4.27±0.72 ^{abB}	3.40±0.35 ^{bcCD}	3.20±0.00 ^{cB}	3.20±0.00 ^{cB}
5% BPP	6.70±0.52 ^{aA}	6.10±0.36 ^{abA}	5.40±0.10 ^{bcB}	4.57±0.40 ^{cdA}	3.94±0.32 ^{dA}
10 % BPP	7.30±0.46 ^{aA}	6.70±0.52 ^{aA}	7.13±0.42 ^{aA}	5.17±0.35 ^{bA}	4.20±0.20 ^{bA}

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.

MPP - Mango Peel Pectin, BPP - Banana Peel Pectin

Figure 2(B) shows that the control plain set yoghurt scored highest across all attributes, significantly outperforming all banana peel pectin-fortified samples. However, the control yoghurt and the 1% banana peel pectin sample received the highest scores across all sensory attributes, with no significant differences between them, indicating excellent consumer acceptability. Both samples had mean scores close to 7, suggesting minimal impact on sensory quality at 1% banana peel pectin inclusion. In contrast, yoghurts containing 0.1% and 0.5% mango peel pectin as well as 5% and 10% banana peel pectin scored significantly lower across all attributes, though still within the moderately acceptable range of 5 to 6. These results highlight 1% banana peel pectin as a promising fortification level for consumer-preferred yoghurt.

To determine the most consumer-preferred formulation, 1% mango peel pectin and 1%

banana peel pectin yoghurts were compared with the control using a 7-point hedonic scale (Figure 2(C)). The results demonstrated comparable acceptability across color, texture, Oduor, and overall acceptability, with all three samples receiving similarly high scores (around 6) and no statistically significant differences. A significant difference was observed in taste scores (p < 0.05), where the control yogurt scored lower (5.20 ± 0.47) than banana peel pectin (6.08 ± 0.37), indicating improved flavor in fortified samples. Therefore, 1% banana peel pectin was the most preferred overall.

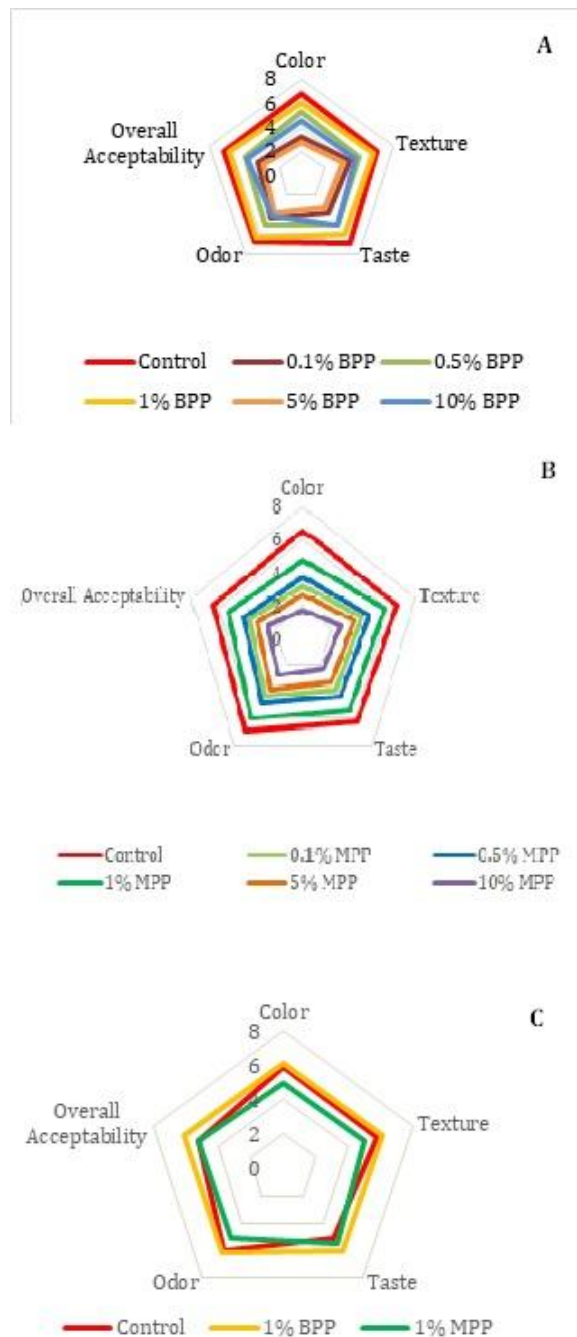


Figure 2: Sensory Profile Comparison of Control with Fresh Mango peel pectin (MPP) -A, Control with Banana peel pectin (BPP) - B, and Control with 1% BPP and 1% MPP Yoghurts (C) based on 7-Point Hedonic Scale.

FUTURE RESEARCH

Future research should focus on optimising purification conditions to further reduce ash content in both mango and banana peel pectin, as the present values remain close to the upper limit for food-grade material. Additional extraction studies could explore alternative acid concentrations, increased washing cycles, or different precipitation approaches to further enhance purity and maintain higher yields, particularly for mango peel where the yield was significantly lower. It would also be valuable to investigate how key structural properties observed in this study, such as degree of esterification, equivalent weight and methoxyl content, influence yoghurt texture stability, syneresis control, sensory acceptance and shelf-life performance. Furthermore, future work could include pilot-scale processing and cost analysis to evaluate industrial feasibility, as well as environmental sustainability assessments to support the utilisation of fruit peel waste as a functional ingredient in commercial yoghurt production.

Future research should also investigate how different pectin inclusion levels influence both probiotic survival and sensory quality, as identifying an optimal concentration or formulation strategy may help resolve the trade-off between probiotic protection at higher levels and consumer acceptability at lower levels.

CONCLUSION

Pectin extracted from banana and mango peels significantly improved the physicochemical, microbiological, and sensory qualities of probiotic yogurt. Both sources yielded high-quality pectin, with banana peel offering superior yield and functional properties. Peel-derived pectin effectively reduced syneresis, supported probiotic survival during storage, and maintained microbial safety within regulatory limits. Sensory evaluation highlighted 1% banana peel pectin as the most acceptable formulation, providing enhanced taste without compromising texture or overall appeal. These results underscore the potential of fruit peel pectin

as a natural, sustainable fortification strategy for dairy products, contributing to waste reduction and functional food development. Future research should explore large-scale processing and the synergistic effects of fruit peel pectin with other bioactive compounds to expand applications in the dairy industry.

Conflict of Interest

The authors declare that there is no conflict of interest.

Acknowledgments

Authors acknowledge the technical staff of the Rich Life Lanka Pvt Ltd, Wadduwa, Sri Lanka, for the assistance given during the study.

REFERENCES

- Abdi-Moghadam, Z., Darroudi, M., Mahmoudzadeh, M., Mohtashami, M., Jamal, A. M., Shamloo, E., & Rezaei, Z. (2023). Functional yogurt, enriched and probiotic: A focus on human health. *Clinical nutrition ESPEN*, 57, 575-586.
- Ahsan, M., Ashraf, H., Liaquat, A., Nayik, G.A., Ramniwas, S., Alfarraj, S., Ansari, M.J. and Gere, A., 2024. Exploring pectin from ripe and unripe Banana Peel: A novel functional fat replacers in muffins. *Food Chemistry: X*, 23, p.101539.
- Alam, M., Majid, I., Kaur, S., Dar, B. N., & Nanda, V. (2025). An Updated Review on Exploring Hydrocolloids Application in Food Matrix: Current Insights into Fruit, Bakery, Meat, and Dairy Based Products. *Journal of Texture Studies*, 56(2), e70020.
- Association of Official Analytical Chemists (AOAC) (2005). Official methods of analysis. Food composition, additives and natural contaminants. *Aldric*, RC 15th Edn. Association of Official Analytical Chemists Inc. USA.
- Chandan, R. C., Gandhi, A., & Shah, N. P. (2017). Yogurt: Historical background, health benefits, and global trade. *Yogurt in health and disease prevention* (pp. 3-29). Academic Press.
- Chua, B.L., Tang, S.F., Ali, A. and Chow, Y.H. (2020). Optimisation of pectin production from dragon fruit peels waste: drying, extraction and characterisation studies. *SN Applied Sciences*, 2(4), p.621.
- De Toledo, Nataly Maria Viva, Adriano Costa De Camargo, Paula Bortolotto Mendes Ramos, David Charles Button, Daniel Granato, and Solange Guidolin Canniatti-Brazaca (2018) Potentials and pitfalls on the use of passion fruit by-products in drinkable yogurt: Physicochemical, technological, microbiological, and sensory aspects. *Beverages* 4(3), 47.
- Dönmez, Ö., Mogol, B.A. and Gökmen, V. (2017). Syneresis and rheological behaviors of set yogurt containing green tea and green coffee powders. *Journal of dairy science*, 100(2), pp.901-907.
- FCC. *Food Chemical Codex*, 3rd ed.; National Academy of Science: Washington, DC, USA, 1981.
- Gemechu, B., Keyata, E.O., Geleta, T.E., Gemede, H.F. and Bayata, A. (2024). Optimization of mango peel pectin extraction (*Mangifera indica* L.): For the production of jam and jelly. *Applied Food Research*, 4(1), 100411.
- Halahlah, A., Piironen, V., Mikkonen, K. S., & Ho, T. M. (2023). Polysaccharides as wall materials in spray-dried microencapsulation of bioactive compounds: Physicochemical properties and characterization. *Critical Reviews in Food Science and Nutrition*, 63(24), 6983-7015.
- Hussein, Z.E.H., Silva, J.M., Alves, E.S., Castro, M.C., Ferreira, C.S.R., Chaves, M.L.C., da Silva Bruni, A.R. and Santos, O.O. (2021). Technological advances in probiotic stability in yogurt: a review. *Research, Society and Development*, 10(12), e449101220646-e449101220646.
- Jany, J.F., Nupur, A.H., Akash, S.I., Karmoker, P., Mazumder, M.A.R. and Alim, M.A. (2024). Fortification of functional yogurt by the phytochemicals extracted from pomegranate peel. *Applied Food Research*, 4(2), 100479.
- Jiffry, N. and Nandaneer, G.G.W. (2024). Assessment of Physicochemical and Microbiological Parameters of Plain Set Yoghurt Sold in Colombo, Sri Lanka. *Advances in Technology*, 4(01).
- Kazemi, F., Sharifi, A., & Mahmoudi, R. (2024). Evaluation of Viability of Probiotic Bacteria in some Iranian Probiotic Dairy Products.

- Journal of Food and Bioprocess Engineering*, 7(1), 72-78.
- Khamsucharit, P., Laohaphatanalert, K., Gavinlertvatana, P., Sriroth, K. and Sangseethong, K. (2018). Characterization of pectin extracted from banana peels of different varieties. *Food science and biotechnology*, 27(3), 623-629.
- Kothalawala, S.G. and Yatiwella, L.N.S.B. (2018). Analysis of antioxidant activities in Mango Peel among different Sri Lankan Cultivars. *Journal of Pharmacognosy and Phytochemistry*, 7, 1668-1671.
- Lee, W.J. and Lucey, J.A. (2010). Formation and physical properties of yogurt. *Asian-Australasian Journal of Animal Sciences*, 23(9), 1127-1136.
- Macias-Frotto, B., Rostro-Alanís, M., Escobedo-Avellaneda, Z. and Welte-Chanes, J. (2025). Conventional and innovative methods for pectin extraction from Agro-industrial by-products. *Food Engineering Reviews*, 17(1), 161-188.
- Mada, T., Duraisamy, R. and Guesh, F. (2022). Optimization and characterization of pectin extracted from banana and papaya mixed peels using response surface methodology. *Food Science & Nutrition*, 10(4), 1222-1238.
- Maduwanthi, S.D.T. and Marapana, R.A.U.J., (2019). Induced ripening agents and their effect on fruit quality of banana. *International journal of food science*, 2019(1), 2520179.
- Mahomud, M.S., Islam, M.N., Hossen, D., Wazed, M.A., Yasmin, S. and Sarker, M.S.H. (2024). Innovative probiotic yogurt: Leveraging green banana peel for enhanced quality, functionality, and sensory attributes. *Heliyon*, 10(19).
- Mani-López, E., Palou, E. and López-Malo, A. (2014). Probiotic viability and storage stability of yogurts and fermented milks prepared with several mixtures of lactic acid bacteria. *Journal of Dairy Science*, 97(5), 2578-2590.
- Naik, A. (2023). Production Cost Analysis and Marketing of Fermented Foods: Yoghurt. *Food Microbiology Based Entrepreneurship: Making Money from Microbes*. Singapore: Springer Nature Singapore, 215-231.
- Ospanov, A., Velyamov, S., Tlevlessova, D., Schetinina, E., Kairbayeva, A., Makeeva, R., & Tastanova, R. (2023). Survival of lactic acid bacteria when using the developed yogurt from the milk of small cattle under in-vitro conditions. *Food Science and Technology*, 43, 117722.
- Pacheco-Jiménez, A.A., Lizardi-Mendoza, J., Heredia, J.B., Gutiérrez-Grijalva, E.P., Quintana-Obregón, E.A. and Muy-Rangel, M.D. (2024). Physicochemical characterization of pectin and mango peel (*Mangifera indica* L.) from Mexican cultivars. *Heliyon*, 10(15).
- Parichat, P., & Pongsak, R. (2023). Probiotics: Sources, selection and health benefits. *Research Journal of Biotechnoly*, 18, 5.
- Rashwan, A. K., Osman, A. I., & Chen, W. (2023). Natural nutraceuticals for enhancing yogurt properties: a review. *Environmental Chemistry Letters*, 21(3), 1907-1931.
- Rutella, G. S., Tagliazucchi, D., & Solieri, L. (2016). Survival and bioactivities of selected probiotic lactobacilli in yogurt fermentation and cold storage: New insights for developing a bi-functional dairy food. *Food Microbiology*, 60, 54-61.
- Safdari, Y., Vazifedoost, M., Didar, Z. and Hajirostamloo, B. (2021). The effect of banana fiber and banana peel fiber on the chemical and rheological properties of symbiotic yogurt made from camel milk. *International Journal of Food Science*, 2021(1), 5230882.
- Sagar, N.A., Pareek, S., Sharma, S., Yahia, E.M. and Lobo, M.G. (2018). Fruit and vegetable waste: Bioactive compounds, their extraction, and possible utilization. *Comprehensive reviews in food science and food safety*, 17(3), 512-531.
- Said, N. S., Olawuyi, I. F., & Lee, W. Y. (2023). Pectin hydrogels: Gel-forming behaviors, mechanisms, and food applications. *Gels*, 9(9), 732.
- Sasanka, I., Wijewardane, N.A., Wijesinghe, W.A.J.P., Jeewanthi, W. and Priyadarshana, I.B. (2024). Development of Banana Flour Incorporated Biscuit and Evaluation of its Physicochemical Properties. *Advances in Technology*, 4(1).
- Senaratne, S.M.D.S.C., Somaratne, G.M., Athukorala, L.U. and Roy, D. (2025). Quality, Shelf-life, and Consumer Acceptability of Probiotic Yogurt Enriched with Banana and Mango Fruit Peels. *Asian*

- Journal of Food Research and Nutrition*, 4(3), 1095-1109.
- Siddiqi, M., Tarrah, A., Chen, Z. H., & LaPointe, G. (2024). Phenotypic Differentiation of *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus* Isolates Found in Yogurt Starter Cultures. *Fermentation*, 10(12), 601.
- Thilakarathna, P.T.S. and Perera, O.D.A.N. (2024). Comparative Studies on Antioxidant Properties of Selected Varieties of Banana Peels and Formulation of Yoghurt with Banana Peel Extract to Study the Storability of Yoghurt. *World Journal of Agriculture and Forestry Sciences*, 2(3), 1-16. <https://doi.org/10.61784/wjafs3011>.
- Wazzan, H. (2024). Fortification of dairy products using plant-derived bioactive compounds. *Current Research in Nutrition and Food Science Journal*, 12(2), 561-571.
- Yang, Y., Zhang, R., Zhang, F., Wang, B., & Liu, Y. (2023). Storage stability of texture, organoleptic, and biological properties of goat milk yogurt fermented with probiotic bacteria. *Frontiers in Nutrition*, 9, 1093654.
- Zahid, H. F., Ranadheera, C. S., Fang, Z., & Ajlouni, S. (2021). Utilization of mango, apple and banana fruit peels as prebiotics and functional ingredients. *Agriculture*, 11(7), 584.
- Zahid, H. F., Ranadheera, C. S., Fang, Z., & Ajlouni, S. (2022). Functional and healthy yogurts fortified with probiotics and fruit peel powders. *Fermentation*, 8(9), 469.
- Zaki, A.H., Gazwi, H.S.S., Hamed, M.M., Galal, S.M., Almeahadi, A.M., Almuraee, A.A., Alqurashi, A.F. and Yassien, E.E. (2024). The synergistic potential of orange peel extract: A comprehensive investigation into its phenolic composition, antioxidant, antimicrobial, and functional fortification properties in yogurt. *Food Chemistry: X*, 22, 101458.
- Żbikowska A., Szymańska I., Kowalska M. (2020). Impact of inulin addition on properties of natural yogurt. *Applied Sciences*, 10(12), 4317. <https://doi.org/10.3390/app10124317>.