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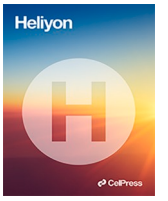

Research article

Innovative probiotic yogurt: Leveraging green banana peel for enhanced quality, functionality, and sensory attributes

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ABSTRACT

Yogurt, a popular dairy product renowned for its nutritional benefits and probiotic content, serves as a functional food with potential health-promoting properties. The objective of this study was to investigate whether incorporating green banana peel polyphenol extract (GBPPE) into yogurt formulations enhances the viability and functionality of probiotics while also potentially improving the overall quality and health-promoting properties of the yogurts. GBPPE was extracted and added to the yogurt formulation at 0.0 %, 0.5 %, 1 %, and 2 %. Various physicochemical properties of GBPPE as well as a range of physical, biochemical, sensory, and microbial assessments of formulated yogurts were carried out. Compared to the control, yogurt containing GBPPE improves functional characteristics by increasing antioxidant activity while having no detrimental impact on physicochemical and organoleptic properties. In terms of antioxidant capabilities, all fortified yogurts showed significantly ($p < 0.05$) higher total phenolic, flavonoid contents and antioxidant activities than the control yogurt. The addition of GBPPE also affected ($p < 0.05$) pH, titratable acidity, viscosity, water-binding capacity, syneresis, and total soluble solids, while no significant differences in the color parameters were detected in both control and all fortified yogurts with reduced brightness (L^*) and increased redness (a^*) of the product. The initial viable counts of all yogurt samples were almost similar, and the maximum and minimum viability loss of probiotics were observed in control and 2 % GBPPE fortified samples, respectively. Sensory assessment revealed that yogurt with 0.5 % banana peel extract outperformed all other treatments except the control. These findings support the sustainable use of GBPPE to create probiotic yogurt with improved physicochemical, microbiological, and sensory qualities.

1. Introduction

Functional foods are one of the most significant areas of the modern food industry. Studies have demonstrated that functional foods offer potential health benefits beyond their widely recognized nutritional benefits, including reducing the risk of chronic disease [1,2]. Yogurt that includes probiotics, prebiotics, antioxidants, plant extracts, calcium, vitamins, or a combination of these are referred to as

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functional yogurt products [3]. Probiotics are live microbial meals that have positive medicinal benefits for the digestive system, such as lowering cholesterol, improving lactose intolerance, preventing infections, and boosting immunity [4]. Health-conscious populations often favor probiotic products that contain strains of the beneficial bacteria *Lactobacilli* and *Bifidobacteria* [5].

The nutraceutical advantages, sensory characteristics, and physicochemical characteristics of natural bioactive components are numerous and well-documented. Natural antioxidants like polyphenols, flavonoids, and other bioactive compounds derived from fruits and plant sources have shown significant health benefits, including anti-inflammatory, anti-carcinogenic, and cardiovascular health-promoting properties [6,7]. These compounds can inhibit oxidative stress, a key factor in ageing and many chronic diseases [8].

Polyphenols, in particular, are widely recognized for their antioxidant activity, which helps in scavenging free radicals and reducing the risk of various chronic diseases. They also contribute to the stability and shelf life of food products by preventing oxidation [9,10]. Polyphenols extend the shelf life of milk-based products by inhibiting lipid oxidation and microbial growth, both of which are primary causes of food spoilage. By neutralizing free radicals that can catalyze oxidation reactions, polyphenols maintain the integrity of fats and proteins within the product. Additionally, their antimicrobial properties inhibit the growth of spoilage organisms, thereby preserving the quality and extending the shelf life of dairy products. Studies have highlighted that incorporating polyphenols into dairy products like yogurt can enhance their nutritional profile without compromising sensory attributes such as taste, flavor, and mouthfeel [11].

The banana (*Musa* x *paradisiaca* L.), one of the most widely consumed fruits, especially in tropical countries, is rich in polyphenols, dietary fiber, and essential minerals [12]. Historically, the green banana peel has been utilized for its medicinal properties in treating ailments such as burns, anemia, diarrhea, and diabetes due to its rich bioactive content [13]. Green banana peels at the unripe stage contain higher levels of resistant starch, dietary fiber, and certain bioactive compounds compared to ripe bananas, which have higher levels of simple sugars and lower fiber content. These nutritional differences make green banana peels particularly suitable for functional food development focused on digestive health, blood sugar management, and weight control [14]. Despite its potential, green banana peel often remains an underutilized resource and is typically discarded during processing and consumption [15].

Approximately 826,000 metric tons of bananas were harvested in Bangladesh between 2020 and 2021 [16]. Among the many fruits eaten in Bangladesh, bananas rank high in popularity [17]. The banana peels, although nutritionally important, are often discarded during processing, and cooking in Bangladesh. This could be due to a lack of consumer awareness and commercial applications of banana peels' benefits.

Due to the lower pH and oxidative stress during processing and storage, the viable count of probiotic microorganisms in yogurt decreases, thus hindering their capacity to provide the intended health advantages [18]. Because green banana peel polyphenol has the ability to scavenge free radicals, probiotic yogurt combined with it may present an opportunity to provide functional assistance to enhance the viability of probiotics [19]. The primary objective of this study was to investigate whether incorporating green banana peel polyphenol extract (GBPPE) into yogurt formulations enhances the viability and functionality of probiotics, as well as improves the overall physico-chemical properties and sensory attributes of yogurts. We hypothesized that GBPPE would not only improve the antioxidant properties but also stabilize the probiotic counts during storage. Our formulation is pioneering in its use of GBPPE as a multifunctional additive in yogurt. While polyphenols are commonly used, our innovative approach of deriving them from green banana peels—a sustainable and otherwise wasted resource—adds a unique aspect to the formulation. The integration of this novel ingredient not only enhances the nutritional profile but also aligns with the Sustainable Development Goals (SDG) by reducing food waste through the productive use of banana peels.

2. Materials and methods

2.1. Raw materials collection

Fully mature banana (*Musa* x *paradisiaca* L.), deep green (color stage 1) [20] and skim milk powder were purchased from the local market of "Basher hat" near Hajee Mohammad Danesh Science and Technology University (HSTU) area, Dinajpur. These bananas were organically grown in the "Basher hat" area (25°42′00.3″N 88°39′45.4″E). Green banana peels used in this study, the bananas were collected from several different trees within the same farm to maintain consistency and account for any potential variability within individual trees. The probiotic cultures of *Lactobacillus bulgaricus* and *Streptococcus thermophilus* were obtained from Christian Hansen, (holding A/S, boege Alle 10–12, 2970 hoersholm, Denmark) and other chemicals (Sigma-Aldrich, Shanghai, China) mentioned in the following sections were used from the laboratory stock of department of Agro-processing, Bangabandhu Sheikh Mujibur Rahman Agricultural University.

2.2. Preparation of green banana peel powder

The collected fresh, mature green bananas were sorted manually to remove any visible disorders and disease incidences. Selected bananas were carefully separated from the bunch using sharp knife and washed thoroughly under running tap water. The peels of bananas were removed from the edible part by a stainless-steel knife and sliced into thicknesses of 2–3 mm. To reduce enzymatic browning, sliced banana peel was dipped in a 0.5 % (m/v) citric acid solution for 10 min. After draining the water, the sliced peels were dried in a convective dryer at 65 ± 2 °C until they reached a constant moisture content. The dried sample was placed in a desiccator to cool. A blender (CM/L- 7360065, Japan) was used to blend the dried banana peels. Then, the banana peel powder was sieved to create a powder with a uniform 0.18 mm particle size [21], sealed in high-density polyethylene (HDPE) bags and stored in the desiccator for further use.

2.3. Proximate analysis of green banana peel powder

The moisture, protein, fat, ash, and crude fiber content of green banana peel powder (GBPP) were determined using the standard protocols methods of the Association of Official Analytical Chemists. The amount of carbohydrate was calculated by deducting the measured amounts of protein, fat, ash, moisture, and fiber from 100 [21,22–24].

2.4. Extraction of green banana peel polyphenol

GBPP was taken for the extraction of GBPPE. At first, an acidified solution (100 mL, 0.001 M) of citric acid with distilled water was prepared (pH 3.0). GBPP was dissolved in the acidic solution at 1:20 ratio, then centrifuged using Bench top Universal 32R Centrifuge (Hettich Zentrifugen, Tuttlingen, Germany) at 5000 rpm for 10 min. The clear supernatant was collected, and the acidic solution was removed. The extracted polyphenols were gathered and kept in a refrigerator at 4 °C [25].

2.5. Formulation of yogurts

Reconstituted skim milk was prepared by dispersing 12 g of skim milk powder in 100 g of distilled water. Then the dispersion was agitated using a magnetic stirrer for 1 h. A thermostatically controlled water bath was used to heat skim milk for 30 min at 85 °C. Since fermentation is faster at 43 °C [26], milk was cooled to 43 °C with the help of ice water.

Functional yogurt was made using the following method with GBPPE in various proportions. Traditional yogurt starter culture (*L. bulgaricus* and *S. thermophilus*) 0.5 g, and different concentrations of GBPPE such as 0.0 % (BPY1), 0.5 % (BPY2), 1 % (BPY3), and 2 % (BPY4) were added to make functional yogurt. Samples were incubated at 37 °C for 10 h until they reached the required acidity (pH 4.6). Following that, the yogurt samples were kept in a refrigerator at 4 °C for quality testing.

2.6. Physicochemical analysis of fortified yogurt

Yogurt samples were tested on day-1 and day-8 for various physicochemical, microbial, and sensory properties. The yogurt samples were analyzed for pH using standard procedures [24] by a digital pH meter (HI 2211, Hanna Instruments, Romania). The determination of syneresis, which refers to the expulsion of whey or liquid from the gel, leading to a separation of components, was made according to Modler, Larmond et al. [27]. A portion of 10 g of yogurt was placed on a 10 cm piece of Whatman No. 1 filter paper's surface. Yogurt underwent vacuum filtration for 10-min. Filter paper was used to remove the liquid, which was then collected and recorded. The weight of the liquid was divided by the initial sample weight, and then multiplied by 100, to determine the syneresis percentage.

$$\%\ \text{Syneresis} = \frac{\text{weight of liuid}}{\text{weight of yogurt}} \times 100$$

The viscosity was calculated using the method of Wazed and Islam [22], with slight modifications. By stirring with a glass rod (10 times anticlockwise; 10 times clockwise), the yogurt was homogenized. A viscometer and spindle number 2 (Viscotech Hispania S. L., 43700E Vendrell, and Spain) were used to measure rotational viscosity. Each measurement was taken at room temperature for 1 min at 100 rpm.

Acid base titration was carried out to determine titratable acidity (TA). Using 0.5 % phenolphthalein as an indicator, 10 g sample was combined with 10 mL of hot distilled water and titrated against 0.1N sodium hydroxide. Analysis was done in triplicate [28].

The water holding capacity (WHC) was determined using the centrifugal method [3]. 20 g of yogurt was centrifuged for 20 min at 6000 rpm. The expelled whey was carefully removed, and the precipitant was weighed. The WHC was determined by:

$$\text{WHC}(\%) = \frac{\text{Y} - \text{EW}}{\text{Y}} \times 100$$

where, Y is yogurt and EW is expelled whey.

Total soluble solids (TSS) of yogurt was determined by oven drying method [29]. TSS was determined using the following equation:

$$\text{TSS}(\%) = \frac{\text{Y}_1 \times 100}{\text{Y}_2} \times 100$$

where, Y_1 is the weight of the initial (wet) sample and Y_2 is the weight of the final (dried) sample.

2.7. Color measurement

The color of yogurt was analyzed using a BIOBASE Colorimeter (Biobase, Jinan, Shandong, China). The probe of the colorimeter was placed on the yogurt samples through the transparent glass, and the color attributes (L^*, a^*, and b^*) of yogurt were recorded. The L* value represents brightness (100: white, 0: black), a^* represents redness to greenness, and b^* represents yellowness to blueness. Additionally, hue (h), chroma (C), and yellowness index (YI) were calculated according to Islam, Zhang et al. [30]. C value refers to the intensity of a color, h value represents the attribute of color that classifies red, blue, green, yellow, etc., and YI quantifies the degree of

yellowness in the yogurts [31].

2.8. Determination of total phenolic content

Yogurt sample (10g) was blended with 2.5 ml of distilled water, and its pH was adjusted to 4.0 using 1M HCl. Subsequently, the sample underwent a 10-min incubation at 45 °C, followed by centrifugation at 10000 rpm for 20 min at 4 °C. The resulting supernatant was collected, and its pH was adjusted to 7.0 with NaOH. After neutralization, the supernatant underwent another round of centrifugation at 10000 rpm for 20 min at 4 °C, and the resulting supernatant was used for further analysis. The total phenolic content (TPC) of GBPP and yogurts was determined using the method of Paul, Islam et al. [32]. In a 10 ml test tube, aliquots of 50 μl of each extract were mixed with 1950 μl of water. The test tube was vigorously shaken and then 1 ml of Folin-Ciocalteu reagent was added. Immediately, 5 ml of 20 % sodium carbonate solution was added, and the volume of the mixture was increased to 10 ml with distilled water and thoroughly shaken. The absorbance of the mixture was measured at 735 nm after 20 min using a spectrophotometer (Double Beam Spectrophotometer, UH5300, Japan). The results were expressed as mg gallic acid equivalents (GAE) per 100 g of dry weight.

2.9. Determination of total flavonoid content

The colorimetric approach described by Zhou, Cao et al. [33] was slightly modified to determine the total flavonoid content (TFC). In a 15 ml falcon tube, 4 ml of distilled water was combined with 1 ml of the extracts and 0.3 ml of the 5 % sodium nitrite solution. The tubes were then left to stand for another 5 min, after which 0.3 ml of 10 % aluminum chloride was added to the mixture and the mixture was again left to stand for another 1 min. Finally, 2.4 ml of distilled water and 2 ml of 1 M sodium hydroxide were added. The tubes were centrifuged for 10 min at 4000 rpm, and then left at room temperature in the dark for 15 min. At 510 nm, the absorbance was measured in comparison to a blank. The TFC was calculated using a quercetin standard curve and expressed as mg quercetin equivalent (QE) per 100 g.

2.10. DPPH free radical-scavenging assay

The ability of the GBPP to scavenge free radicals on the 1, 1-diphenyl-2-picrylhydrazyl (DPPH) radical was assessed in order to determine its antioxidant potential. In this experiment, we chose widely used electron-transfer (ET) based method as it is a well-established, straightforward, and for assessing antioxidant activity, since our primary goal was to evaluate the initial antioxidant capacity of GBPP using a reliable and reproducible method. The method provided by Rahman, Islam et al. [3] with some changes, was used to determine the DPPH free radical scavenging capacity. In a test tube, the extract (50 μl) and DPPH solution (1950 μl of 0.13 mM) were mixed. Following a thorough vortexing step, the mixture was held at room temperature for 30 min in a dark environment. Absorbance was measured at 517 nm. As a blank, methanol was utilized. Antioxidant activity was expressed as mg gallic acid equivalents (GAE) per 100 g dry matter (DM).

2.11. Microbiological analysis of fortified yogurt

According to Ali, Saha et al. [34], all media were purchased in dehydrated forms and processed. The overall bacterial count was determined using an agar plate count. The Petri dishes were autoclaved for 15 min at 121 °C to sterilize them.

The pour plate method was used to count all bacteria and coliforms. Standard nutrient agar plates for the total bacterial count and MacConkey agar plates for coliform detection was used. To create eight-fold dilutions from 10^{-1} to 10^{-8}, one ml from a homogenous yogurt sample was serially diluted into 9 ml of Ringer solution. To determine the total number of bacteria and coliforms present 1 ml of each sample was put into a sterile duplicate plate, together with 15–20 ml of the chosen media. The cultivated plates were incubated at 32 °C for 48 h, 37 °C for 24 h, and 25 °C for 5 days to determine the total bacterial count. The plates holding 15–150 CFU/ml were counted for coliform, whereas the plates carrying 25–250 CFU/ml were counted for the total bacterial count.

2.12. Sensory evaluation

The sensory evaluation panel, consisting of thirty individuals [35], comprised ten women aged between 25 and 50, each with more than two years of experience in sensory evaluation within the laboratory setting. For this study, the panel size was determined using statistical power analysis to ensure it had sufficient sensitivity to detect significant differences in perceptions of acceptability. Panelists were selected through purposive sampling, taking into account factors such as age, gender, cultural background, and familiarity with the product. To maintain consistency, panelists participated in two practice sessions before the actual evaluation. These sessions included an introduction to the products, information about the ingredients used, safety measures, and specific instructions for evaluating the products. The panelists collectively chose to use a hedonic rating system, rating taste, mouth feel, color, flavor, texture, and overall acceptability on a scale from 1 to 9, ranging from extreme dislike (1) to extreme like (9). Samples were presented to panelists under controlled conditions (24 °C) to minimize potential biases [36].

2.13. Statistical analysis

All experiments were carried out in triplicate and the values were presented as mean values ± standard deviation. A single-factor

experiment with a completely randomized design (CRD) was used. Analysis of variance (ANOVA) was performed using statistical software SPSS (Version 26.0). The significant differences between the mean values at the ($p < 0.05$) level were ascertained using Duncan's Multiple Range Test (DMRT). Person correlation analysis and heatmap analysis were carried out using R statistical software (R version 3.5.1, R core development team, Vienna, Austria) [37,38].

3. Results and discussion

3.1. Physicochemical and antioxidant properties of the green banana peel powder

The potential applications of GBPP depend on their physico-chemical and functional properties. Table 1 displays the findings of the proximate composition of GBPP.

The moisture content (MC) of the GBPP was found to be 10.5 %. Similar MC of 10.88 % for GBPP was reported by Rodriguez-Morales, Cardona-Ospina et al. [39]. The obtained MC value was found to be lower than the value of 11.20 % reported by Ramli, Alkarkhi et al. [40]. This variation could be attributed to differences in the varieties and processing parameters employed.

The crude fiber content of GBPP was observed 3.81 %, a value similar to 3.20 % reported previously [41]. The fiber contents of green banana peels are affected by the maturation of bananas. Regarding ash content, GBPP showed a value of 4.61 %, which is consistent with the findings of Menezes, Tadini et al. [42]. The variation in ash content in green banana peels might be due to variations in cultivars and drying techniques.

In the present research, GBPP showed a fat content of 1.28 %, whereas a higher value of 1.70 % was reported by Anhwange, Ugye et al. [43]. Also, Haslinda, Cheng et al. [44] observed that green banana powder with and without peel had fat concentrations of 0.94 and 1.94 %, respectively. GBPP had protein content of 7.70 %, which is higher than that reported previously (6.77 %) by Haslinda, Cheng et al. [44].

In addition, the carbohydrate content of GBPP was found to be 72.1 % in this study. A slightly lower value (66.92 %) was reported by Alam, Akter et al. [45]. GBPP had a higher carbohydrate content in this study, which could be attributed to factors such as variety, maturity stage, and geographical location [46].

Table 1 also presents the antioxidant properties of GBPP, including TFC, TPC, and DPPH. TPC in GBPP was found to be 70 mg GAE/100g DM. TPC varies among different samples found in literature; for example, a lower value of TPC (29 mg GAE/100g DM) was reported by Rebello, Ramos et al. [47], while Kabir, Hasan et al. [48] reported 53.80 mg GAE/100g DM. Maturity stage of banana, sample preparation methods, and measurement techniques may have an impact on the TPC value of GBPP [49].

The TFC of GBPP was found to be 39 mg QE/100g. Like TPC, the TFC value was also found to be higher compared to the other reported values, such as 4.28 mg QE/100g reported by Oguntoyinbo, Olumurewa et al. [41]. One of the most important polyphenols in the green banana peel is quercetin, which has shown significant antioxidant activity [47]. DPPH antioxidant activity of GBPP was found to be 79 mg GAE/100g. Lower values of DPPH in GBPP were reported as 43 mg GAE/100g and 30.93 mg GAE/100g by Oguntoyinbo, Olumurewa et al. [41] and Hernández-Alcántara, Totosaus et al. [50], respectively. Different factors that might be involved in the variation of antioxidants, such as the growing conditions, variety, extraction methods, and pre-processing methods such as blanching. It is noted that incorporating hydrogen-atom transfer (HAT) based assays could provide a more comprehensive understanding of the antioxidant activity. This may be considered for future studies to broaden analysis and better capture the antioxidant potential of GBPP.

3.2. Physicochemical analysis of fortified yogurts

GBPPE supplements the yogurt with additional dietary fiber and essential nutrients, thus enhancing its overall nutritional profile; however, this change also affects the texture, pH, acidity, syneresis, water holding capacity, and a number of other physical and chemical characteristics. Fig. 1a shows the viscosity values for various yogurts. It can be seen that BPY1 had low viscosity, whereas BPY4 exhibited a high level of viscosity, i.e., with the addition of GBPPE, the viscosity of the yogurt increased significantly [51]. Cho,

Table 1
Proximate composition and antioxidant properties of the green banana peel powder.

Parameters	Content
Moisture (%)	10.5 ± 0.50
Fiber (%)	3.81 ± 0.08
Ash (%)	4.61 ± 0.50
Fat (%)	1.28 ± 0.24
Protein (%)	7.70 ± 0.10
Carbohydrate (%)	72.1 ± 0.8
TPC (mg GAE/100 g DM)	70.80 ± 0.32
TFC (mg QE/100 g DM)	39.44 ± 0.62
DPPH (mg GAE/100 g DM)	79.07 ± 1.22

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

Kim et al. [52] reported similar findings. Furthermore, greater viscosity in yogurt may be related to enhanced milk coagulation [53].

Findings from this study showed that the WHC of control sample (BPY1) was 52.35 %, followed by BPY2 (54.54 %), and the highest WHC was 57.35 % in BPY4 (Fig. 1b). WHC variation in yogurt could be attributed to total solids in yogurt fortified with GBPPE. Ahmad, Hao et al. [51] reported similar increased WHC values in reconstituted yogurt powder.

Syneresis is apparently a potential problem in the production of commercial yogurt that can affect the perception of consumers. Fig. 1c displays the syneresis values of the various yogurts. As can be observed, the control yogurt showed significantly lower syneresis values than the yogurts produced with GBPPE. The higher syneresis level in fortified yogurt is consistent with the findings of prior investigations regarding yogurts produced with kiwi fruit marmalade [54] and pineapple peel powder [55]. This could be because milk proteins and the polysaccharides in GBPPEs are thermodynamically incompatible. Furthermore, as indicated by Sah, Vasiljevic et al. [55], the rise in syneresis of polyphenol-containing yogurts is owing to the continued reduction of pH of yogurts, resulting in contraction of the casein network. In contrast, Staffolo, Bertola et al. [56] reported reduced syneresis in yogurt that contained apple and orange fiber. The addition of inulin lowers the syneresis of yogurt and other fermented milks, as demonstrated by Żbikowska, Szymańska et al. [57]. Moreover, Ramirez-Santiago, Ramos-Solis et al. [58] showed that potato fiber-enriched yogurt exhibited decreased syneresis. According to Bierzuńska, Cais-Sokolińska et al. [59], increasing the dry matter stabilizes the gel network, boosts its ability to bind water, and lessens syneresis.

The pH range of control and fortified yogurts was 4.33–4.59 (Fig. 1d), and due to the rehydration process, all fortified yogurts showed significantly ($p < 0.05$) lower pH values than control samples. As can be seen, the pH of the yogurt samples decreased as the amount of banana peel extract increased. These results are consistent with those of Casarotti, Borgonovi et al. [60], who reported a discernible pH fall in yogurt enriched with by-products from orange, guava, and passion fruit. This could be due to the continual production of lactic acid by the lactic acid bacteria. Furthermore, according to Aly, Galal et al. [61], yogurt with carrot extract showed a pH that was lower than control yogurt due to the presence of organic acids. The findings of this study also agreed with those reported by Bonczar [62] and Tseng and Zhao [53].

The decrease in pH of the fortified yogurt samples was related with an increase in titratable acidity (TA). When compared to the control, significantly ($p < 0.05$) higher values of TA were recorded in the fortified yogurts (Fig. 1e). Espírito-Santo, Lagazzo et al. [63] reported similar TA levels in yogurt supplemented with passion fruit peel.

The total soluble solid contents of yogurt samples with GBPPE were lower than those of the control sample. The findings showed that BPY4 had the lowest TSS contents (11.56 %), whereas control had the highest TSS contents (14.11 %). A significant effect was observed with the addition of GBPPE on the TSS contents of fortified yogurt (Fig. 1f).

Fig. 2 presents the correlation analysis of the various properties of control and fortified yogurt samples. From Fig. 2, it can be seen that water holding capacity, viscosity, and syneresis are strongly and positively correlated. In addition, the redness properties of color are positively correlated with its acidity, and viscosity related properties. Interestingly, we found that TSS has a strong negative correlation with the properties mentioned earlier [64]. However, TSS and pH were found to be positively correlated. The lightness value and yellowness value had little or no correlation with other physicochemical properties. Similar results have been reported by Arab, Yousefi et al. [65].

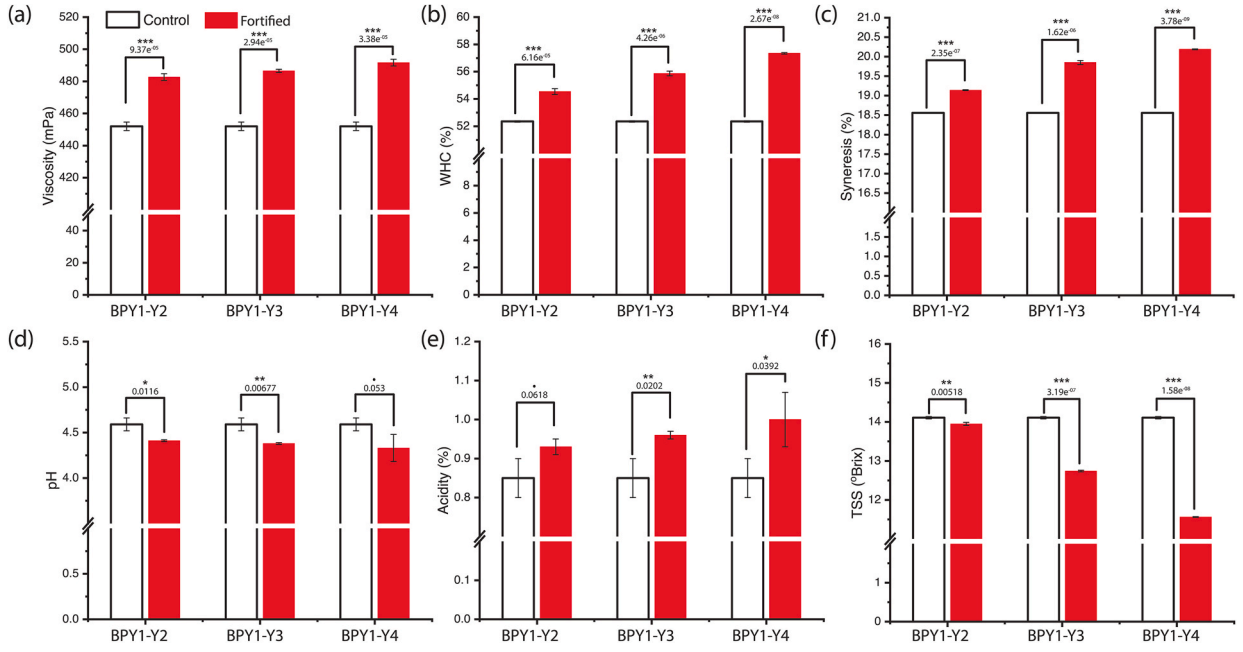

Fig. 1. Comparison of physico-chemical properties a) viscosity, b) WHC, c) syneresis, d) pH, e) acidity, f) TSS of control and banana polyphenol fortified yogurt.

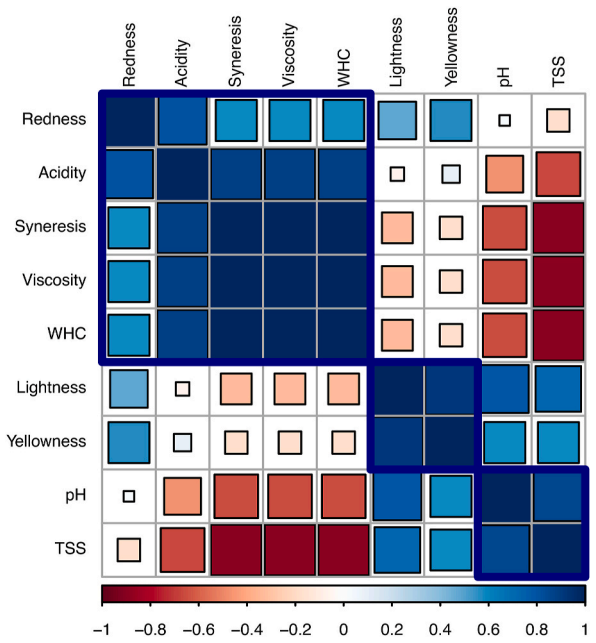

Fig. 2. Correlation analysis of the various properties of control and fortified yogurt.

3.3. Impact of added GBPPE on fortified yogurts color

Yogurt color is one of the most important quality features that affect customer satisfaction and attractiveness [66]. Table 2 shows the results obtained for the color coordinates of the control and fortified yogurts. The luminosity or lightness (L^*) of the yogurts decreased significantly ($p < 0.05$) when GBPPE was added compared to the control. This decline was more noticeable in yogurts supplemented with 2 % GBPPE (BPY4). Such a significant decrease in lightness (L^*) might be due to the darker brown color of the banana peel extract.

The parameter a^* in the GBPPE fortified yogurt formulation increased significantly ($p < 0.05$) from 0.86 (BPY1) to 0.91 (BPY4), reflecting more redness. These findings corroborated the lower L^* in BPY4 yogurt (Table 2) because more red (a^*) would result in lower lightness (L^*). Similar observations for a^* values were found as reported by Ścibisz, Ziarno et al. [67] and Szołtysik, Kucharska et al. [68] for yogurts enriched with strawberry fruits and *Rosa spinosissima* fruit extracts, respectively.

The yogurt samples with GBPPE additions did not show any trend in the b^* color coordinate. Nevertheless, compared to all the other fortified samples, the control samples (BPY1) had higher ($p < 0.05$) b^* values. However, all b^* values recorded were positive, indicating that the yogurt samples were yellow. These color reading discrepancies between fortified and non-fortified yogurts might be attributed to variable amounts of phenolic component concentrations, which are known to interact with anthocyanins and lead to changes in color intensities [67,69]. Moreover, no significant differences ($p > 0.05$) in color characteristics were identified between the fresh and GBPPE fortified yogurts, as reported by Jouki, Khazaei et al. [66]. Furthermore, hue, chroma, and yellowness index lowered significantly ($p < 0.05$) with the addition of GBPPE in the yogurt samples. The lowest values of hue, chroma, and yellowness index were observed in BPY4.

3.4. Total phenolic contents of fortified yogurts

Banana peel is a potential source of polyphenols [70,71]. In the current experiment, regarding antioxidant capabilities, all fortified

Table 2
Color properties of fresh and fortified yogurts.

Parameters	Color properties of formulated yogurt					
	L*	a*	b*	h	C	YI
BPY1	27.62 ± 2.28^{a}	$0.86 \pm .02^{a}$	2.19 ± 0.72^{a}	2.53 ± 0.77^{a}	2.36 ± 0.67^{a}	11.17 ± 2.81^{d}
BPY2	26.14 ± 2.16^{a}	$0.88 \pm .03^{a}$	2.08 ± 0.60^{a}	2.34 ± 0.60^{a}	2.26 ± 0.56^{b}	11.23 ± 2.35^{b}
BPY3	24.99 ± 1.52^{a}	$0.90 \pm .06^{a}$	1.84 ± 0.26^{a}	2.03 ± 0.15^{b}	2.04 ± 0.25^{c}	10.48 ± 0.85^{a}
BPY4	24.50 ± 1.72^{a}	$0.91 \pm .07^{a}$	1.76 ± 0.30^{a}	1.92 ± 0.18^{c}	1.98 ± 0.29^{d}	10.21 ± 1.03^{c}

Data presented as means ± Std. Different superscript letters in the same column represents significant differences ($p < 0.05$) between the means of different yogurt samples as determined by Duncan's Multiple Range Test.

yogurts showed significantly ($p < 0.05$) higher TPC levels than the control yogurt (Fig. 3). The highest phenolic content was observed in BPY4 with 3.56 mg GAE/100 g of yogurt. Such changes might be related to the quicker interactions between proteins and polyphenols, as well as the formation of insoluble substances in the fresh yogurt. However, yogurt fortification inhibited such chemical interactions, revealing higher TPC levels in fortified yogurts (Fig. 3). Similarly, Karaaslan, Ozden et al. [72] observed a greater TPC value for yogurt treated with grape and callus extracts. Chouchouli, Kalogeropoulos et al. [73] reported a higher TPC value in yogurt using grape seed extracts in another investigation. Strawberry pulp was also proven to increase yogurts phenolic content and antioxidant qualities [74]. Moreover, adding green tea to probiotic yogurt improved its TPC value while it was stored in the refrigerator [75]. In a recent study, yogurt mixed with osmo-airdried mulberry showed a higher TPC value than the control [76]. The high polyphenol content in GBPPE significantly boosts the antioxidant properties of the fortified yogurt, offering better protection against oxidative stress compared to control sample.

3.5. Total flavonoid contents of fortified yogurts

Flavonoids, which are particularly potent scavengers of reactive oxygen species and have a wide spectrum of biological and biochemical functions, and also the most prevalent naturally available phenolics. The results showed (Fig. 3) that GBPPE-fortified yogurt with concentrations of 0.5 %, 1.0 % and 2.0 % significantly increased TFC (1.53, 1.70, and 1.88 mg QE/100g of DM) as compared to control yogurt (1.23 mg QE/100g of DM). Ahmad et al. (2020) showed a similar outcome for yogurt treated with apple peel polyphenol extract. Moreover, Can-Cauich, Sauri-Duch et al. [77] discovered that peel extracts of 11 tropical fruits have good antioxidant activity, with total flavonoid levels substantially higher in purple sugar apple and green sugar apple.

3.6. DPPH assay of fortified yogurts

The DPPH test is regarded as a simple approach that provides information on the radical scavenging activity of the antioxidant compounds present in a sample. Fig. 3 depicts the DPPH results of all yogurt samples. There were significant variations in DPPH scavenging activity ($p < 0.05$) across the four yogurt types. All the GBPPEs containing yogurts showed scavenging abilities in the descending order as BPY1 < BPY2 < BPY3 < BPY4 where the highest DPPH values was observed in BPY4 (42.65 mg GAE/100g DM). Similarly, DPPH scavenging assays revealed that adding grape seed extract [73], sour cherry pulp [78], and grape and callus extract [72] to yogurt increased antioxidant activity compared to control yogurt. Another study found that an aqueous extract of *Matricaria recutita* increased DPPH activity in yogurt [79]. Ramos, Santos et al. [80] discovered increased DPPH activity in fermented milk supplemented with an herbal extract blend of *Syzygium aromaticum*, *Ilex paraguariensis*, and *Cymbopogon citratus*. In the present study, the increased antioxidant activity may result from the synergistic effect of citric acid since banana peels were immersed in a solution containing it.

3.7. Total plate count of fortified yogurts

The results of microbiological characteristics in probiotic yogurt on day 1 and after 7 days at 4 °C showed significant ($p < 0.05$) effects (Table 3). Also, it was noted that during storage, the viability of bacteria in control yogurt samples drastically decreased. The results showed that on day 1, the viable count in the control sample was 12.12 log cycles, and after 7 days, the loss in viability was 0.19

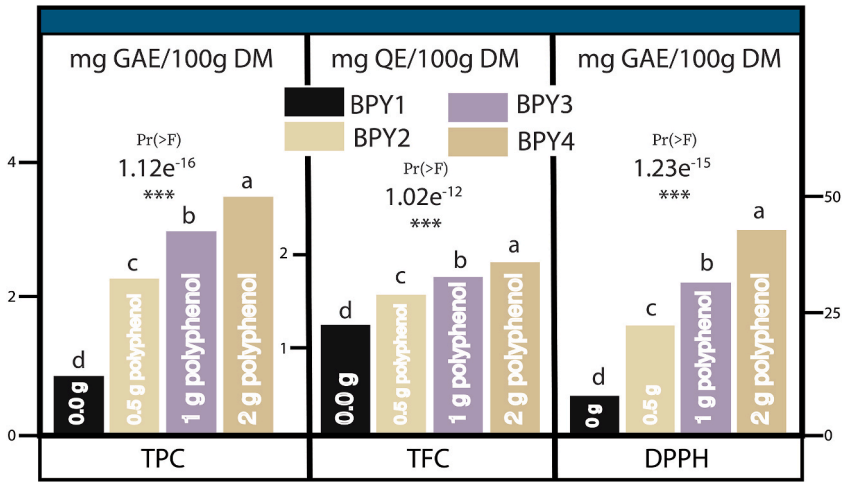

Fig. 3. Total phenolic content, total flavonoids content and DPPH antioxidant activity of yogurt fortified with GBPPE. Bars with different notations are statistically significantly different ($p < 0.05$). BPY1, BPY2, BPY3, and BPY4 represents control, 0.5 %, 1 % and 2 % green banana polyphenol extract fortified yogurt respectively. DPPH, TFC and TPC represents 1,1-diphenyl-2-picrylhydrazyl radical scavenging activity, total flavonoids and total phenolic content respectfully.

log cycles, but with GBPPE 0.5 %, 1 %, and 2 % fortification, the losses were 0.18, 0.16, and 0.10 log cycles, respectively. The lowest viability loss of probiotic bacteria was seen in yogurt samples fortified with GBPPE at 2 % significantly ($p < 0.05$). After 7 days, the maximum viability loss was found in the control yogurt sample ($p < 0.05$). During refrigerated conditions, all yogurt samples with GBPPE fortification showed a slight decrease in viable count. This tendency is consistent with prior research, which found a drop in plate count after 7 days of storage [19]. Also, the inclusion of polyphenol extracts considerably improved the vitality of *B. lactis* and *L. acidophilus* strains [81]. These findings support the possible use of GBPPE as a polyphenol source to improve the functioning of probiotics in dairy products and to provide value to this waste stream agro-industrial material [82]. The GBPPE helps maintain a higher viable count of probiotics during storage, ensuring that consumers receive the maximum health benefits from the probiotics in the fortified yogurt.

3.8. Sensory evaluation of GBPPE fortified yogurt

Table 4 illustrates how banana peel extract affects the sensory qualities of yogurt samples. Considering the sensory qualities of the yogurt, we discovered a significant difference ($p > 0.05$) between the control and yogurt fortified with GBPPE during storage in terms of color, taste, and flavor. As compared to the other samples, the BPY2 sample received the highest score for color, taste, and flavor qualities, followed by the BPY3 and BPY4.

As can be seen in Table 4, when GBPPE level increased, the texture and mouth feel of yogurt samples decreased significantly compared to the control sample. The 2 % banana peel extract sample had the lowest texture, whereas the control sample had the highest. The overall acceptability of the yogurt decreased significantly as the amount of banana peel extract increased. The sample with 2 % polyphenol and the control treatment had the lowest and highest overall acceptance, respectively.

Heatmap analysis of sensory scores also revealed how different sensory properties are linked. We found that overall acceptability was closely related to the texture of yogurt (Fig. 4). The scores of taste, mouth feel and flavor was close [83]. Color, flavor, taste, mouth feel together with textural properties contributed to overall acceptability. Control samples were completely different from those of fortified samples.

Yogurt fortification with health promoting compounds is currently a prominent topic within the scientific community. A recent meta-analysis shows that, functional yogurt containing vitamin D raised human serum 25-hydroxy vitamin D levels by 31.00 nmol/L. Furthermore, it led to a reduction in parathyroid hormone levels by 15.47 ng/L, body weight by 0.92 kg, waist circumference by 2.01 cm, HOMA-IR by 2.18 mass units, fasting serum glucose by 22.54 mg/dL, total cholesterol by 13.38 mg/dL, and triglycerides by 30.12 mg/dL compared to the control treatments [84]. There remains a notable shortage of literature on active human studies concerning polyphenol-enriched yogurts. Future research endeavors should prioritize addressing this gap to advance knowledge and understanding using scientific evidences.

This study aimed to employ GBPPE to enhance probiotics' viability and functionality in yogurt. Our results demonstrated that increasing the GBPPE content effectively improved the antioxidant properties (including total polyphenols, flavonoids, and DPPH capacity) and slowed the reduction rate of beneficial bacteria in yogurt. These findings indicate the potential of GBPPE to improve the functional properties of probiotic yogurt.

However, the sensory evaluation revealed a significant decrease in overall acceptability with higher concentrations of GBPPE. Specifically, attributes such as taste, texture, and mouthfeel were adversely affected as the GBPPE concentration increased. This presents a challenge for the practical application of GBPPE in yogurt production. To overcome this challenge, future studies could therefore focus on identifying the optimal concentration of GBPPE that balances functional benefits and sensory acceptability. It would be worth investigating the synergistic effects with other natural flavor-enhancing or texture-improving agents that could help mask any undesirable sensory attributes introduced by GBPPE. Moreover, microencapsulation of GBPPE could be employed to deliver the functional benefits without compromising sensory properties.

4. Conclusion

The primary goal of the current research was to examine how probiotic viability and functionality of yogurts can be improved by the green banana peel polyphenol extract. We found that green banana peel extract continues to have a favorable influence on the intended physicochemical, antioxidant, microbiological, and sensory properties of fortified yogurt. Further research is required to establish the precise health consequences linked to the consistent use of these fortified yogurts. Overall, the study's findings highlight the possibility of using yogurt enriched with polyphenols from green banana peels as a practical means of increasing dietary intake of these advantageous substances and eventually promoting improved general health and wellness. In future research, it is recommended

Table 3
Changes in the total plate counts of control and fortified yogurts.

Period of storage (Days)	Yogurt samples			
	BPY1	BPY2	BPY3	BPY4
Day 1 (Log CFU/ml)	12.12 ± 0.02^{a}	12.07 ± 0.02^{b}	12.01 ± 0.03^{b}	11.92 ± 0.02^{b}
Day 7 (Log CFU/ml)	11.93 ± 0.11^{a}	11.89 ± 0.09^{a}	11.85 ± 0.10^{a}	11.82 ± 0.09^{a}

Data are expressed as mean ± standard deviation. Means in the same row without common superscript letter differ significantly ($p < 0.05$).

Table 4
Effect of fortification on sensory qualities of yogurt.

Samples	Sensory attributes of yogurt samples after 7 days of storage					
	Color	Taste	Flavor	Texture	Mouth feel	Overall acceptability
BPY1	7.45 ± 0.89^{a}	7.06 ± 0.79^{a}	7.13 ± 0.63^{a}	6.86 ± 0.83^{a}	7.13 ± 0.63^{a}	7.40 ± 0.63^{a}
BPY2	7.40 ± 1.12^{a}	6.86 ± 0.83^{ab}	6.80 ± 0.77^{b}	6.26 ± 0.79^{ab}	6.93 ± 0.79^{ab}	7.06 ± 0.79^{a}
BPY3	6.73 ± 1.09^{ab}	6.33 ± 0.89^{bc}	6.33 ± 0.88^{bc}	6.33 ± 0.81^{ab}	6.40 ± 0.82^{bc}	6.93 ± 1.16^{ab}
BPY4	6.26 ± 0.79^{b}	6.13 ± 0.91^{c}	6.13 ± 0.83^{c}	6.00 ± 0.84^{b}	6.26 ± 0.79^{c}	6.26 ± 1.22^{b}

Data expressed as mean ± standard deviation. Different superscript letters in the same column indicates significant differences ($p < 0.05$).

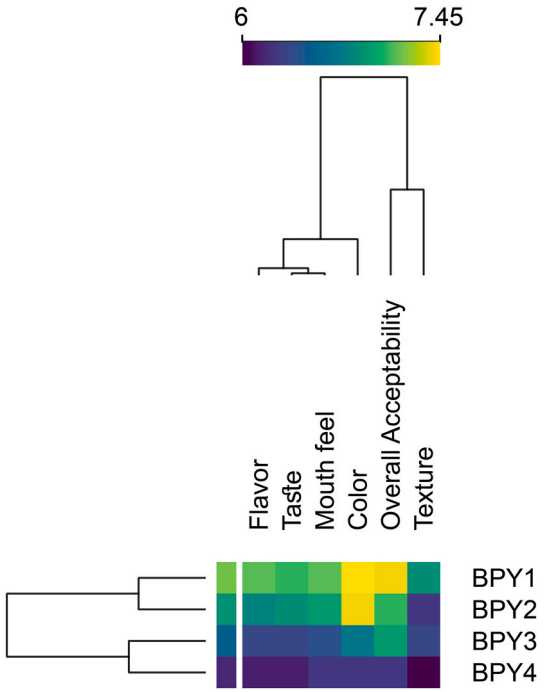

Fig. 4. Heatmap analysis of the sensory scores of the control and fortified yogurt. BPY1, BPY2, BPY3, and BPY4 represents control, 0.5 %, 1 % and 2 % green banana polyphenol extract fortified yogurt respectively.

to extend the duration of the experiment to properly unlock the storage potential and incorporate human studies to comprehensively evaluate the potential health benefits of functional yogurt consumption.

Declarations

The authors declare that all experiments were carried out in accordance with the ethical standards set forth by Institute of Research and Training (IRT) of Hajee Mohammad Danesh Science and Technology University and comply with all relevant regulations (Ref. No. HSTU/IRT/4123(1)). Moreover, informed written consent was obtained from all participants prior to their participation in the study. The participants were fully informed about the nature, purpose, and any potential risks of the study. Furthermore, all personal information collected during the study was kept confidential and used solely for research purposes.

Data and code availability statement

Data will be made available on request.

CRediT authorship contribution statement

Md. Sultan Mahomud: Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Methodology, Funding acquisition, Conceptualization. **Md. Nahidul Islam:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Diloar Hossen:** Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis. **Md. Abdul Wazed:** Writing – review & editing,

Writing – original draft, Supervision. **Sabina Yasmin:** Writing – review & editing, Supervision, Resources. **Md. Sazzat Hossain Sarker:** Writing – review & editing, Validation, Supervision, Investigation, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e38781.

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