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INCORPORATION OF GINGER PEEL POLYPHENOL INTO YOGURT IMPROVES ITS STABILITY: PHYSICOCHEMICAL AND MICROBIOLOGICAL CHARACTERIZATIONS

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ABSTRACT. Microencapsulation is a novel process of plant-extracted polyphenol enrichment into yogurt to extend storage stability with improved quality. This study was intended to develop and characterize functional yogurt that had been microencapsulated with ginger-extracted polyphenol to observe stability at refrigeration temperature (4 ± 1 °C). The phenolic content, microencapsulation efficiency, physiochemical properties, texture, microbiological, and sensory properties were evaluated. The microencapsulation efficiency was found to be 94.40 ± 0.05%. In comparison to the dairy yogurt, the polyphenol-enriched yogurt was darker and had a lower a* (redness to greenness) value and a higher b* (yellowness to blueness) value. Yogurt with added polyphenols decreased the rate at which the pH changed. The phenolic yogurt sample outperformed the control yogurt in terms of water-holding capacity and syneresis. The texture of the treated sample was also superior after three weeks of storage compared to the control. In phenolic yogurt, the rate of Lactobacillus viability decline was reduced. Including ginger extract in yogurt reduced the sensory score in color, flavor, taste, and overall acceptability, but the decreasing rate was reduced. This study demonstrates that the ginger extract polyphenol can be effectively microencapsulated to increase yogurt stability under refrigeration.

KEY WORDS: Ginger, Polyphenols¸ Microencapsulation, Yogurt, Shelf life

INTRODUCTION

Components of food and detect the pollutants present in it and their concentrations. It also aims to develop techniques and methods to detect contaminants in food and significantly improve the quality and type of foods, paving the way for a safer and healthier food supply [1-4]. Yogurt is one of the most popular dairy-based dessert items, and it has developed an excellent reputation among consumers as a functional food item. Yogurt contains different health-promoting constituents such as high protein, calcium, vitamins, and probiotics. The yogurt market is projected to increase from US$ 140.819 billion in 2021 to US$ 185.484 billion in 2028, with a CAGR of 4.01% [5]. Scientists are increasingly analyzing different foods and foodstuffs due to their importance to human health. This research investigates how it is produced under controlled conditions by mixing UHT/pasteurized milk with lactic acid bacteria, especially *Streptococcus thermophilus* and *Lactobacillus bulgaricus*. Adding phenolic chemicals from plants or plants to probiotic lactic acid bacteria containing dairy products could be a novel way to develop functional

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yogurt. A sizable category of chemical substances called polyphenols are present in plants naturally. Ginger and ginger peels contain polyphenolic compounds such as shogaols and gingerols, which are effective on the digestive tract, as well as several volatile and nonvolatile oils. The antioxidant capabilities of polyphenols may lower the risk of specific ailments like cardiovascular conditions, diabetes mellitus, arthritis, cognitive disorders, and cancer and enhance overall health by combating free radicals and shielding cells from oxidative stress [6]. In addition to their wide range of medical uses, antioxidants contribute to food preservation by increasing food products' shelf lives. Numerous research has investigated the antioxidant properties of ginger's bioactive components. It is frequently utilized as a nutritional supplement and a component of some herbal treatments, functional foods, and drinks. Foods made from herbs or plant extracts are prized for their antibacterial, nutritive, antioxidant, and medicinal characteristics [7].

Microencapsulation is a protective technology that encapsulates solid, liquid, or gaseous components in 1–1000 μm diameter microparticles. It involves coating or entrapping active compounds with wall material or other sub-substances known as carrier material. Microencapsulated products are considerably more straightforward to handle than non-encapsulated items and have a longer shelf life. Microencapsulation could safeguard the delicate bioactive components, prolong the time used, boost bioavailability, and create a solid form that is easier to handle. The materials used for coating play a vital role in keeping the encapsulation process stable. These coating materials must be safe for consumption, biodegradable, and food grade, and they can protect the core compounds. Different types of coating materials such as polysaccharides (starches, gum Arabic, corn syrups, maltodextrins), lipids (stearic acids, glycerides), and proteins (gelatin, casein, milk serum) are used to encapsulate enzymes, flavors, iron in food and isoflavone in milk [8]. Maltodextrin could be used as a coating material due to its high solubility and low viscosity. Nonetheless, maltodextrins show poor emulsifying and surfactant properties. Research revealed that maltodextrins can be mixed with other coating materials to form a stable capsule. Gum acacia is one of the most pursued coating agents. Gum Acacia comprises branching arrangements of simple sugars, including galactose, glucuronic acid, arabinose, and rhamnose, with small amounts of covalently linked protein. Gum acacia has low viscosity and water solubility compared to other gums [9]. In addition to this, it can produce a thick layer that functions as an emulsifier to prevent aggregation and a protective coating surrounding the core element. Our research, which is the first of its kind, explores the incorporation of ginger peel polyphenols into yogurt. We have determined the stability and effectiveness of polyphenol-encapsulated yogurt using a mix of gum acacia and maltodextrin. This work has the potential to inspire the development of functional yogurt supplemented with polyphenols extracted from ginger by the encapsulation process.

EXPERIMENTAL

Materials

Ginger peels preparation

Ginger peel was collected from local households in the university campus area. The collected peel was cleaned with running water. The peels were air-dried in a strainer for 20 min. The peel was chopped and cabinet-dried for 8 h at 55 °C (OV-165, Gallenkamp, UK). The peels were ground into a fine powder using a heavy-duty grinder (M-101, India) and sieved through a 30-mesh sieve (0.0232 inches). Ginger peel powder (GPP) was kept in a re-sealable HDP zipper (Ziploc®, San Diego, CA, USA) and stored in the refrigerator (4 ± 1 °C).

Experimental design

The study experiment aimed to determine the impact of microencapsulating GPP-extracted polyphenols on the physicochemical characteristics, microcapsule stability, and shelf life of yogurt. It was entirely randomized and had three replicates. Dairy yogurt (DY) represents yogurt prepared from dairy milk, while phenolic yogurt (PY) represents yogurt encapsulated with ginger polyphenol. DY and PY were refrigerated at 4 ± 1 °C for further study. Every 7 days, the variations in color, pH, phenolic content, encapsulation efficiency, and sensorial properties were examined.

Extraction of polyphenol from GPP

The extraction was carried out by following the modified methods of Moghadam *et al.* [10]. To extract polyphenol from GPP, 50 g of GPP was extracted with 500 mL of 80% ethanol (w/v) and mixed by magnetic stirring at 950 rpm for 40 min. The suspension was sonicated (ATS-1, India) for 50 min at 45 °C at 50% ultrasound amplitude probe. The mixer was centrifuged at 8000 g for 15 min at -20 °C. The extraction was performed in three stages, as the recovery of polyphenol by single-stage extraction is insufficient. The suspension was filtered by solvent resistance Whatman filter paper No.1. A vacuum rotary evaporator (MKVI, Amketle ANalysis, India) concentrated the resulting aqueous organic extract while operating at 50 °C and 100 rpm until the organic solvent evaporated. Nitrogen was passed through the ginger peel extract (GPE) to remove the ethanolic flavor and kept at 4 ± 1 °C for further use.

Microencapsulation of GPE into yogurt

Deionized water prepared a gum acacia suspension (4% w/v) at 60 °C. The gum acacia solution was gradually included with GPE at a 1:10 ratio. A mechanical stirrer stirred the suspension for 5 min at 1100 rpm. The suspension was mixed with 200 mL of whole milk and pasteurized at 70 °C for 2 min. Maltodextrin (10% w/v) was mixed with the suspension and homogenized by an inline homogenizer (HM1200D, South Korea) from 2000 to 2500 psi. Standardized 1800 mL of whole milk was combined with 200 mL of encapsulated solution. The mixer was filtered and homogenized (2000 to 2500 psi). Only fresh milk is used in the production of DY. The yogurt was subsequently produced at the ideal growing temperature for the starter culture by first heating the milk to 203 °F (95 °C) for 5 min, then cooling it to 108 °F (42 °C) and inoculating it with a starter culture (45 mL of starter culture per 500 mL of milk). After the fermentation, the yogurt was refrigerated to 4 °C and stored there to stop the fermentation process. No additional flavor or color was provided for the sake of the study.

Physicochemical analysis

Color analysis

Color parameters were determined by Chroma Meter (CR-400/410, Konica Minolta, Japan) using 10° standard observers, illuminant D65. The colorimeter was calibrated with a standard white plate. The values of 10 randomly chosen samples for L*, a*, b*, and E were shown on the chroma meter. The results were reported according to the Commission International d'Eclairage (CIE) Lab col system. The L*-value ranged from darkness (L* = 0) to (L* = 100) to white. The a*-value ranged from a positive (red) to a negative (green) value. The b*-value ranged from positive (yellow) to negative (blue)-value. The mean value of color was calculated based on triplicate measurement [11].

pH content

The pH of the samples was measured using a pH meter (Delta 320, Mettler, Shanghai, China). The meter was calibrated with buffer solutions, using a pH between 4.0 and 7.0. The electrode of the pH meter was dipped into the yogurt, giving the electrode some time to stabilize before recording the pH measurement on the meter. After each measurement, the pH electrode was cleaned with distilled water to remove any leftover residue.

Titratable acidity

Acid-base titration was used to determine the acidity. The yogurt samples were tested for acidity using Iranian National Standard No. 2852. Using 0.5% phenolphthalein as an indicator, the 10 g sample was mixed with 10 mL of distilled water (hot). The solution was titrated against 0.1 N NaOH.

$$\text{Titratable acidity} = \frac{\text{Volume of titrant} \times \text{N} \times 90}{\text{weight of sample} \times 1000} \times 100 \quad (1)$$

where, N = normality of titrant; equivalent weight for lactic acid = 90.

Water holding capacity (WHC)

The WHC was determined to use a modified method of Luana *et al.* [12]. A 20 g sample was centrifuged (Make-Remi, India) at 5000 g for 10 min at 20 °C. The weight of the ejected whey (EW) was measured in grams and calculated as follows:

$$\text{WHC (\%)} = \frac{(\text{Weight of sample} - \text{Weight of EW})}{(\text{Weight of sample})} \times 100 \quad (2)$$

Syneresis

The whey separation of the yogurt sample was determined using the modified methods of Vareltzis *et al.* [13]. A 25 mL of frozen yogurt was gradually transferred to 50 mL capacity centrifuge tubes and centrifuged at 4000 g for 20 min (Make-Remi, India). Whey syneresis was measured using the weight fraction of the supernatant liquid (mL/100 g yogurt). The volume of the obtained whey was calculated using the following formula:

$$\text{Syneresis (\%)} = \frac{\text{Whey volume}}{\text{Initial volume}} \times 100) \quad (3)$$

Texture profile analysis (TPA)

The TPA was measured using a texture analyzer TA-XT Plus (M/s Stable Micro Systems, Surrey, UK) equipped with a 5 kg load cell and 40 mm cylinder probe. The probe applied a compressive force to the product over a 30 mm distance. The texture analyzer established the following conditions to measure textural properties: trigger force = 10 g; test speed =1 mm/s; post speed = 1 mm/s; time = 5 s.

Determination of total phenolic content (TPC)

The TPC in GPE and PY were measured according to the modified methods developed by Vázquez *et al.* [14] and consequently quantified by the Folin-Ciocalteu method. First, 1 mL of the

extract solution (100 mg of ginger powder/100 mL of ethanol volume) was adequately mixed with 5 mL of the Folin-Ciocalteu reagent (Merck, Germany) for 2 min. Four (4) mL of 7.5% (w/v) sodium carbonate (Merck, Germany) was added to the mixer. The mixer was vortexed for 15 s before standing for 30 min at 40 °C to develop the color. A spectrophotometer (Photolab 7600, UV-VIS, EU) measured the absorbance at 765 nm. The calibration curve's standard was gallic acid (Sigma Aldrich, Germany). For the results, the mg gallic acid equivalent (GAE) per gram of dry matter was used. The same method was used to determine the phenolics on the microcapsule surface of the polyphenol-enriched yogurt, except that water was used in place of ethanol in the extracts after the ethanol was removed under vacuum at 40 °C.

Efficiency of microencapsulation

Microencapsulation efficiency (E) was calculated using the following formulas based on dry matter content, where TPC was calculated as mg GAE/g. The ginger extract's total phenol content was known. The phenolic component on the microcapsule surface was extracted as described in section 2.3 after the microcapsule was dried to a powder. According to section 2.8, the phenolic content of the microcapsule surface was measured.

$$\text{Efficiency (E) \%} = \frac{\text{Total phenolic of ginger extract} - \text{phenolic on microencapule surface}}{\text{Total phenolic of ginger extract}} \times 100 \quad (4)$$

Microbiological analysis of treated and untreated yogurt

To measure the total viable count (TVC) and total lactobacillus count (TLC), 90 mL of sterile peptone water was used to dilute 10 g of yogurt. The sample was then homogenized for 2 min using a stomacher (Stomacher 400 Circulator; Seward Medical Ltd., London, UK), and 10-fold serial dilutions were prepared using 0.1% sterile peptone water. A sterile pipette was used for each dilution to transfer and disseminate 0–1 mL of each 10-fold dilution onto triplicate plate count agar (PCA) and De Man, Rogosa, and Sharpe agar (MRS), respectively. Using a sterilized glass spreader, the diluted samples were distributed throughout the plate's surface as soon as possible. A single sterile spreader was utilized for every plate. The plates were incubated at 37 °C for 24 h for TVC and 72 h for TLC. Plates displaying 30–300 colonies were counted after incubation using a colony counter. The dilution factor was multiplied by the average number of colonies in each dilution to determine the total microbial count. The number of organisms of colony-forming units per gram (CFU/g) of the yogurt sample was used to express the TVC and TLC results.

Sensory evaluation

The sensory qualities of processed yogurt were assessed using a 9-point hedonic scale, where 1 = extreme dislike and 9 = extreme like. Sensory analysis was performed for consumer testing at the Food Sensory Lab, Bangladesh Agricultural University, Mymensingh, Bangladesh. Sensory analysis was conducted by 40 untrained panelists from Mymensingh City, Bangladesh, aged 20 to 50. Panelists received samples one at a time to minimize the impact of sample order presentation. Panelists were told to rinse their palates with water in between samples. The sensory session occurred in separate cabins at 28 °C with 300 lx white light and 65% relative humidity. The impact of any potential shock was mitigated by informing all panelists beforehand about the new goods they would be receiving.

Statistical analysis

Data were collected in triplicate except for the color parameter and TPA. All the data were analyzed using one-way analysis of variance (ANOVA) utilizing the Statistical Program for Agricultural Research (STAR) software program (International Rice Research Institute, Manila, the Philippines). The 5% significance level was considered to compare the significant differences between the two means.

RESULTS AND DISCUSSION

Effect of GPE on physicochemical parameters of yogurt

Effect of GPE on color analysis of yogurt. The result of the color analysis comprising lightness, redness, and yellowness of the DY and PY during storage periods of 4 weeks was shown in Table 1. Lightness (L*) values of all samples decreased during storage periods. This might be due to the proteolysis process and lowering of pH. The numeric data showed that the PY was darker than the DY. Moghadam *et al.* [10] found that yogurt enriched with microencapsulated phenolic olive leaf extracts exhibited less whiteness than control yogurt. In this study, the range of redness to greenness (a*) value also showed a gradual decrease by storage time. However, the DY a* (redness to greenness) value was higher than PY. The DY was reddish than the PY. The b* (yellowness to blueness) value was increased regarding storage time. After fermentation, the yellowness (b*) value of DY was 12.44 ± 0.04, whereas PY was 14.32 ± 0.05, which showed significant differences ($p < 0.05$).

Table 1. Effect of GPE on lightness (L*), redness (a*), and yellowness (b*) value of dairy yogurt and polyphenol-enriched yogurt during storage (DY: dairy yogurt, PY: polyphenol-enriched yogurt).

Parameters	Treatments	Storage intervals (weeks)			
		0	1	2	3
L^*	DY	88.44 ± 0.06^{aA}	86.19 ± 0.05^{bA}	85.54 ± 0.05^{cA}	84.34 ± 0.05^{dA}
	PY	78.32 ± 0.41^{eB}	76.14 ± 0.04^{fB}	75.14 ± 0.05^{gB}	74.14 ± 0.06^{hB}
a^*	DY	-2.76 ± 0.01^{aA}	-2.82 ± 0.02^{abA}	-2.90 ± 0.05^{bcA}	-2.98 ± 0.06^{cA}
	PY	-3.24 ± 0.02^{dB}	-3.46 ± 0.02^{eB}	-3.68 ± 0.03^{fB}	-3.88 ± 0.08^{gB}
b^*	DY	12.44 ± 0.04^{gB}	14.35 ± 0.02^{fB}	15.54 ± 0.03^{eB}	17.04 ± 0.05^{cB}
	PY	14.32 ± 0.05^{fA}	16.46 ± 0.05^{dA}	17.64 ± 0.04^{bA}	19.32 ± 0.05^{aA}

Effect of GPE on the pH and acidity of yogurt

The pH value is an important quality parameter for judging the yogurt's stability during storage. pH values of DY and PY during storage are shown in Figure 1. The relation between titratable acidity and pH is always the opposite. Figure 2 represents the titratable acidity of DY and PY at 4 ± 1 °C. The pH of freshly prepared DY significantly differed from that of PY. After three weeks of refrigerated storage, the pH of the treated DY and PY decreased significantly. This might be because bacteria converted lactose to lactic and acetic acid, which reduced pH. It was noticeable that the titratable acidity of both DY and PY significantly ($p < 0.05$) increased during storage. As documented in most related investigations, pH was expected to drop, and the acidity would rise after storage. A significant difference ($p < 0.05$) between DY and PY regarding pH during refrigerated storage exists. During storage, the starting culture changed lactose into organic acids, raising the acidity and decreasing the pH value. The titratable acidity increased with the incorporation of GE in yogurt. Incorporating the GPE appears to boost the metabolism of yogurt bacteria, which raises the acidity of yogurt by causing lactic acid bacteria to produce more organic acids. This study agreed with Shori [15], who found that yogurt enriched with the polyphenol

extract from white pepper, nutmeg, and black pepper had a similar outcome. Pandey *et al.* [16] also found similar results using polyphenols from black carrots to enrich yogurt.

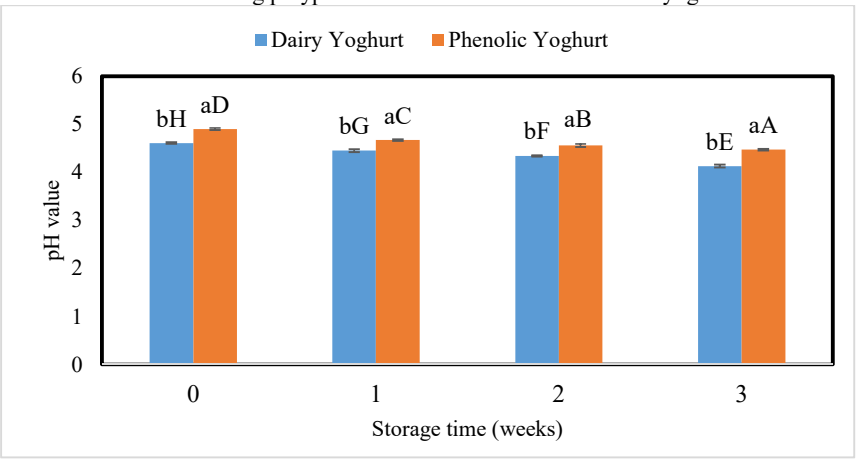

Figure 1. Changes in pH value of dairy yogurt (DY) and polyphenol-enriched yogurt (PY) during refrigeration storage (Bar represents standard deviations).

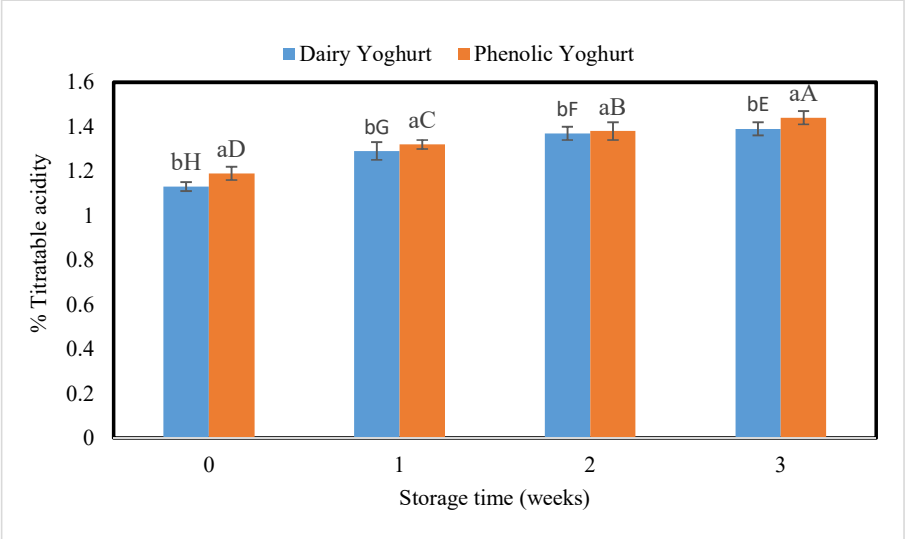

Figure 2. Changes in titratable acidity of dairy yogurt (DY) and polyphenol-enriched yogurt (PY) during refrigeration storage at 4 ± 1 °C (Bar represents standard deviations).

Effect of GPE on WHC and syneresis of yogurt

Figure 3 and Figure 4 represent the WHC and syneresis of DY and PY during storage at 4 ± 1 °C. In this investigation, the DY had a lower WHC than the PY (Figure 3). An increase in yogurt's total solids in PY due to added GPE enhanced yogurt consistency and accelerated rate of WHC.

There is a 17% decrease in WHC in DY and an 11% decrease in PY during three weeks of storage. This showed that phenolic compounds help to hold water in yogurt. Yogurts containing polyphenols attained and maintained higher WHC. On the initial day, the WHC in PY (66.59 ± 0.49) was significantly higher than the DY (60.05 ± 1.14). The syneresis of the yogurts during storage indicates the amount of WHC. Higher syneresis represents the lower WHC. Syneresis in the DY was higher than PY (Figure 4). However, syneresis increased with storage time at refrigeration temperature in both DY and PY. In the initial days, the syneresis in DY was 8.08% higher than the PY. After 3 weeks of refrigeration storage, there was a 16% increase in syneresis in DY and a 14% increase in PY. Increases in syneresis during storage could be caused by weak yogurt consistency over time. Yogurt consistency is primarily determined by the gel structure of proteins, mainly casein, and the interaction between proteins and other components like calcium ions. Over time, different things can weaken this gel structure, including temperature variation, pH, and enzymes. When the gel structure weakens, it retains the liquid phase (whey) within the yogurt matrix less effectively. Moghadam et al. [10] encapsulated pennyroyal extracts (polyphenol) in yogurt and found a similar result.

TPC and microencapsulation efficiency of yogurt

The phenolic content of GPE and PY was 34.37 ± 0.3 mg GAE/g and 1.92 ± 0.01 mg GAE/g, respectively. Wijayanti et al. [17] found that ginger has a TPC of 485.18 ± 3.7 mg GAE/g dry weight. The TPC of ginger rhizome extracts extracted using several solvents, including methanol, acetone, and chloroform, was evaluated by Ghasemzadeh et al. [18]. The TPC yields varied from 9.2 to 13.4 mg GAE/g in all three solvents. The TPC of the yogurt supplemented with nutmeg and black pepper was significantly higher than the control sample. Microencapsulation efficiency refers to how effectively the phenolic extracts are incorporated and protected within the microcapsules. The higher the efficiency, the more phenolic compounds are successfully encapsulated, and the better they can be delivered and preserved in the yogurt. The microencapsulation efficiency in this investigation was determined to be 94.40 ± 0.05%, which was more significant than other studies' findings. The microencapsulation efficiency of the polyphenols from pennyroyal extracts in yogurt was 60.06% in the survey by Moghadam et al. [10].

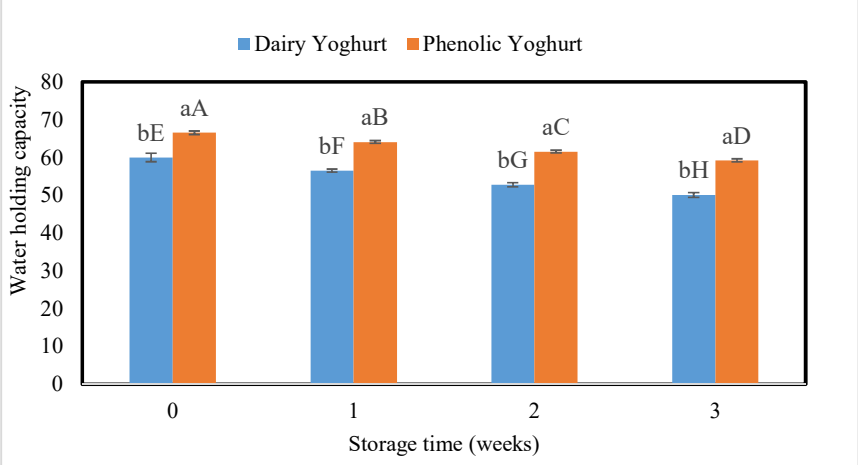

Figure 3. Changes in water holding capacity on dairy yogurt (DY) and polyphenol-enriched yogurt (PY) during refrigeration storage (Bar represents standard deviations).

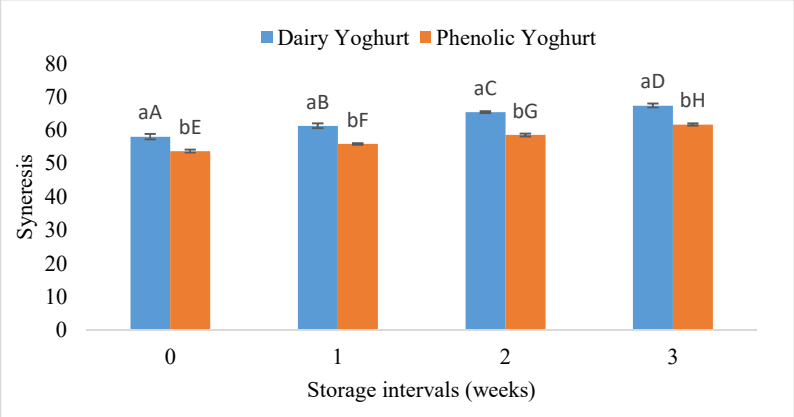

Figure 4. Changes in syneresis of dairy yogurt (DY) and polyphenol-enriched yogurt (PY) during refrigeration storage (Bar represents standard deviations).

Effect of GPE on the texture of yogurt

The choice of yogurt processing method is essential for the final product's texture. For consumers, firmness is one of the most critical rheological properties and significantly impacts purchasing decisions. This study indicates that the addition of GPE decreases the firmness of yogurt. This might be due to the rise of water content while adding GPE due to polyphenols' hydrophilic properties. Research suggests that interaction between casein and polyphenols reduces yogurt syneresis because more water is present in the gel and, in consequence, causes yogurt's hardness to decline. In the previous studies, grape extract, rice berry rice extract, and mulberry pomace to yogurt had similar firmness outcomes.

Effect of GPE on the growth of starter culture in yogurt

Figure 5 shows that *Lactobacillus* decreased with storage time in DY and PY. An identical outcome was observed in the work by Moghadam *et al.* [10]. A lower pH of yogurt may cause *Lactobacillus* to decline during storage. Based on a comparison of control and treated samples, using GPE significantly influenced ($p \leq 0.05$) the survival of *Lactobacillus*. In particular, the population of *Lactobacillus* in the DY decreased from 8.93 ± 0.02 log CFU/mL to 6.91 ± 0.09 log CFU/mL after three weeks of refrigeration storage. For the PY, TLC decreased from 9.93 ± 0.03 to 8.68 ± 0.06 log CFU/mL in the same course of time and same storage condition. Here, the decrease in the DY was 22.62%, and the reduction in the PY was about 12.59% throughout the storage periods. This is because plant extracts include phenolic chemicals that act as stimulants and enhance yogurt starter bacteria growth. The GPE in PY can provide a favorable environment for *Lactobacillus* growth, leading to a higher count than DY. The phenolic compounds responsible for antioxidant activity in PY can help protect *Lactobacillus* bacteria from oxidative stress during fermentation.

This can lead to a higher survival rate of *Lactobacillus* in yogurt, resulting in a higher total count. Ginger contains compounds like gingerol and other polyphenols that can serve as prebiotics. When GPE is added to yogurt, it can provide a source of nutrients for probiotic bacteria, allowing them to proliferate and thrive. Ginger has antibacterial characteristics that may help *Lactobacillus* cultures grow and multiply in the yogurt by lowering competition from unwanted bacteria. The TVC decreased in DY and PY throughout storage (Figure 6). The TVC

value significantly reduced from 8.87 ± 0.06 log CFU/mL to 6.98 ± 0.08 log CFU/mL for DY, from 9.61 ± 0.10 log CFU/mL to 8.12 ± 0.03 log CFU/mL for PY, respectively after three weeks of storage. Due to yogurt's low pH and firm acidity, TVC may degrade while stored. The DY sample decreased by 21.30%, whereas the PY sample decreased by 15.50%. Therefore, polyphenol extracts demonstrated a protective effect against the decline in bacterial viability in yogurt. The prebiotic effect of gingerol, a phenolic compound in ginger, may promote the growth of beneficial bacteria, providing a source of nutrients in PY. Ginger also possesses antimicrobial properties, which can help inhibit the growth of harmful pathogens or undesirable bacteria in the yogurt. By reducing the competition from unwanted microorganisms, the probiotic bacteria in the yogurt can grow more effectively, resulting in a higher total viable count in PY than DY. Adding phenolic extract seems to speed up the metabolism of yogurt bacteria.

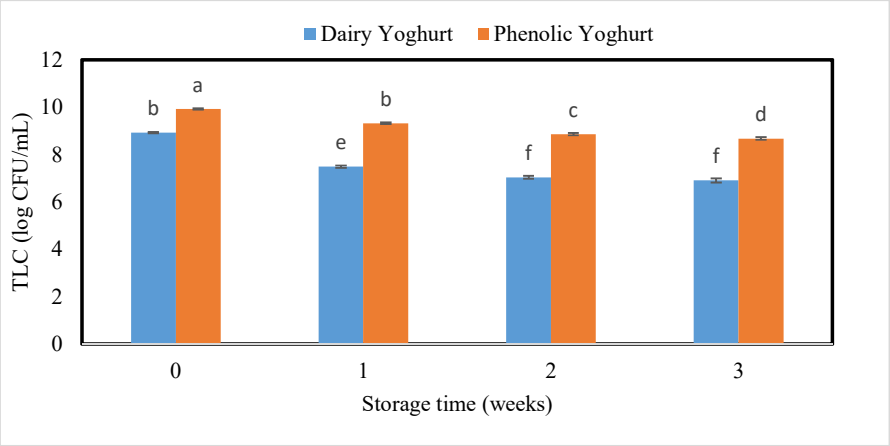

Figure 5. Changes in lactobacillus (TLC) on dairy yogurt and polyphenol-enriched yogurt during refrigeration storage. All values are means of triplicate determinations ± standard deviation.

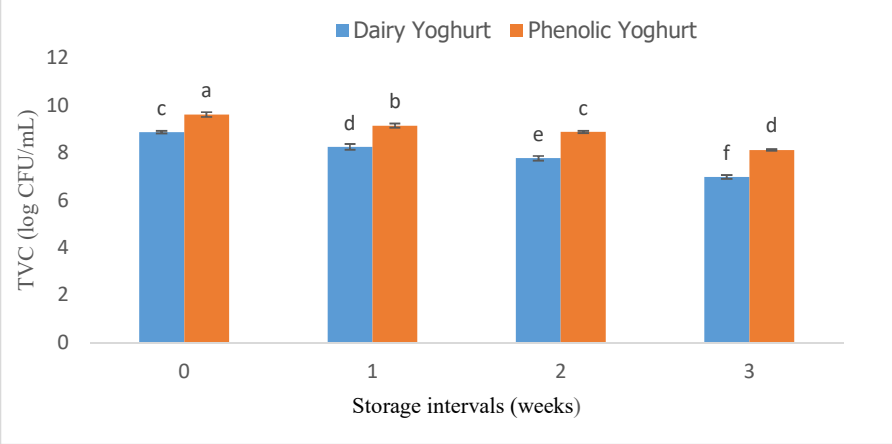

Figure 6. Changes in total viable count (TVC) of DY and PY during refrigeration storage. All values are means of triplicate determinations ± standard deviation.

Sensory evaluation

Table 2 shows the sensory assessment of DY and PY. DY initially had a significantly higher overall acceptability than PY. However, all the sensory quality parameters were decreased after storage, showing significant differences. The color changed slowly during storage DY compared to PY. The texture of PY was significantly higher ($p < 0.05$) than DY. This might be due to the addition of maltodextrin, which is known as a thickening agent (binding material) used for yogurt processing. The flavor of DY was significantly ($p < 0.05$) better than PY. The change in flavor might be due to the addition of GPE. There was a significant difference ($p < 0.05$) in the taste of PY and DY. Polyphenols contained in ginger extract had a different taste. Ginger contains some pungent polyphenolic compound, so its flavor is slightly bitter. However, after three weeks, the overall acceptability of PY was higher than DY. Ginger is essential for worldwide food preparation due to its reviving smell, bite, and carminative properties. It was acceptable that adding phenolic plant extract to yogurt reduced its sensory properties. Moghadam et al. [10] suggest that in addition to phenolic extracts in yogurt, the sensory attributes such as odor, taste, and overall acceptance were lower than in control samples.

Table 2. The mean sensory score for dairy yogurt and polyphenol-enriched yogurt during storage at refrigeration temperature (DY: dairy yogurt, PY: polyphenol-enriched yogurt with 0.05% ginger peel extract (GPE)).

Storage intervals (Weeks)	Treatments	Sensory quality attributes				
		Color	Texture	Flavor	Taste	Overall acceptability
0	DY	7.46 ± 0.31^{a}	6.66 ± 0.79^{a}	6.73 ± 0.08^{a}	7.00 ± 0.16^{a}	6.96 ± 0.18^{a}
	PY	6.40 ± 0.41^{bc}	6.85 ± 0.29^{a}	5.96 ± 0.88^{bc}	6.53 ± 0.70^{bc}	6.43 ± 0.46^{bc}
1	DY	6.90 ± 0.08^{b}	6.20 ± 0.23^{bc}	6.60 ± 0.75^{ab}	6.88 ± 0.28^{ab}	6.64 ± 0.25^{ab}
	PY	6.16 ± 0.33^{cd}	6.74 ± 0.15^{a}	5.60 ± 0.53^{c}	6.30 ± 0.44^{cd}	6.20 ± 0.41^{cd}
2	DY	6.20 ± 0.30^{c}	5.40 ± 0.32^{d}	6.53 ± 0.54^{ab}	6.20 ± 0.40^{cd}	6.08 ± 0.17^{cd}
	PY	5.92 ± 0.89^{cd}	6.46 ± 0.19^{ab}	5.60 ± 0.40^{c}	5.87 ± 0.33^{d}	5.96 ± 0.14^{d}
3	DY	6.01 ± 0.12^{cd}	5.00 ± 0.29^{d}	5.48 ± 0.56^{c}	5.10 ± 0.29^{e}	5.39 ± 0.44^{e}
	PY	5.62 ± 0.75^{d}	5.95 ± 0.39^{c}	5.30 ± 0.59^{c}	5.35 ± 0.25^{e}	5.55 ± 0.23^{e}

All values are means of triplicate determinations ± standard deviation. Different lowercase letters in a column stand for significantly ($p < 0.05$) various mean values.

CONCLUSION

The microencapsulation of ginger-extracted polyphenols into yogurt presents a promising approach to enhancing yogurt's flavor, nutritional value, and shelf life. The encapsulation process protects the polyphenols from degradation, oxidation, and undesirable interactions with yogurt components. GPE increases the shelf life of yogurt and preserves the bioactive properties of ginger polyphenols, offering potential health benefits to consumers. The microencapsulated ginger extracted polyphenol greatly affected the color, pH content, acidity, water holding capacity, syneresis, texture, viability of starter culture, and sensory score of yogurts. The ginger extract reduced the decreasing rate of pH, water holding capacity, and microorganism viability in yogurt. The microencapsulated phenolic yogurt had higher acidity, phenolic content, *Lactobacillus count*, lower syneresis, and firmness. These findings will contribute to developing precious polyphenol-enriched dairy products. The resulting product can also satisfy the needs of consumers looking for functional foods with improved flavor and health-improving qualities. Further research and development may yield innovative yogurt products that appeal to many consumers. Our future research will continue to explore the potential of polyphenols in yogurt by studying the

incorporation of polyphenols from various other peels. This ongoing work will further expand our understanding of the benefits of polyphenol-enriched yogurt.

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