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Physiochemical properties, antioxidant activity, viability of probiotic bacteria and sensory characteristics of plant-based yogurt fortified with strawberry puree

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ABSTRACT

The consumption of plant-based yogurt has increased due to its health benefits and its importance in the nutritional intake of the elderly and individuals with higher energy requirements. Additionally, it provides a lactose-free alternative for people with lactose intolerance and those following a vegetarian lifestyle. This study aimed to enhance the quality characteristics of plant-based yogurt by developing a probiotic and antioxidant-rich product prepared from oat milk supplemented with 8% sugar, 0.5% xanthan gum, and inoculated with 3% ABT-3 starter culture (Streptococcus thermophilus, Lactobacillus acidophilus, and Bifidobacterium bifidum). After fermentation at 39°C for 16 hours, strawberry puree was added at ratios ranging from 0 to 20%. The final products were stored at 4°C for 21 days. The evaluation of the physiochemical characteristics of oat milk and yogurt samples was conducted after preparation, including changes in acidity, pH values, color attributes, phenolic compounds, anthocyanins, antioxidant activities, viable probiotic count, and sensory properties during 21 days of cold storage at 4°C. The results showed that adding strawberry puree to yogurt samples significantly increased total solids, carbohydrates, acidity, phenolic and anthocyanin contents, and antioxidant activity, with these increases being directly proportional to the amount of strawberry puree added. This also improved probiotic viability, maintaining levels above the recommended minimum of 10^6 CFU/mL or g during cold storage. The yogurt containing 15% strawberry puree achieved the highest sensory scores. The study demonstrates the potential for producing a highly acceptable, antioxidant-rich, probiotic plant-based yogurt from oat milk enriched with strawberry puree.

Contribution/Originality: This study presents new plant-based alternatives to conventional dairy products, a lactose-free alternative that combines nutritional and functional benefits with good sensory properties, by producing oat-based yogurt prepared from oat milk, strawberry purée, and probiotic bacteria. It demonstrates improved antioxidant activity, phenolic, and anthocyanin content and maintains probiotic viability throughout cold storage.

1. INTRODUCTION

The production of plant-based yogurt plays an important role in meeting the nutritional needs of various groups, particularly the elderly and individuals who require energy- and protein-rich foods. Recently, the plant-based milk sector has experienced significant growth. The use of plant-based milk is increasing, and the industry is evolving to produce beverages with beneficial properties, such as those that mitigate the effects of aging, prevent disease, or improve nutrition, meeting the diverse needs of various populations. In recent years, soybean, oat, and coconut have been recognized as functional foods due to their richness in proteins, dietary fiber, minerals, antioxidants, vitamins, and energy (Naz, Raza, Murtaza, Naz, & Farooq, 2023). Functional foods are characterized as foods or dietary components that provide health benefits exceeding basic nutrition. A food's functionality can be achieved through the application of various technological or biological methods, which may include increasing the concentration of certain elements, adding, removing, or modifying specific components, as well as improving their bioavailability, provided these changes have a functional effect (Roberfroid, 1999). Arpita, Raychaudhuri, and Chakraborty (2012) observed that growing health awareness and the widespread accessibility of information regarding the advantages of various diets and their connection to overall well-being have steadily driven up the demand for functional foods. These include foods or ingredients that deliver positive effects on health and/or reduce the risk of chronic diseases beyond their fundamental nutritional roles. With consumers increasingly focused on health and the potential of functional foods to promote healthier lifestyles, there is now a heightened demand for food products offering diverse health benefits. It is important to note that functional foods are not merely dietary supplements, pharmaceuticals, or antibiotics; rather, they constitute a fundamental part of a typical diet for both humans and animals. Moreover, functional foods are cost-effective and readily accessible in the marketplace. Regular intake of functional foods can help prevent gastrointestinal disorders and also alleviate various acute and chronic health problems. Incorporating probiotics into human food can effectively transform standard food items into functional foods, providing additional health benefits (Shiomi & Savitskaya, 2022).

Oat milk is considered a promising alternative to conventional milk. It has a creamy, milk-like flavor and serves not only as a fundamental plant-based nutritional drink but also contributes to a healthy lifestyle (Bocchi et al., 2021). Oat milk yogurt is devoid of many allergens present in other milk varieties. Additionally, it offers numerous health advantages, such as reducing blood sugar levels, lowering cholesterol, and preventing cancer (Jeske, Zannini, & Arendt, 2018). Oat yogurt is rich in fiber that acts as a prebiotic, promoting the growth of beneficial bacteria and exhibiting anti-pathogenic properties. Furthermore, oat milk yogurt contains protein, fat, carbohydrates, dietary fibers, riboflavin, calcium, phosphorus, iron, potassium, calories, and vitamins A and D (El-Batawy, Mahdy, & Gohari, 2019). Oat milk yogurt provides various health benefits, as it is a lactose-free, plant-based yogurt. Moreover, it is a source of vitamins B2 and B12, which aid in lowering blood cholesterol levels, thus benefiting heart and bone health. Plant-based yogurt is rich in unsaturated fatty acids that help reduce the risk of cardiovascular diseases. For those with lactose intolerance, consuming plant-based milk is advantageous. This type of yogurt is nutrient-dense and mineral-rich, serving as synbiotic foods that are vital for the human gut and intestines, while also enhancing antibody production in the body, thereby boosting immunity (Osundahunsi, Amosu, & Ifesan, 2007).

Yoghurt has numerous health benefits, most notably enhancing gut bacteria and releasing a range of bioactive peptides with functional characteristics such as lowering blood pressure, antioxidant, anticoagulant, opioid, antimicrobial, cell-regulating, and immunomodulatory properties (Mann et al., 2015).

The most prevalent method for producing functional dairy products is the incorporation of probiotic microorganisms into yogurt. The Food and Agriculture Organization and the World Health Organization characterize probiotics as live microorganisms which, when administered in adequate amounts, confer a health benefit on the host (FAO, 2013). Recently, food products that contain probiotic bacteria, referred to as 'probiotic foods', have been defined as 'foods that contain live and specific bacteria which, when consumed in adequate amounts, yield beneficial effects by modifying the host's microflora' (FAO, 2013; Schrezenmeir & De Vrese, 2001).

The incorporation of whey protein concentrate powder into food formulations is primarily due to its health advantages. Additionally, whey proteins can enhance the technological attributes of food products, as they can boost the protein levels and improve the viscosity of fortified items. As a result, fortifying vegetarian fermented products with whey proteins may enhance their attributes, such as nutritional value, consumer acceptability, and the viability of probiotic microorganisms (El-Batawy et al., 2019).

Strawberries *Fragaria ananassa* are among the most widely consumed fruits and are known for their high nutritional value. Strawberry is a soft, juicy, and delicious fruit that is available during the spring and summer seasons. Strawberries are appreciated for their outstanding sensory characteristics, including their vibrant red hue, smooth texture, delightful taste, and fragrant aroma. Moreover, they are a good source of micronutrients and phytochemical compounds, particularly ascorbic acid, anthocyanins, and phenolic compounds (Cao et al., 2012; Jiang et al., 2022).

Fruits, especially strawberries, possess pharmacological and biochemical characteristics, primarily due to their antioxidant properties, fiber content, and a variety of other compounds. Due to its importance as a nutritious source of bioactive compounds with antioxidant, anti-inflammatory, and antimicrobial effects, its use in yogurt production has increased in recent years. Strawberries are added to yogurt not only to enhance its taste but also to improve its functional and health benefits (Nikmaram, Mousavi, Emam-Djomeh, Kiani, & Razavi, 2015; Sadaghdar, Mortazavian, & Ehsani, 2012; Sobti, Alhefeiti, Alahdali, Al Samri, & Kamal-Eldin, 2023). The health benefits of the fruit are primarily related to its antioxidant components, especially phenolic compounds and flavonoids (Pérez-Lamela, Franco, & Falqué, 2021).

This study aimed to enhance the nutritional values and functional characteristics of plant-based yogurt through the incorporation of oat milk, probiotic cultures (Streptococcus thermophilus, Lactobacillus acidophilus, and Bifidobacterium bifidum), and fortification with whey protein and strawberry puree as sources of bioactive compounds.

2. MATERIALS AND METHODS

2.1. Materials and Equipment

Dried whey protein concentrate (DWPC) was procured from Mullins Whey Company, originating from the USA. Oat flakes, strawberries, skimmed milk powder (97% DM) produced in Poland, and sugar were acquired from the local market in Jeddah, Saudi Arabia. Food-grade α-amylase derived from Bacillus subtilis in powder form (activity of 2000 IU) and ABT-3 DIP 50 µM, containing lyophilized strains of Streptococcus thermophilus, Lactobacillus acidophilus, and Bifidobacterium bifidum, were obtained from Chr. Hansen Laboratories in Denmark. Meanwhile, the equipment used in this study included incubator oven dehydrators, vortex mixers, pH meter, homogenizer, blender, grinders, analytical scales, centrifuges, and spectrophotometer.

2.2. Preparation of Starter Cultures

The mother cultures were prepared by adding 1% lyophilized strains of Streptococcus thermophilus, Lactobacillus acidophilus, and Bifidobacterium bifidum (ABT-3 DIP 50 µM) to 12% reconstituted sterile skim milk powder. This mixture was then incubated at 39°C for 4–6 hours until ready for use.

2.3. Preparation of Oat Milk

Approximately 1000 grams of oat grains were ground in a laboratory mill to produce fine oat flour, which was subsequently mixed with 2.7 liters of water, and a 0.04% (w/w) calcium chloride solution was incorporated as an enzyme catalyst. The oat mixture was treated with amylase enzyme (77.78 mg/kg of rolled oats) to facilitate liquefaction, a process that continued for 49 minutes at 75°C. Following this phase, the liquefied oat solids were filtered through a muslin cloth to yield OM. Finally, the amylase enzyme activity was inhibited by heating the mixture to 100°C for 5 minutes (Deswal, Deora, & Mishra, 2014).

2.4. Preparation of Strawberry Puree

The strawberry puree was obtained according to the following stages: Initially, the strawberry fruits were sorted to eliminate any non-conforming fruits and inedible components. Following this, they were thoroughly cleaned, washed, and cut into small pieces. Strawberry pieces were mixed with 20% (w/w) sugar, blended using a blender for 3 minutes until a homogeneous mass was obtained. They were then pasteurized at 85°C for 20 minutes. The strawberry puree was immediately transferred into sterile containers, and the packaged product was stored at 5°C until use.

2.5. Production of Plant-Based Yogurt Samples

Oat milk samples were fortified with 2% DWPC (whey protein concentrate powder) and heated with continuous stirring until they reached 60°C. Following this, 8% sugar and 0.5% xanthan gum were incorporated into the mixture. Subsequently, the mixture was homogenized at 5000 rpm for 3 minutes. The homogenized mixture underwent pasteurization at 95°C for 15 minutes and was then cooled to 40°C. After cooling, the mixture was inoculated with 3% ABT-3 starter culture, containing *Streptococcus salivarius thermophilus*, *Lactobacillus acidophilus*, and *Bifidobacterium bifidum*. The inoculated mixture was incubated at 39°C for 16 hours (reaching a pH value of 4.5) until curd formation was complete (plant-based yogurt). After the incubation period, yogurt samples were cooled to 25°C for 30 minutes and then stored in a refrigerator at 4°C overnight. The plant-based yogurt was divided into five equal parts, with strawberry puree added as follows: the first portion (PY0) was the control sample of plant-based yogurt (without strawberry puree), the second portion (PY1) was plant-based yogurt with 5% strawberry puree added, the third portion (PY2) was plant-based yogurt with 10% strawberry puree added, the fourth portion (PY3) was plant-based yogurt with 15% strawberry puree added, and the fifth portion (PY4) was plant-based yogurt with 20% strawberry puree added. After thorough mixing, the final products were transferred into 150-ml plastic containers and stored at 4°C for 21 days. Plant-based yogurt samples were analyzed on the 1st, 7th, 14th, and 21st days of storage at 4°C.

2.6. Physicochemical Analysis

Total solids, fat, titratable acidity, crude fibers, ash, and protein contents in oat milk, whey protein concentrate powder, strawberry puree, and plant-based yogurt samples were determined according to the method (AOAC, 2019). Total carbohydrate content was calculated by difference. The pH value of the homogenized samples, prepared by adding water in a 1:1 ratio, was measured using a digital pH meter. The color properties of the plant-based yogurt samples were evaluated using a Minolta Chroma Meter CR-300 (Minolta, Osaka, Japan). The measurements included L* for whiteness, a* for redness, and b* for yellowness, following the CIE L*a*b* color system.

The total phenolic content of oat milk, strawberry puree, and plant-based yogurt samples was determined using the Folin-Ciocalteu method, adhering to the procedure described by Singleton, Orthofer, and Lamuela-Raventós (1999). In this procedure, 40 μL of the extract was diluted with 3.16 mL of distilled water and mixed with 200 μL of Folin-Ciocalteu solution. After a three-minute interval, 600 μL of 20% sodium carbonate (Na_2CO_3) solution was added, and the mixture was maintained in the dark at a temperature of 25°C for two hours. The absorbance of the mixture was measured at a wavelength of 760 nm using a UV-1650 PC spectrophotometer. The total phenolic content was determined in milligrams of gallic acid equivalent (GAE) per 100 grams of sample by referencing a standard curve prepared using gallic acid.

The antioxidant activity of oat milk, strawberry puree, and plant-based yogurt samples was assessed using the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay, following the method described by Apostolidis, Kwon, and Shetty (2007). A volume of 200 mL of sample extract was mixed with ethanol in a test tube, followed by the addition of 2.4 mL of DPPH solution, and then kept in the dark for 30 minutes. Afterwards, the absorbance was recorded at 517 nm using a UV-1650 PC spectrophotometer, compared to the blank sample, which consisted of 200 μL of distilled water. The results were calculated as a percentage of free radical inhibition based on the following equation.

$$\text{DPPH (\%)} = \frac{[\text{Absorbance}\ {}^{\text{control}}_{517} - \text{Absorbance}\ {}^{\text{sample extract}}_{517}]}{[\ \text{Absorbance}\ {}^{\text{control}}_{517}\ ]} \times 100 \qquad (1)$$

The anthocyanin content of oat milk, strawberry puree, and plant-based yogurt samples was assessed using the method described by Moor, Karp, Põldma, and Pae (2005). For this assessment, 20 grams of the sample were homogenized with 40 grams of a mixture consisting of ethanol and hydrochloric acid (85:15 v/v) for one minute. Subsequently, the mixture was filtered, and the sediments were washed three times with 10 mL of ethanol and 1.5 M hydrochloric acid (3 x 10 mL). The absorbance of the filtrate was measured at a wavelength of 535 nm using a UV spectrophotometer.

2.7. Viable Counts of Probiotic Bacteria

Bifidobacterium bifidum was enumerated following the method outlined by Dave and Shah (1998), utilizing modified MRS agar supplemented with 0.05% L-cysteine and 0.3% lithium chloride. The plates were incubated anaerobically at 37°C for 48–72 hours. Lactobacillus acidophilus was counted using Bile MRS agar, based on the guidelines provided by Vinderola and Reinheimer (1999). These plates were incubated aerobically at 37°C for 72 hours. Streptococcus thermophilus was enumerated using M17 agar following the protocols described by Terzaghi and Sandine (1975) as well as Turgut and Cakmakci (2018) with aerobic incubation at 37°C for 48 hours.

2.8. Sensory Evaluations

A thirty-member committee from the Department of Food and Nutrition at the Faculty of Human Sciences and Design, King Abdulaziz University, Saudi Arabia, conducted an evaluation of the sensory attributes of plant-based yogurt samples. The participants, aged between 33 and 55 years, received training in sensory analysis following established guidelines as outlined by Uzuner, Kinik, Korel, Yildiz, and Yerlikaya (2016). During the assessment, the samples were labeled with random three-digit codes and presented in 100 g plastic containers. The participants assessed various sensory characteristics such as taste, flavor, appearance, texture, and overall acceptability using a 5-point hedonic scale (where 1 indicated "unacceptable" and 5 signified "excellent"). To prevent cross-contamination of flavor, participants were offered water and unsalted crackers between tastings to cleanse their palate.

2.9. Statistical Analysis

All results were conducted in triplicate, with the exception of the sensory characteristics data (n = 30). The findings were presented as the mean ± standard deviation (SD) in this research. The results were analyzed using one-way ANOVA through the general linear model (GLM) procedure in SPSS (version 20; SPSS Inc., Chicago, IL, USA). The means were compared using the Duncan multiple comparison test at the $p<0.05$ level.

3. RESULTS AND DISCUSSION

3.1. Physicochemical Characteristics

3.1.1. Physicochemical Characteristics of Oat Milk, Strawberry Puree and DWPC

Table 1 summarizes the physicochemical characteristics of oat milk, strawberry puree, and dried whey protein concentrate (DWPC). The findings revealed that the moisture, total solids, protein, fat, ash, fiber, and carbohydrate contents of oat milk were 81.63, 18.37, 2.43, 1.68, 0.46, 3.23, and 13.80 g/100g, respectively. These results are consistent with those of a study conducted by Atwaa, Hassan, and Ramadan (2020), which reported that oat milk contained 2.30, 2.04, 0.354, 1.74, and 17.30 g/100g of protein, crude fiber, ash, fat, and carbohydrates, respectively. Furthermore, these findings were confirmed by Singhal, Baker, and Baker (2017) and El-Batawy et al. (2019), who indicated that oat milk contained 2.20%, 1.88%, 0.34%, and 2.04% of protein, fat, ash, and fiber, respectively. The same table showed that oat milk contained 32.34 mg GAE/100 g phenolic compounds, with titratable acidity and pH values of 0.42% and 5.90, respectively. Meanwhile, the total solids, protein, fat, ash, and carbohydrate contents of dried whey protein concentrate (DWPC) were 95.37, 87.32, 0.11, 2.54, and 5.40 g/100g, respectively. These results align with those reported by Frederico et al. (2016) and El-Batawy et al. (2019), who found that the total solids, protein, fat, ash, and carbohydrate content of DWPC were 95.40, 87.36, 0.10, 2.62, and 5.32 g/100g, respectively. In contrast, the total solids, protein, fat, ash, fiber, and carbohydrate content of strawberry puree were 30.47, 0.87, 0.24, 0.43, 2.44, and 26.71 g/100g, respectively. Additionally, strawberry puree contained 330.36 mg GAE/100 g phenolic compounds and 42.62 mg of anthocyanins per 100 g. These findings are consistent with a study conducted by

Mohamed, Helal, Awad, and Yacoub (2024), which reported that strawberry puree contained 0.67% protein, 0.29% fat, 0.42% ash, and 2.13% crude fiber. Furthermore, these results were confirmed by Kaptan and Kayisoglu (2024); Miller, Feucht, and Schmid (2019) Segantini et al. (2015) and De Souza et al. (2014), which showed that strawberry puree contains phenolic compounds in the range of 300 to 400 mg GAE per 100 g, with titratable acidity between 0.57% and 0.95%, and pH values ranging from 3.67 to 3.75.

Table 1. Physicochemical properties of oat milk, strawberry puree and dried whey protein concentrate (DWPC).

Component	*oat milk*	Strawberry puree	DWPC
Moisture content g/100g	81.63±0.80^{a}	71.84 ±0.25^{b}	4.63 ± 0.15^{c}
Crude protein g/100g	2.43±0.04^{b}	0.87±0.15^{c}	87.32±1.04^{a}
Crude fat g/100g	1.68 ±0.02^{a}	0.24±0.10^{b}	0.11 ± 0.01^{c}
Crude fiber g/100g	3.23±0.08^{a}	2.44±0.01^{b}	ND
Total Ash g/100g	0.46±0.02b	0.43±0.06^{b}	2.54±0.02^{a}
Total solids %	18.37±0.60^{c}	28.16±0.38^{b}	95.37 ±1.2^{a}
Total carbohydrate g/100g	13.80±0.45^{b}	26.71±0.77^{a}	5.40±0.15^{c}
Titratable acidity %	0.42±0.01^{b}	0.95±0.07^{a}	0.10±0.01^{c}
pH value	5.90±0.06^{a}	3.30±0.02^{c}	4.66±0.04^{b}
Total Anthocyanin content (mg /100 g)	ND	42.62±1.93^{a}	ND
Total phenolic content (mg GAE/100 g)	32.34±0.87^{b}	330.36 ±4.60^{a}	10.12±0.11^{b}

Note The values represent the averages of three replicates (mean ± standard deviation). Means appearing with different letters within a row are significantly different (P < 0.05). ND = Not detected.

3.1.2. Chemical Composition of Plant-Based Yogurt Samples

Table 2 presents the composition of plant-based yogurt prepared from oat milk, combined with 2% DWPC and different proportions of strawberry puree (0, 5, 10, 15, and 20%). The results revealed that increasing the amount of strawberry puree added to plant-based yogurt samples significantly ($p<0.05$) affected the moisture, total solids, fat, protein, and carbohydrate content compared to the control plant-based yogurt sample (PY0) prepared without strawberry puree. Plant-based yogurt samples showed a gradual decrease in moisture, protein, fat, crude fiber, and ash content, while the total solids and carbohydrate contents increased with increasing proportion of added strawberry puree. The moisture content of the control yogurt sample prepared without strawberry puree (PY0) was 70.59%, which decreased to 69.44%, 68.46%, 67.29%, and 66.30% for samples PY1, PY2, PY3, and PY4, respectively. The addition of strawberry puree to the yogurt samples led to a reduction in their moisture content. These findings align with those reported by Amal, Eman, and Nahla (2016). The strawberry puree added solids to the plant-based yogurt samples, thereby lowering their moisture content. The total solids of the control yogurt sample (PY0) were 29.41%, increasing to 30.56%, 31.54%, 32.71%, and 33.70% for samples PY1, PY2, PY3, and PY4, respectively. As expected, total solids in the yogurt samples increased with increasing strawberry puree content. This finding is similar to the results of Jaster et al. (2018). Conversely, fat and protein content decreased as the percentage of added strawberry puree increased. The protein content of the control sample (PY0) was 2.24%, and gradually decreased to 2.19%, 2.13%, 2.10%, and 2.05% in samples PY1, PY2, PY3, and PY4, respectively. The protein content of the yogurt samples gradually decreased with increasing proportions of added strawberry puree. This is attributed to the lower protein content of strawberry puree compared to oat milk. Regarding fat content, the control sample (PY0) contained 1.57%. However, as strawberry puree was incorporated at increasing levels, the fat content gradually decreased to 1.50%, 1.43%, 1.37%, and 1.30% for samples PY1, PY2, PY3, and PY4, respectively. This decline is consistent with the lower fat content of strawberry puree compared to oat milk. These findings align with previous studies, which observed that yogurts with fruit additives tend to exhibit increased total solids but decreased protein and fat content (Cuşmenco & Bulgaru, 2020). The lower fat content in yogurts prepared with strawberry puree added compared to the control yoghurt sample is attributed to the low-fat content of the strawberry pulp. Similar results were obtained by Şengül, Erkaya, and Yildiz (2014). They also reported that as the ratios of added strawberry pulp increased, the fat and protein content of plant-based yogurt samples decreased.

Table 2. Chemical constituents of plant-based yogurt samples.

Component (%)	Treatments				
	PY0	PY1	PY2	PY3	PY4
Moisture content	70.59±0.20^{a}	69.44±0.05^{b}	68.46±0.14^{c}	67.29±0.11^{d}	66.30±0.10^{e}
Crude protein	4.14±0.09^{a}	3.94.19±0.07^{b}	3.73±0.06^{c}	3.52.10±0.04^{d}	3.32±0.06^{e}
Crude fat	1.57±0.12^{a}	1.50±0.14^{b}	1.43±0.07^{c}	1.37±0.10^{d}	1.30±0.04^{e}
Crude fiber	2.14±0.04^{a}	2.12±0.06^{ab}	2.09±0.05^{b}	2.06±0.03^{b}	2.04±0.09^{bc}
Total Ash	0.42±0.15^{a}	0.41±0.09^{ab}	0.40±0.06^{b}	0.39±0.11^{c}	0.38±0.04^{d}
Total solids	29.41±0.92e	30.56±0.19^{d}	31.54±0.20^{c}	32.71±0.13^{b}	33.70±0.70^{a}
Total carbohydrate	23.28±0.18^{e}	24.71±0.12^{d}	25.98±0.22^{c}	27.43±0.16^{b}	28.70±0.32^{a}

Note: The values represent the averages of three replicates (mean ± standard deviation). Means shown in the same row with different letters denote a significant difference (P < 0.05). PY0 (control sample of plant-based yogurt without strawberry puree), PY1 (plant-based yogurt with 5% strawberry puree added), PY2 (plant-based yogurt with 10% strawberry puree added), PY3 (plant-based yogurt with 15% strawberry puree added), and PY4 (plant-based yogurt with 20% strawberry puree added).

Conversely, the carbohydrate content of plant-based yogurt samples increased with increasing proportions of strawberry puree added, where the carbohydrate content of the control plant-based yogurt sample (PY0) was 23.28% and increased to 24.71%, 25.98%, 27.43%, and 28.70% for samples PY1, PY2, PY3, and PY4, respectively. This increase in carbohydrates corroborates findings from other research that noted higher carbohydrate levels in yogurts when fruit was added.

3.1.3. Changes in pH and Titratable Acidity During Cold Storage Periods

Table 3 shows the variations in pH values and titratable acidity of plant-based yogurt samples during 21 days of cold storage at 4°C. The findings demonstrate that both the titratable acidity and pH values were significantly influenced (P < 0.05) by the proportion of strawberry puree added to the yogurt samples. On the first day of storage, a notable increase in titratable acidity was observed with increasing amounts of added strawberry puree compared to the control sample (PY0), which was prepared without added strawberry puree. This upward trend in titratable acidity persisted throughout the storage period. At the beginning of storage, the titratable acidity of the control sample (PY0), prepared without strawberry puree, was 0.34 and increased to 0.40, 0.44, 0.47, and 0.51 for samples PY1, PY2, PY3, and PY4, respectively. This pattern indicated a direct positive relationship between the amount of strawberry puree added and the titratable acidity of the plant-based yogurt. During the storage period, the titratable acidity of the plant-based yogurt sample (PY2), supplemented with 10% strawberry puree, was 0.44 on the first day of storage and increased to 0.48, 0.53, and 0.57 on the 7th, 14th, and 21st days of storage at 4°C, respectively.

Table 3. Changes in pH values and titratable acidity of yogurt samples during 21 days of cold storage at 4°C.

Treatments	Storage period (Days)			
	1	7	14	21
Acidity (%)				
PY0	0.34±0.01$^{D e}$	0.37±0.05$^{C e}$	0.42±0.02$^{B e}$	0.48±0.06^{Ae}
PY1	0.40±0.05$^{D d}$	0.44±0.08 $^{C d}$	0.49±0.06^{AB}	0.53±0.03^{Ad}
PY2	0.44±0.03$^{D c}$	0.48±0.06$^{C c}$	0.53±0.04$^{B c}$	0.57±0.05^{Ac}
PY3	0.47±0.07$^{D b}$	0.51±0.09$^{C b}$	0.57±0.05$^{B b}$	0.61±0.04^{Ab}
PY4	0.51±0.06$^{D a}$	0.54±0.07$^{C a}$	0.60±0.03$^{B a}$	0.64±0.02^{Aa}
pH values				
PY0	4.84 ±0.09^{Aa}	4.80±0.04^{Ba}	4.77±0.10^{Bca}	4.73±0.06^{Da}
PY1	4.75 ±0.06^{Ab}	4.71±0.10^{Bb}	4.65±0.09^{Cb}	4.60±0.12^{Db}
PY2	4.70 ±0.10^{Ac}	4.66±0.07^{Bc}	4.61±0.05^{BCc}	4.54±0.11^{Dc}
PY3	4.64±0.04^{Ad}	4.61±0.05^{Ad}	4.55±0.11^{Bd}	4.49±0.08^{Cd}
PY4	4.57±0.07^{Ae}	4.54±0.03^{ABe}	4.50±0.08^{Be}	4.46±0.04^{Ce}

Note The values represent the averages of three replicates (mean ± standard deviation). Means shown in the same row with different uppercase letters denote a significant difference (P < 0.05). Means appearing in the same column with different lowercase letters indicate a significant difference (P < 0.05). PY0 (control sample of plant-based yogurt without strawberry puree), PY1 (plant-based yogurt with 5% strawberry puree added), PY2 (plant-based yogurt with 10% strawberry puree added), PY3 (plant-based yogurt with 15% strawberry puree added) and PY4 (plant-based yogurt with 20% strawberry puree added).

The increase in titratable acidity during storage time may be attributed to the activity of Bifidobacterium and S. thermophilus cultures. The acidity of the plant-based yogurt samples increased with increased amounts of strawberry puree added. This finding aligns with earlier research. A similar observation was confirmed by Roy et al. (2015).
The pH values of the yogurt samples showed a significant decrease ($P < 0.05$) with the addition of increasing proportions of strawberry puree on the first day of storage, compared to the control samples without puree (PY0). This decreasing trend in pH values continued throughout the storage period. On the first day, the pH value of the control sample (PY0), prepared without strawberry puree, was 4.84 and decreased to 4.75, 4.70, 4.64, and 4.57 for samples PY1, PY2, PY3, and PY4, respectively. During storage, the pH values of yogurt sample supplemented with 15% strawberry puree (PY3) were 4.64 on the first day and decreased to 4.61, 4.55, and 4.49 on the 7th, 14th, and 21st days of storage at 4°C, respectively. These results are consistent with previous research by Varedesara, Ariaii, and Hesari (2021) and Jaster et al. (2018), who observed that pH values decreased while total acidity increased in different types of yogurts with added fruit puree, due to increased activity during storage.

3.1.4. Colour Attributes of Plant-Based Yogurt Samples During Cold Storage Periods

Table 4 illustrates the color attributes of plant-based yogurt samples prepared from oat milk, 2% DWPC, and various percentages of strawberry puree (ranging from 0 to 20%), with regard to L* (Lightness), a* (redness), and b* (yellowness) values during 21 days of cold storage at 4°C. The findings indicate that the addition of strawberry puree to yogurt samples significantly influenced ($p<0.05$) the color characteristics. The L* (Lightness) values of yogurt samples showed a gradual decrease with increasing strawberry puree addition, compared to the control yogurt sample prepared without strawberry puree (PY0), on the first day of storage. Thereafter, the L* (Lightness) values continued to decrease throughout the storage period. These results are consistent with a study by Jaster et al. (2018), who found that the addition of strawberry puree resulted in a decrease in the L* values of yogurt samples. The L* (Lightness) value of the control yogurt sample (PY0), prepared without strawberry puree, was 72.43 on the first day of storage. This value decreased to 70.24, 68.21, 66.52, and 64.49 for samples PY1, PY2, PY3, and PY4 respectively. The observed reduction in the L* value, indicating a decrease in Lightness, can be linked to the high pigment content found in the strawberry puree. During the storage period, the L* (Lightness) values of the yogurt sample prepared with 15% strawberry puree (PY3) were recorded as 66.52 on the first day of storage. These values gradually decreased to 62.32, 59.87, and 58.36 on the 7th, 14th, and 21st days of cold storage at 4°C, respectively. The control yogurt samples (PY0), which were prepared without strawberry puree, consistently exhibited the highest L* (Lightness) values during the storage period compared to the yogurt samples containing strawberry puree. On the other hand, the lowest L* (Lightness) values were observed in yogurt samples (PY4) prepared with 20% added strawberry puree at the end of the storage period. On the initial day of storage, the a* (redness) values of the yogurt samples gradually increased with increasing proportions of strawberry puree added into the yogurt samples compared to the control yogurt samples. Thereafter, the a* (redness) values decreased from the 7th day of storage until the end of the storage period. On the first day of storage, the a* (redness) values of the control yogurt sample (PY0) prepared without strawberry puree (control) were -1.22 and increased to 3.34, 4.55, 5.72, and 6.83 for samples PY1, PY2, PY3, and PY4 respectively. These results are consistent with a study by Jaster et al. (2018), who found that the a* values of control yogurts without strawberry puree were negative, while the addition of strawberry puree increased the a* values of the samples. In contrast, the a* (redness) values of yogurt samples gradually decreased with increasing storage periods. During the storage periods, the a* (redness) values of yogurt sample (PY2) supplemented with 10% strawberry puree were 4.55 on the first day of storage and decreased to 3.93, 3.47, and 3.04 on the 7th, 14th, and 21st days of storage at 4°C, respectively. This reduction in a* (redness) during storage is largely attributed to the degradation of anthocyanins and/or the formation of yellow and brown polymerization complexes (Ścibisz, Ziarno, & Mitek, 2019).

Table 4. Colour characteristics of plant-based yogurt samples during 21 days of cold storage at 4°C.

Treatments	Storage period (Days)			
	1	7	14	21
L* (Lightness) values				
PY0	72.43±2.75^{Aa}	69.23±2.22^{Ba}	65.82±2.85^{Ca}	64.22±2.09^{Da}
PY1	70.24±2.75^{Ab}	65.67±2.83^{Bb}	63.34±2.85^{Cb}	62.96±2.09^{Db}
PY2	68.21±4.81^{Ac}	63.43±3.20^{Bc}	61.68±3.30^{Cc}	60.40±3.58^{Dc}
PY3	66.52±4.02^{Ad}	62.32±4.23^{Bd}	59.87±5.58^{Cd}	58.36±1.70^{Dd}
PY4	64.49±4.02^{Ae}	60.84±4.63^{Be}	58.51±5.58^{Ce}	56.83±3.58^{De}
a* (redness-greenness) values				
PY0	-1.22±0.20^{Ae}	-1.45±0.21^{Be}	-1.59±0.24^{Ce}	-1.78±0.09^{De}
PY1	3.34±0.20C^{Ad}	3.11±0.17^{Bd}	2.47±0.20^{Cd}	2.14±0.19^{Dd}
PY2	4.55±0.20C^{Ac}	3.93±0.17^{Bc}	3.47±0.20^{Cc}	3.04±0.19^{Dc}
PY3	5.72±0.34^{Ab}	4.99±0.04^{Bb}	4.26±0.16^{Cb}	3.83±0.12^{Db}
PY4	6.83±0.36^{Aa}	6.24±0.18^{Ba}	5.45±0.30^{Ca}	4.87±0.19^{Da}
b* (yellowness-blueness) values				
PY0	6.41±0.34^{Aa}	6.23±0.41^{Ba}	6.15±0.47^{Ca}	6.12±0.35^{Da}
PY1	4.82±0.11^{Ab}	4.74±0.31^{Bb}	4.52±0.27^{Cb}	4.34±0.35^{Db}
PY2	3.74±0.25^{Ac}	3.27±0.28^{Bc}	3.20±0.26^{Cc}	3.14±0.38^{Dc}
PY3	3.38±0.24^{Ad}	3.19±0.21^{Bd}	3.12±0.20^{Cd}	3.07 ±0.32^{Dd}
PY4	3.27±0.23^{Ae}	3.10±0.17^{Bd}	3.07±0.39^{Ce}	3.02±0.34^{Dd}

Note: The values represent the averages of three replicates (mean ± standard deviation). Means shown in the same row with different uppercase letters denote a significant difference (P < 0.05). Means appearing in the same column with different lowercase letters indicate a significant difference (P < 0.05). PY0 (control sample of plant-based yogurt without strawberry puree), PY1 (plant-based yogurt with 5% strawberry puree added), PY2 (plant-based yogurt with 10% strawberry puree added), PY3 (plant-based yogurt with 15% strawberry puree added), and PY4 (plant-based yogurt with 20% strawberry puree added).

The b* value, representing the yellowness of the yogurt samples, showed a gradual decrease with increasing proportion of strawberry puree added to the yogurt samples on the first day of storage, compared to the control sample (PY0). Similarly, the L* (lightness) values continued to decline throughout the storage period. On the first day, the b* (yellowness) value of the control sample (PY0), prepared without strawberry puree, was 6.41 and decreased to 4.82, 3.74, 3.38, and 3.27 for samples PY1, PY2, PY3, and PY4 respectively. During storage, the b* (yellowness) values of yogurt sample PY3, supplemented with 15% strawberry puree, were 3.38 on the first day and decreased to 3.19, 3.12, and 3.07 on the 7th, 14th, and 21st days of cold storage at 4°C, respectively. On the 14th day of storage, the b* (yellowness) values of the control yogurt sample (PY0) were 6.15 and decreased to 4.52, 3.20, 3.12, and 3.07 for samples PY1, PY2, PY3, and PY4 respectively.

3.1.5. Changes in Total Phenolic Content, Antioxidant Activity and Anthocyanin Content During Cold Storage Periods

Table 5 presents the total phenolic content, antioxidant activity, and anthocyanin content of plant-based yogurt samples during 21 days of cold storage at 4°C. The findings revealed a significant increase (P < 0.05) in the total phenolic content of plant-based yogurt samples with increasing proportions of strawberry puree added on the first day of storage compared to the control yogurt samples (PY0) prepared without strawberry puree. Following this initial increase, phenolic content continued to rise during the cold storage period. On the first day of storage, the phenolic content of the control yogurt sample (PY0) was 28.01 mg Gallic acid/100g and increased to 33.89, 36.68, 38.95, and 41.44 mg Gallic acid/100g for samples PY1, PY2, PY3, and PY4, respectively. The addition of strawberry puree was more effective in increasing the total phenolic compounds of yogurt (P < 0.05), which was attributed to the high content of bioactive phenolic compounds in strawberries, including hydroxycinnamic acids, ellagic acids, ellagitannins, xavan-3-ols, zavonols, and anthocyanins, as well as flavonoids and phenolic acids (Chen, Bai, Zhang, Li, & Liu, 2015), whereas fruit-free yogurts showed decreased total phenolic compounds (Bueno, Silva, Perina, Bogsan, & Oliveira, 2014). Consequently, total phenolic content was highest in plant-based yogurt with 20% strawberry puree added (PY4), followed by the yogurt sample with 15% strawberry puree added (PY3), the yogurt sample with 10% strawberry puree added (PY2), the yogurt sample with 5% strawberry puree added (PY1), and the control yogurt sample (PY0) prepared without strawberry puree, respectively. During the storage period, the total phenolic content of the yogurt sample prepared with 15% strawberry puree (PY3) was 38.95 mg Gallic acid / 100g on the first day. This value gradually increased to 40.86, 42.69, and 43.55 mg Gallic acid / 100g on the 7th, 14th, and 21st days of cold storage at 4°C, respectively. The observed rise in phenolic content during storage was attributed to the breakdown of polyphenolic compounds into smaller, more extractable or stable units. Additionally, the complex structures formed through polyphenol-protein interactions were considered a contributing factor to this increase (El-Said, Haggag, El-Din, Gad, & Farahat, 2014). The results demonstrated that the antioxidant activity of plant-based yogurt samples gradually increased with increasing proportions of strawberry puree added on the first day of storage, in comparison to the control sample (PY0). This increasing trend in antioxidant activity continued until the 14th day of storage, after which it decreased until the end of the storage period. The antioxidant activity of the control sample (PY0), prepared without strawberry puree, was 22.33%. This value increased to 30.65%, 38.84%, 38.46%, and 55.74% for samples PY1, PY2, PY3, and PY4, respectively. Increasing the proportion of strawberry puree added to the plant-based yogurt samples resulted in increased antioxidant activity, which is attributed to the high content of antioxidant compounds in strawberries, such as hydroxycinnamic acids, ellagic acids, ellagitannins, xavan-3-ols, zavonols, and anthocyanins, in addition to flavonoids and phenolic acids (Chaves, Calvete, & Reginatto, 2017; Jaster et al., 2018).

Strawberries are a rich source of anthocyanin compounds, which function effectively as antioxidants. These anthocyanins neutralize DPPH free radicals by donating hydrogen atoms from their hydroxyl groups, leading to the formation of a more stable DPPH molecule (DPPH-H). As the concentration of anthocyanins increases, the ability to donate hydrogen atoms enhances, thereby improving the inhibition of DPPH free radical activity (Kaptan & Kayisoglu, 2024). Among various formulations, plant-based yogurt enriched with 20% strawberry puree (PY4) exhibited the highest antioxidant activity, followed by yogurt sample with 15% strawberry puree added (PY3), yogurt sample with 10% strawberry puree added (PY2), yogurt sample with 5% strawberry puree added (PY1), and the control yogurt sample (PY0) prepared without strawberry puree, respectively. During the storage period, plant-based yogurt supplemented with 15% strawberry puree (PY3) showed an antioxidant activity of 46.37% on the first day. This activity gradually increased to 51.30% and 55.22% on the 7th and 14th days, respectively, before decreasing to 51.65% at the end of storage at 4°C. Antioxidant activity increased in all samples until day 14 before starting to decline thereafter. The highest antioxidant activity was observed in yogurt samples on the 14th day, reaching 28.38%, 40.81%, 47.39%, 55.22%, and 64.23% for samples PY0, PY1, PY2, PY3, and PY4, respectively.

Table 5. Changes in the total phenolic content, total antioxidant activity, and total anthocyanin content of plant-based yogurt samples during 21 days of cold storage at 4°C.

Treatments	**Storage period (days)**			
	1	**7**	**14**	**21**
Total phenolic content (mg GAE/100g)				
PY0	28.01±1.22^{De}	29.36±1.45^{Ce}	30.57±5.12^{Be}	31.84 ±5.11^{Ae}
PY1	33.89±1.52^{Dd}	34.77±1.79^{Cd}	35.85±2.47^{Bd}	36.73±2.22^{Ad}
PY2	36.68±1.75^{Dc}	36.66±1.11^{Cc}	38.58±2.38^{Bc}	39.67 ±1.29^{Ac}
PY3	38.95±1.86^{Db}	40.86±1.28^{Cb}	42.69±1.85^{Bb}	43.55 ±7.63^{Ab}
PY4	41.44±2.10^{Da}	42.94±2.32^{Ca}	43.43±2.37^{Ba}	44.28±8.58^{Aa}
Antioxidant activity				
PY0	22.33±0.35^{De}	25.27±0.40^{Be}	28.38±0.46^{Ae}	24.96±0.52^{Ce}
PY1	30.65±0.42^{Dd}	36.42±1.13^{Bd}	40.81±0.65^{Ad}	34.22±0.43^{Cd}
PY2	38.84±0.33^{Dc}	43.53±1.08^{Bc}	47.39±0.77^{Ac}	40.34±0.62^{Cc}
PY3	46.37±0.52^{Db}	51.30±0.96^{Bb}	55.22±0.68^{Ab}	51.65±0.30^{Cb}
PY4	55.74±0.60^{Da}	61.58±1.02^{Ba}	64.23±0.42^{Aa}	59.33±0.46^{Ca}
Total anthocyanin content (mg /100 g)				
PY0	ND	ND	ND	ND
PY1	2.34±0.10^{Ad}	2.26±0.12^{Bd}	2.18±0.13^{Cd}	2.13±0.11^{Dd}
PY2	4.26±0.16^{Ac}	4.27±0.17^{Ac}	4.21±0.22^{Bc}	4.15±0.18^{Cc}
PY3	6.23±0.17^{Ab}	6.16±0.25^{Bb}	6.11±0.34^{Cb}	6.06±0.26^{Db}
PY4	8.42±0.22^{Aa}	8.37±0.32^{Ba}	8.31±0.42^{Ca}	8.26±0.31^{Da}

Note: The values represent the averages of three replicates (mean ± standard deviation). Means shown in the same row with different uppercase letters denote a significant difference ($P < 0.05$). Means appearing in the same column with different lowercase letters indicate a significant difference ($P < 0.05$). PY0 (control sample of plant-based yogurt without strawberry puree), PY1 (plant-based yogurt with 5% strawberry puree added), PY2 (plant-based yogurt with 10% strawberry puree added), PY3 (plant-based yogurt with 15% strawberry puree added) and PY4 (plant-based yogurt with 20% strawberry puree added). ND = Not detected.

The decrease observed after day 14 was attributed to interactions between polyphenols and milk proteins, which reduced their antioxidant capability by decreasing the number of free hydroxyl groups available to scavenge free radicals, as noted by Dubeau, Samson, and Tajmir-Riahi (2010).

The anthocyanin content gradually increased with increasing proportions of strawberry puree added to the yogurt samples compared to the control sample (PY0) on the first day of storage. Thereafter, the anthocyanin content gradually decreased until the end of the storage period. On the initial day, the yogurt sample (PY1), prepared with 5% strawberry puree, showed an anthocyanin content of 2.34 mg/100 g. In contrast, the anthocyanin content increased to 4.26, 6.23, and 8.42 mg/100 g for samples PY2, PY3, and PY4, respectively. This increase in anthocyanin content correlated with the proportion of strawberry puree added, a result stemming from the higher anthocyanin concentration naturally present in strawberries. During the storage period, the anthocyanin content in yogurt samples prepared with 15% strawberry puree added (PY3) was 6.23 mg/100 g on the first day, gradually decreasing to 6.16, 6.11, and 6.06 mg/100 g on the 7th, 14th, and 21st days of cold storage at 4°C, respectively. The anthocyanin content in yogurt samples with added strawberries gradually decreased during the storage period, which aligns with the findings of Oliveira et al. (2015) and Raikos, Ni, Hayes, and Ranawana (2019). This decrease may be attributed to the degradation of anthocyanins through oxidation and other chemical reactions, which are influenced by the reduction of pH during storage. Additionally, probiotic bacteria are known to produce β-glucosidase, an enzyme capable of hydrolyzing the glycosidic bonds of anthocyanins into anthocyanidins, which are highly unstable and prone to degradation (Acar & Yüksekdağ, 2023; Ścibisz & Ziarno, 2023).

3.2. Viable Counts of Probiotic Bacteria

Table 6 presents the changes in viable counts (log cfu/g) of Streptococcus thermophilus, Lactobacillus acidophilus, and Bifidobacterium bifidum in plant-based yogurt samples during a 21-day cold storage period at 4°C. The results indicate that the viable counts of *Streptococcus thermophilus*, *Lactobacillus acidophilus*, and *Bifidobacterium bifidum* increased with the proportion of strawberry puree added to the yogurt samples on the first day of storage. However, the counts began to gradually decline from the 7th day of storage until the end of the period. The viable counts of *Streptococcus thermophilus* in the control yogurt sample (PY0), prepared without strawberry puree, was 7.61 log cfu/g. This increased to 8.22, 8.56, 8.70, and 8.80 log cfu/g on the first day for samples PY1, PY2, PY3, and PY4, respectively, with increasing strawberry puree added. The observed increase in viable counts of *Streptococcus thermophilus*, *Lactobacillus acidophilus*, and *Bifidobacterium bifidum* is attributed to phenolic compounds, which are major components of the fruit (Mullen et al., 2002). Phenolic compounds in fruits have been found to enhance the growth of beneficial bacteria such as *Streptococcus thermophilus*, *Lactobacillus acidophilus*, *and Bifidobacterium bifidum* (Molan, Lila, Mawson, & De, 2009).

This prebiotic effect is largely attributed to the polyphenols and insoluble fibers present in strawberry puree, which selectively promote the growth of beneficial bacteria in the gut (Fernandez & Marette, 2017). The phenolic components found in strawberries, including anthocyanin pigments such as pelargonidin-3-monoglucoside, cyanidin-3-monoglucoside, and delphinidin-3-monoglucoside, play an important role in encouraging the growth of probiotic bacteria (Werlein, Kütemeyer, Schatton, Hubbermann, & Schwarz, 2005). During storage, yogurt samples enriched with 15% strawberry puree (sample PY3) showed that the viable count of *Streptococcus thermophilus* was 8.70 log cfu/g on the first day, which gradually decreased to 8.58, 8.33, and 7.89 log cfu/g on the 7th, 14th, and 21st days of storage at 4°C, respectively.

Meanwhile, the viable counts of *Lactobacillus acidophilus* in the control yogurt sample (PY0) without strawberry puree was 7.58 log cfu/g and increased to 8.12, 8.33, 8.52, and 8.76 log cfu/g for samples PY1, PY2, PY3, and PY4 on the first day of storage, respectively.

Table 6. Changes in the viable counts of probiotic bacteria in plant-based yogurt samples during a 21-day cold storage period at 4°C.

Treatments	Storage period (Days)			
	1	7	14	21
Streptococcus thermophilus				
PY0	7.61 ± 0.09^{Ae}	7.54 ± 0.12^{Be}	7.41 ± 0.08^{Ce}	7.22 ± 0.08^{De}
PY1	8.22 ± 0.17^{Ad}	8.10 ± 0.20^{Bd}	7.72 ± 0.16^{Cd}	7.46 ± 0.14^{Dd}
PY2	8.56 ± 0.22^{Ac}	8.36 ± 0.21^{Bc}	8.12 ± 0.24^{Cc}	7.78 ± 0.16^{Dc}
PY3	8.70 ± 0.25^{Ab}	8.58 ± 0.07^{Bb}	8.33 ± 0.26^{Cb}	7.89 ± 0.17^{Db}
PY4	8.80 ± 0.23^{Aa}	8.63 ± 0.08^{Ba}	8.49 ± 0.15^{Ca}	8.17 ± 0.22^{Da}
Lactobacillus acidophilus				
PY0	7.58 ± 0.18^{Ae}	7.44 ± 0.07^{Be}	7.32 ± 0.16^{Ce}	7.20 ± 0.09^{De}
PY1	8.12 ± 0.13^{Ad}	7.93 ± 0.12^{Bd}	7.64 ± 0.18^{Cd}	7.39 ± 0.16^{Dd}
PY2	8.33 ± 0.22^{Ac}	8.21 ± 0.09^{Bc}	7.92 ± 0.20^{Cc}	7.54 ± 0.11^{Dc}
PY3	8.52 ± 0.24^{Ab}	8.40 ± 0.08^{Bb}	8.14 ± 0.21^{Cb}	7.78 ± 0.12^{Db}
PY4	8.76 ± 0.20^{Aa}	8.61 ± 0.20^{Ba}	8.38 ± 0.19^{Ca}	7.90 ± 0.08^{Da}
Bifidobacterium bifidum				
PY0	7.36 ± 0.05^{Ae}	7.22 ± 0.10^{Be}	7.11 ± 0.05^{Ce}	6.82 ± 0.02^{De}
PY1	7.68 ± 0.09^{Ad}	7.56 ± 0.11^{Bd}	7.32 ± 0.09^{Cd}	7.14 ± 0.04^{Dd}
PY2	7.81 ± 0.10^{Ac}	7.60 ± 0.13^{Bc}	7.46 ± 0.10^{Cc}	7.25 ± 0.07^{Dc}
PY3	7.94 ± 0.18^{Ab}	7.72 ± 0.20^{Bb}	7.58 ± 0.18^{Cb}	7.36 ± 0.15^{Db}
PY4	8.10 ± 0.12^{Aa}	7.84 ± 0.15^{Ba}	7.62 ± 0.12^{Ca}	7.41 ± 0.10^{Da}

Note: The values represent the averages of three replicates (mean ± standard deviation). Means shown in the same row with different uppercase letters denote a significant difference ($P < 0.05$). Means appearing in the same column with different lowercase letters indicate a significant difference ($P < 0.05$).PY0 (Control sample of plant-based yogurt without strawberry puree), PY1 (Plant-based yogurt with 5% strawberry puree added), PY2 (Plant-based yogurt with 10% strawberry puree added), PY3 (Plant-based yogurt with 15% strawberry puree added) and PY4 (Plant-based yogurt with 20% strawberry puree added).

The yogurt samples enriched with strawberry puree showed significantly higher ($p<0.05$) viable counts of *Streptococcus thermophilus*, *Lactobacillus acidophilus*, *and Bifidobacterium bifidum* during a 21-day storage period at 4°C compared to the control yogurt sample (PY0). The reduction in viable counts in the control sample, which was prepared without strawberry puree, is likely due to the absence of substances that encourage microbial growth. During the storage period, the viable counts of *Lactobacillus acidophilus* in the yogurt sample (PY2) supplemented with 10% strawberry puree were recorded at 8.33 log cfu/g on the first day of storage. These counts gradually decreased to 8.21, 7.92, and 7.54 log cfu/g on storage days 7, 14, and 21 at 4°C, respectively. The viable counts of *Bifidobacterium bifidum* in the control yogurt sample (PY0), prepared without strawberry puree, were 7.36 log cfu/g. These counts increased to 7.68, 7.81, 7.94, and 8.10 log cfu/g for samples PY1, PY2, PY3, and PY4, respectively, on the first day of storage. During the storage period, the viable counts of *Bifidobacterium bifidum* in yogurt sample (PY3), supplemented with 15% strawberry puree, were 7.94 log cfu/g on the first day of storage. However, they decreased to 7.72, 7.58, and 7.36 log cfu/g on the 7th, 14th, and 21st days of cold storage at 4°C, respectively. The counts of *Streptococcus thermophilus*, *Lactobacillus acidophilus*, *and Bifidobacterium bifidum* in the different yogurt samples also showed a gradual decrease starting from the seventh day of storage until the end of the period. Despite this decline, the levels remained above the recommended threshold of 10^6 log cfu/g after 21 days at 4°C (FAO, 2013). The observed reduction in the viable counts across all samples by the end of the storage period is likely linked to increased acidity levels.

3.3. Sensory Attributes

Table 7 presents the sensory characteristics, including taste, aroma, appearance, texture, and overall acceptability of plant-based yogurt samples during 21 days of cold storage at 4°C. The results indicated a significant improvement ($P < 0.05$) in the sensory characteristics (taste, aroma, appearance, texture, and overall acceptability) of plant-based yogurt samples with increased proportion of strawberry puree added on the first day of storage, compared to the control yogurt sample (PY0), prepared without strawberry puree. However, these sensory attributes gradually declined in all samples as the storage period progressed.

Table 7. Sensory characteristics of plant-based yogurt samples during 21 days of cold storage at 4°C.

Treatments	Storage period (days)			
	1	7	14	21
Taste				
PY0	2.77±0.10^{Ae}	2.55±0.10^{Bd}	2.36±0.22^{Ce}	2.13±0.08^{De}
PY1	3.69±0.05^{Ad}	3.30±0.22^{Bc}	3.12±0.11^{Cd}	2.88±0.18^{Dd}
PY2	4.38±0.03^{Ac}	4.25±0.10^{Bb}	3.9±0.22^{Cc}	3.70±0.10^{Dc}
PY3	4.70±0.15^{Aa}	4.56±0.06^{Ba}	4.41±0.20^{Ca}	4.30±0.13^{Da}
PY4	4.61±0.04^{Ab}	4.48±0.13^{Bab}	4.24±0.13$^{C b}$	4.11±0.23^{Db}
Flavor				
PY0	2.73±0.20^{Ae}	2.56±0.23^{Be}	2.30±0.10^{Ce}	2.23±0.57^{De}
PY1	3.41±0.03^{Ad}	3.14±0.25^{Bd}	2.86±0.07^{Cd}	2.56±0.05^{Dd}
PY2	3.84±0.06^{Ac}	3.66±0.15^{Bc}	3.40±0.15^{Cc}	3.28±0.10^{Dc}
PY3	4.83±0.02^{Aa}	4.30±0.11^{Ba}	4.17±0.20^{Ba}	3.83±0.15^{Da}
PY4	4.65±0.11^{Aab}	4.20±0.26^{Bab}	4.03±0.76^{Bab}	3.57±0.76^{Dab}
Appearance				
PY0	2.68±0.22^{Ae}	2.53±0.04^{Be}	2.35±0.15^{Ce}	2.12±0.20^{Dd}
PY1	3.72±0.24^{Ad}	3.56±0.15^{Bd}	3.36±0.09^{BCd}	3.11±0.42^{Cc}
PY2	4.41±0.17^{Ac}	4.12±0.10^{Bc}	3.70±0.11^{Cc}	3.30±0.34^{Db}
PY3	4.72±0.12^{Aa}	4.67±0.11^{ABa}	4.37±0.14^{Ba}	3.70±0.30^{Ca}
PY4	4.60±0.13^{Ab}	4.38±0.18^{Bab}	4.20±0.13^{Bab}	4.05±0.50^{Cab}
Texture				
PY0	2.94±0.14^{Ad}	2.76±0.13^{Be}	2.43±0.04^{Ce}	2.26±0.20^{Dd}
PY1	3.33±0.20^{Ac}	3.15±0.12^{Bd}	2.84±0.07^{Cd}	2.64±0.12^{Dc}
PY2	4.20±0.04^{Ab}	3.93±0.20^{Bbc}	3.58±0.08^{Cb}	3.28±0.22^{Db}
PY3	4.37±0.11^{Aa}	4.33±0.16^{ABa}	3.83±0.24^{Ba}	3.73±0.30^{Ca}
PY4	4.20±0.10^{Ab}	4.10±0.12^{ABb}	3.63±0.17^{Cbc}	3.233±0.21^{Db}
Overall Acceptability				
PY0	2.85±0.16^{Ad}	2.57±0.08^{Be}	2.34±0.12^{Ce}	2.13±0.07^{De}
PY1	3.67±0.07^{Ac}	3.38±0.13^{Bd}	3.21±0.03^{Cd}	3.06±0.13^{Dd}
PY2	4.12±0.05^{Ab}	3.89±0.23^{Bc}	3.58±0.05^{Cc}	3.27±0.12^{Dc}
PY3	4.55±0.10^{Aa}	4.42±0.03^{Ba}	4.16±0.06^{Ca}	3.99±0.05^{Da}
PY4	4.51±0.02^{Aa}	4.29±0.11^{Bb}	3.76±0.10$^{C b}$	3.54±0.04^{Db}

Note: The values represent the averages of thirty panelists (Means ± standard deviation). Means shown in the same row with different uppercase letters denote a significant difference ($P < 0.05$). Means appearing in the same column with different lowercase letters indicate a significant difference ($P < 0.05$). PY0 (Control sample of plant-based yogurt without strawberry puree), PY1 (Plant-based yogurt with 5% strawberry puree added), PY2 (plant-based yogurt with 10% strawberry puree added), PY3 (Plant-based yogurt with 15% strawberry puree added) and PY4 (Plant-based yogurt with 20% strawberry puree added).

The addition of strawberry puree significantly improved sensory properties ($P < 0.05$), such as taste, aroma, texture, appearance, and overall acceptability, compared to the control sample (Kaptan & Kayisoglu, 2024). The yogurt sample (PY3) supplemented with 15% strawberry puree achieved the highest sensory scores for taste, aroma, appearance, texture, and overall acceptability during storage. This was followed by yogurt sample (PY4) prepared with 20% strawberry puree, yogurt sample (PY2) prepared with 10% strawberry puree, yogurt sample (PY1) prepared with 5% strawberry puree, and finally, the control sample (PY0) without strawberry puree.

Furthermore, yogurt containing natural fruit sugars was preferred over plain yogurt. Fruit-enriched yogurts garnered higher acceptance scores in sensory evaluations, reaffirming their preference among consumers (Feng et al., 2019; Werlein et al., 2005).

4. CONCLUSION

The present study indicates the potential for producing plant-based yogurt that meets the nutritional and sensory needs of diverse consumers, particularly those with lactose intolerance or those adhering to a vegan diet. Fortification with strawberry puree significantly enhanced the total solids, carbohydrate content, acidity, phenolic compounds, anthocyanins, and antioxidant activity of the product. Moreover, strawberry puree promoted the viability of Streptococcus thermophilus, Lactobacillus acidophilus, and Bifidobacterium bifidum during refrigerated storage, keeping them above the recommended therapeutic threshold. Among the formulations, yogurt containing 15% strawberry puree received the highest sensory scores, demonstrating its superior balance between health benefits and consumer acceptance. This innovation holds significance in creating functional nutritional options for children, adults, and the elderly, addressing a noticeable gap in non-dairy products within the market. Future work includes improving the formulation of plant-based yogurt by using different plant protein sources, nutrient-rich fruits, bioactive components, and stabilizers to enhance the sensory, functional properties, and nutritional quality of plant-based yogurt.

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