Food Technology Research Journal, Vol. 8, issue 1, 60-71, 2025

FTRJ

Several Qualities of Sweet Potato Flavored Yogurt

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Original Article

Article information

Received 05/05/2025
Revised 07/06/2025
Accepted 12/06/2025
Published 15/06/2025
Available online
18/06/2025

Keywords:
yogurt, sweet potato, antioxidant activity, syneresis.

ABSTRACT

Yogurt and sweet potato are both functional foods known for their rich nutrient content and beneficial health effects. In this study, six types of buffalo yogurt were produced by adding: 3.5% skim milk powder (control), 3.5% sweet potato powder (T1), 5% pieces of sweet potato purée without or with gelatin (T2, T3), and 5% pieces of sweet potato powder without or with gelatin (T4, T5). The yogurts were evaluated for their physicochemical, microbiological, rheological, textural, and organoleptic properties during cold storage for 15 days at 5°C. The results showed significant differences ($p < 0.05$) in the physicochemical, microbiological, and sensory properties of plain yogurt enhanced by the addition of sweet potato. Physicochemical parameters such as pH, acidity, aroma compounds namely acetaldehyde (AC) and diacetyl (DA), total phenolic compounds (TP%), and antioxidant activity (AA%) in yogurts flavored with sweet potato powder were comparable to those of the plain yogurt. Notably, yogurt enriched with pieces of sweet potato powder and gelatin showed increased levels of TP and AA%. It also demonstrated improved viscosity, reduced syneresis, increased hardness, enhanced sensory attributes, and better survival of lactic acid bacteria (LAB), with viable counts exceeding 6.0 log cfu/g, thereby meeting generally accepted standards.

1. Introduction

Throughout history, yogurt has been known by various names, including *zabadi* (Egypt), *leban* or *laban rayeb* (Lebanon and some Arab countries), *jugurt* (Turkey), *katyk* (Armenia), *yiaourti* (Greece), *cieddu* (Italy), *dahi* (India), and *rob* (Iraq). It is believed that the domestication of milk-producing animals such as cows, sheep, goats, yaks, horses, buffalo, and camels led to the introduction of milk products into the human diet between approximately 10,000 and 5,000 BC (Fisber and Rachel, 2015). In Egypt, *zabadi* or *laban zabady* is the traditional type of yogurt, typically made from buffalo milk, although it can also be produced from cow's milk or a mixture of both. It is believed that *zabadi* is derived from the ancient Egyptian fermented milk known as *laban rayeb* (Abou-Donia, 2008). Around 9000–8000 BC, an early form of yogurt emerged in Egypt and Mesopotamia. It gradually spread throughout northeast Africa, the Middle East, Central Asia, and eventually the Balkan countries, where various types of "fermented milks" were developed. In those regions, milk fermentation was primarily used as a method of preservation. By definition, yogurt is a fermented milk product made by fermenting milk with a combination of starter cultures, primarily *Streptococcus thermophilus* and *Lactobacillus delbrueckii* ssp. *bulgaricus*, along with other suitable lactic acid bacteria (LAB). Yogurt has experienced a remarkable resurgence in recent decades, largely driven by its health benefits and the introduction of new product innovations, including a wide range of flavors and varieties, which have increased global consumption. Yogurt is widely recognized for its therapeutic and nutraceutical properties, including improved digestion, enhanced immune function, reduced serum cholesterol, and anticancer potential. Nutritionally, yogurt is a rich source of protein, calcium, phosphorus, riboflavin (vitamin B2), thiamine (vitamin B1), and vitamin B12.

Journal website: https://ftrj.journals.ekb.eg/
Published by Food Technology Research Institute, ARC
*https://DOI:*10.21608/ftrj.2025.434216

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It also provides folate, niacin, magnesium, and zinc due to its similarity to milk in nutritional content. Its proteins have a high biological value (i.e., they contain all essential amino acids), and the vitamins and minerals in dairy products are bioavailable (i.e., they can be readily absorbed and utilized by the body). Furthermore, yogurt is easier to digest than milk and is often tolerated by individuals, including children, who are lactose intolerant or allergic to milk proteins (Chandan et al., 2017). To further enhance its health benefits, yogurt has been fortified with calcium, vitamins, fiber, and natural extracts from plants and animals. The addition of plant polyphenols, in particular, has been shown to significantly increase its antioxidant activity (Ahmad et al., 2023). Sweet potatoes (*Ipomoea batatas* L.), belonging to the family *Convolvulaceae*, are the world's sixth most important food crop after sugar cane, maize, rice, wheat, and oil palm fruit, and the fourth most important crop in tropical regions (FAOSTAT, 2023). Compared to other staple crops, sweet potatoes offer several advantages: wide cultivation adaptability, resilience to marginal conditions, a short growing cycle, high nutritional value, and a wide variety of flesh colors, flavors, and textures that contribute to sensory diversity (Ahmad et al., 2023). Sweet potatoes are a critical tuber crop for global food and nutritional security, being rich in starch, beta-carotene, anthocyanins, and micronutrients. They are low in calories and fat but high in fiber, complex carbohydrates, and a range of essential nutrients such as vitamin A, potassium, and vitamin C. These attributes make sweet potatoes highly beneficial for improving food security and creating economic opportunities, particularly for underprivileged communities. Sweet potatoes are also known for their therapeutic and nutraceutical properties, including promoting digestive regularity, supporting cardiovascular health, protecting vision, and reducing the risk of cancer and oxidative damage (Pati et al., 2021; Bhuyan et al., 2022). The main objective of this study was to investigate the effect of incorporating various forms of sweet potato into yogurt on its physicochemical, microbiological, rheological, and organoleptic properties during a cold storage period of 15 days at 5°C.

2. Materials and methods

Materials

Fresh buffalo skim milk (9.11% total solids, 0.4% fat) and fresh cream were obtained from the Dairy Technology Unit, Faculty of Agriculture, Cairo University. The milk was standardized to 3% fat. Skimmed milk powder (SMP) (96% total solids, 1% fat, 35% protein, 52% lactose, and 7.8% ash) from Finland was procured from Master Trade Company, Egypt. Orange-fleshed sweet potato tubers were obtained from the Horticulture Research Institute, Agricultural Research Center, Giza, Egypt. A freeze-dried starter culture (FD-DVS YC-X11), containing *Lactobacillus delbrueckii* ssp. *bulgaricus* and *Streptococcus thermophilus*, was purchased from Chr. Hansen A/S, DK-2970 Horsholm, Denmark. Gelatin was obtained from Misr Food Additives (MIFAD) Company, Badr City, Egypt. Citric acid was purchased from El-Gomhoria Company, Cairo, Egypt, while sugar and glucose were obtained from the local market.

Methods

Preparation of Sweet Potato Powder, Purée, and Pieces

Orange-fleshed sweet potato tubers (25.37% total solids, 0.1% fat, 1.58% protein, 19.25% available carbohydrates, 1.61% ash, 2.83% fiber, and 9.25 mg/100g β-carotene) were washed with running water, drained, and divided into three preparations as follows:

Sweet Potato Powder (SPo)

The sweet potatoes were sliced into 3 mm-thick slices and dried in a ventilated oven (Fisher Scientific Model 230, U.S.A.) at 60°C until constant weight was achieved. The dried slices were milled into a fine powder using a Qudrumant senior laboratory mill. The resulting powder contained 94.23% total solids, 0.6% fat, 3.76% protein, 80.09% available carbohydrates, 3.91% ash, 5.87% fiber, and 10.75mg/100g β-carotene.

Sweet Potato Purée (SPu)

Sweet potatoes were diced into small cubes, steamed in a colander while stirring occasionally until fully cooked, and then mashed into a purée. The purée had the following composition: 23.79% total solids, 0.2% fat, 1.37% protein, 18.12% available carbohydrates, 1.48% ash, 2.62% fiber, and 8.59mg/100g β-carotene.

Sweet Potato Pieces (SPp)

Sweet potato purée or powder was added to a sugar syrup (75% sucrose:25% glucose) containing 0.2% citric acid. The mixture was divided into two parts: one without gelatin (saccharified sweet potato) and the other with 9% gelatin (jelly sweet potato), prepared following GMIA (2012). The mixture was heated to a concentration of 68% ± 1, poured into molds, and left to cool until fully set.

Preparation of Yogurt

Yogurt was prepared following the method of Tamime and Robinson (2007), with slight modifications. Six types of buffalo yogurt were formulated as follows:

- C (Control): 3.5% skimmed milk powder
- T1: 3.5% sweet potato powder
- T2, T3: 5% small pieces of sweet potato purée without/with gelatin, respectively
- T4, T5: 5% small pieces of sweet potato powder without/with gelatin, respectively.

For samples C and T1, standardized milk was blended with SMP or sweet potato powder, homogenized, heat-treated at 90°C for 5min., and cooled to 43°C. For samples T2–T5, sweet potato pieces (purée or powder, with or without gelatin) were added to the milk after heat treatment and cooling to 42°C. All mixtures were inoculated with 0.04% DVS starter culture, mixed well, and packed into 100 mL plastic cups. The cups were incubated at 42°C for 3–4 hours until complete coagulation occurred, then stored at 4±2°C for two weeks. This experiment was conducted in triplicate. The average total solids of the yogurt samples ranged from 15.34% to 15.65%.

Physicochemical Analysis

Moisture, fat, total nitrogen, ash, and titratable acidity were determined according to the AOAC (2019) official methods. The pH value was measured using a Hanna digital pH meter equipped with a glass electrode. Acetaldehyde and diacetyl contents (μmol/100g) were determined following the methods described by Lees and Jago (1969 and 1970), respectively. β-Carotenoid content was measured using a Jenway™ 6705 UV-Vis Spectrophotometer at 450nm according to the method of Rodriguez-Amaya and Kimura (2004). Carbohydrate content in all samples was calculated using the formula described by James (1995):

% Carbohydrates = 100 – (% fat+% protein+% ash+% fiber +% moisture).

Determination of Total Phenol Content (TPC) and Antioxidant Activity (AA%)

Total phenolic content (TPC) was determined through the Folin–Ciocalteu assay, following the protocol of Kupina et al. (2019). Absorbance was recorded at 765nm and compared to a gallic acid calibration curve. The results were expressed as milligrams of gallic acid equivalents (GAE) per 100grams of sample. Antioxidant activity (AA%) was assessed using the DPPH (2,2-diphenyl-1-picrylhydrazyl) free radical scavenging method, as described by Brand-Williams et al. (1995). In this procedure, 1mL of 0.01% methanolic DPPH solution was added to the sample extract. After a 30 min. incubation at ambient temperature, absorbance was measured at 517nm using a Jenway spectrophotometer. The inhibition percentage was calculated using the following equation:

% Inhibition = A control 517- A sample 517/A control 517 ×100.

Microbiological Analysis

Streptococcus thermophilus and *Lactobacillus delbrueckii* ssp. *bulgaricus* counts were determined using M17 agar and MRS agar, respectively, following Dave and Shah (1996). Molds and yeasts were enumerated according to APHA (1994), and coliform bacteria were determined using Violet Red Bile Agar (VRBA) as per the method of Atlas (2004).

Measurement of Syneresis and Viscosity (cp)

Syneresis was assessed using the method described by Celik and Temiz (2020). Twenty grams of yogurt were centrifuged at 3000rpm for 10 minutes, and syneresis was expressed as the weight of separated whey per 100g of yogurt. Viscosity was measured at 25°C using a Brookfield DVNext viscometer with spindle No. 4 at 20 rpm.

Two hundred milliliters of yogurt sample were used, and viscosity was recorded in centipoise (cp) according to Gassem and Frank (1991).

Texture Profile Analysis (TPA)

Texture analysis was performed using a Universal Testing Machine (TMS-Pro) connected to a computer running the Texture Pro™ texture analysis software (Program: DEV TPA withhold). The texture parameters were calculated based on the method described by Bourne (2002).

Sensory Evaluation

A trained panel composed of staff members from the Dairy Technology and Horticultural Crops Technology Departments, Food Technology Research Institute, Giza, Egypt, was selected for the sensory evaluation. The yogurt samples were evaluated for appearance, color, texture, odor, taste and overall acceptability using a nine-point hedonic scale, where 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely, as described by Lim (2011).

Statistical Analysis

All data (mean of three replicates) were subjected to statistical analysis using the Statistical Analysis System (SAS) software, version 2004 (SAS Institute Inc., Cary, North Carolina, USA). Analysis of variance (ANOVA) and Duncan's multiple range test were used to evaluate significant differences among means. A significance level of $p < 0.05$ was used for all statistical tests.

3. Results and Discussions

Physicochemical analyses

The titratable acidity (TA%) and pH value

The two critical physicochemical factors influencing the shelf life of fermented dairy products are titratable acidity (TA%) and pH. Data presented in Table 1 show the changes in TA (%) and pH values of yogurt samples during cold storage at 5°C over a 15-day period. A slight but statistically significant difference ($p < 0.05$) was observed among the yogurt treatments. Plain yogurt exhibited the lowest TA (%) and the highest pH values throughout the storage period compared to the other samples. The increased TA (%) values in yogurt samples containing sweet potato may be attributed to the presence of growth-promoting compounds such as starches and simple sugars in sweet potato, which likely enhance the metabolic activity of the starter culture, resulting in higher lactic acid production and, consequently, a greater reduction in pH. As expected, prolonging the cold storage period led to a slight increase in TA (%) and a corresponding, statistically significant ($p < 0.05$) decrease in pH across all treatments. These findings align with those of Januario et al. (2017), who reported that the availability of extractable sugars and nutrients promotes microbial growth, leading to increased production of lactic acid by lactic acid bacteria (LAB). Notably, in prebiotic yogurt fortified with sweet potato, the elevated acidity did not adversely affect LAB viability. Therefore, it can be concluded that the extended storage duration resulted in a minor increase in acidity and a slight decrease in pH.

The main aromatic compound (acetaldehyde and diacetyl)

The primary aromatic compounds in yogurt ac etaldehyde and diacetylare presented in Table 2. Regarding acetaldehyde content, the results show that its variation among yogurt samples as a function of sweet potato addition was slightly significant ($p > 0.05$). Notably, the control sample (C) exhibited the lowest concentration of acetaldehyde compared to the flavored yogurt treatments. During the cold storage period, a gradual and statistically significant decrease ($p < 0.05$) in acetaldehyde levels was observed in all samples. These findings align with those of Beshkova et al. (1998), who reported that the maximum concentration of acetaldehyde was reached after 22 hours of incubation and then declined up to 168 hours in yogurt prepared with mixed cultures of *Streptococcus thermophilus* and *Lactobacillus delbrueckii* ssp. *bulgaricus*. As for diacetyl content, statistical analysis indicated that the flavored yogurt samples had slightly higher diacetyl levels compared to the control. Over the course of storage, diacetyl content increased during the first week, followed by a gradual decline thereafter. This pattern is consistent with observations by Beshkova et al. (1998), who noted that *L. bulgaricus* alone or in mixed cultures produced diacetyl actively during acidification and refrigerated storage, unlike *Streptococcus* cultures.

Importantly, the addition of sweet potato in its different forms had no significant effect on changes in acetaldehyde or diacetyl content, indicating that sweet potato did not alter the aroma-producing capacity of the yogurt starter cultures.

Table 1. Titratable acidity (%) and pH value of flavored yogurt fortified with different kind of sweet potato during cold storage period at 5° C.

Cold storage period (days)	Sample					
	C	T_1	T_2	T_3	T_4	T_5
			Titratable acidity (%)			
1	$0.76^{b,b}$	$0.81^{a,a}$	$0.84^{a,a}$	$0.83^{a,a}$	$0.85^{a,a}$	$0.82^{a,a}$
8	$0.80^{b,ab}$	$0.83^{a,ab}$	$0.87^{a,ab}$	$0.87^{a,ab}$	$0.89^{a,ab}$	$0.90^{a,ab}$
15	$0.85^{b,b}$	$0.89^{a,b}$	$0.93^{a,b}$	$0.96^{a,}$	$0.99^{a,b}$	$1.02^{a,b}$
			pH value			
1	$4.71^{a,a}$	$4.64^{b,a}$	$4.60^{b,a}$	$4.61^{b,a}$	$4.60^{b,a}$	$4.59^{b,a}$
8	$4.62^{a,ab}$	$4.53^{b,ab}$	$4.54^{b,ab}$	$4.52^{b,ab}$	$4.51^{b,ab}$	$4.46^{b,ab}$
15	$4.48^{a,b}$	$4.44^{b,b}$	$4.41^{b,b}$	$4.40^{b,b}$	$4.40^{b,b}$	$4.39^{b,b}$

The letters before comma possess the factor of the kind of sweet potato. While those after comma possess storage period. The means with the same letter at any position were not significantly different (P>0.05). C: plain yoghurt, T_1: yogurt with sweet potato powder, T_2: yogurt with sweet potato puree without gelatin, T_3: yogurt with sweet potato puree with gelatin, T_4: yogurt with sweet potato powder without gelatin, T_5: yogurt with sweet potato powder with gelatin.

Table 2. Acetaldehyde and Diacetyl (µg/100g) of flavored yogurt fortified with different kind of sweet potato during cold storage period at 5° C.

Cold storage period (days)	Sample					
	C	T_1	T_2	T_3	T_4	T_5
			Acetaldehyde			
1	$360.2^{b,a}$	$362.2^{b,a}$	$370.6^{a,a}$	$382.6^{a,a}$	$380.4^{a,a}$	$385.5^{a,a}$
8	$328.0^{b,ab}$	$330.6^{b,ab}$	$344.4^{a,ab}$	$343.7^{a,ab}$	$356.3^{a,ab}$	$362.0^{a,ab}$
15	$288.2^{b,b}$	$297.0^{b,b}$	$307.8^{a,b}$	$300.4^{a,b}$	$312.6^{a,b}$	$314.7^{a,b}$
			Diacetyl			
1	$16.92^{b,b}$	$17.14^{b,b}$	$17.48^{a,b}$	$17.54^{a,b}$	$17.87^{a,b}$	$18.03^{a,b}$
8	$19.10^{b,a}$	$19.00^{b,a}$	$19.38^{a,a}$	$19.83^{a,a}$	$19.92^{a,a}$	$19.95^{a,a}$
15	$17.60^{b,ab}$	$17.66^{b,ab}$	$18.06^{a,ab}$	$18.41^{a,ab}$	$18.63^{a,ab}$	$18.88^{a,ab}$

The letters before comma possess the factor of the kind of sweet potato. While those after comma possess storage period. The means with the same letter at any position were not significantly different (P>0.05). C: plain yoghurt, T_1: yogurt with sweet potato powder, T_2: yogurt with sweet potato puree without gelatin, T_3: yogurt with sweet potato puree with gelatin, T_4: yogurt with sweet potato powder without gelatin, T_5: yogurt with sweet potato powder with gelatin

Total phenolic content (TPC) and antioxidant activity (%)

The total polyphenol content (TPC) in the control yogurt was 8.6mg GAE/100g as shown in Table 3. These phenolic compounds (PCs) are naturally present in buffalo's milk and may originate from the animal's feed and/or from amino acid catabolism, as reported by Niero et al. (2018). Previous studies have shown that sweet potatoes are a rich source of polyphenols, with an average TPC of approximately 0.472mg GAE/g fresh weight (Teow et al., 2007). The incorporation of sweet potato into yogurt significantly increased the polyphenol content ($p < 0.05$), reaching a maximum of 22.64mg GAE/100g in treatment T5, compared to the control. Interestingly, yogurt samples enriched with small pieces of sweet potato (puree or powder) exhibited significantly higher TPC values than yogurt containing only sweet potato powder (T1). This phenomenon may be attributed to the enhanced interaction of phenolic compounds with milk proteins, particularly casein, near its isoelectric point (pH ≈ 4.6), facilitating greater penetration into the casein-gel matrix (Yildirim-Elikoglu and Erdem, 2018). Antioxidant activity (AA%), a critical biological function in protecting against oxidative stress and related disorders (e.g., cancer, inflammation, hypertension, and neurological diseases), was also notably affected. The results demonstrated that yogurt samples containing small pieces of sweet potato (either puree or powder) had significantly higher AA% than both the control yogurt and the yogurt containing only sweet potato powder (T1). This may be explained by the enhanced binding of polyphenols to milk proteins in the blended sweet potato powder sample (T1), which reduces their antioxidant capacity. In contrast, adding small sweet potato pieces likely preserved more free polyphenols, thereby maintaining higher antioxidant activity. These findings are consistent with previous research indicating that protein polyphenol interactions can diminish the antioxidant capacity of polyphenols (Trigueros et al., 2014; Yildirim Elikoglu and Erdem, 2018). Overall, both TPC and AA% values showed a declining trend during cold storage, in agreement with observations by Cho et al. (2017).

Table 3. The total phenolic contents (TPC) and antioxidant activity (AA %) of flavored yogurt fortified with different kind of sweet potato during cold storage period at 5°C.

Cold storage period (days)	Sample					
	C	T_1	T_2	T_3	T_4	T_5
			TPC (µg/100g)			
1	$8.6^{b,a}$	$20.56^{ab,a}$	$21.87^{a,a}$	$22.16^{a,a}$	$22.20^{a,a}$	$22.34^{a,a}$
8	$7.91^{b,b}$	$19.21^{ab,b}$	$20.72^{a,b}$	$21.10^{a,b}$	$21.52^{a,b}$	$21.70^{a,b}$
15	$6.95^{b,c}$	$17.82^{ab,c}$	$19.26^{a,c}$	$19.60^{a,c}$	$19.77^{a,c}$	$20.18^{a,c}$
			DPPH (%)			
1	$23.64^{b,a}$	$25.10^{ab,a}$	$25.86^{a,a}$	$26.00^{a,a}$	$26.24^{a,a}$	$26.32^{a,a}$
8	$21.32^{b,b}$	$22.87^{ab,b}$	$22.94^{a,b}$	$23.23^{a,b}$	$23.48^{a,b}$	$24.57^{a,b}$
15	$15.65^{b,c}$	$17.19^{ab,c}$	$19.67^{a,c}$	$20.40^{a,c}$	$20.80^{a,c}$	$21.53^{a,c}$

The letters before comma possess the factor of the kind of sweet potato. While those after comma possess storage period. The means with the same letter at any position were not significantly different (P>0.05). C: plain yoghurt, T_1: yogurt with sweet potato powder, T_2: yogurt with sweet potato puree without gelatin, T_3: yogurt with sweet potato puree with gelatin, T_4: yogurt with sweet potato powder without gelatin, T_5: yogurt with sweet potato powder with gelatin

Microbiological analysis

Table 4 presents the bacterial counts (log cfu/mL) of *Streptococcus thermophilus* and *Lactobacillus delbrueckii* ssp. *bulgaricus* in yogurt samples during cold storage at 5 °C for 15 days. It was observed that the addition of sweet potato pieces (either puree or powder) resulted in slightly higher ($p < 0.05$) viable counts of lactic acid bacteria (LAB) compared to the plain yogurt. However, no significant difference ($p > 0.05$) was found between the LAB counts in plain yogurt (C) and yogurt fortified with sweet potato powder alone (T1). Additionally, in all treatments, the population of *Str. thermophilus* was consistently higher than that of *Lb. delbrueckii* ssp. *bulgaricus*. This observation is in agreement with Rasic and Kurmann (1978), who noted that during the initial stages of lactic acid fermentation, *Str. thermophilus* multiplies rapidly and typically outnumbers *Lb. delbrueckii* ssp. *bulgaricus* by three- to four-fold within the first hour. Notably, the incorporation of sweet potato did not inhibit LAB growth; on the contrary, it appeared to support and enhance microbial viability throughout the 7-day incubation and storage period. This enhancement is likely due to the availability of oligosaccharides and fermentable carbohydrates in sweet potatoes, which act as prebiotic growth substrates for LAB. These findings are consistent with those of Januario et al. (2017), who reported that the increased acidity in sweet potato–fortified prebiotic yogurt did not negatively impact LAB viability. Furthermore, no coliforms, yeasts, or molds were detected in any of the yogurt samples, whether fresh or stored. This absence of spoilage organisms could be attributed to the inhibitory effects of LAB, which produce organic acids and antimicrobial substances, as well as the stringent hygienic practices followed during the yogurt production process.

Rheological profile (viscosity and syneresis rate)

Viscosity and syneresis are among the most critical parameters influencing yogurt quality during storage. As shown in Table 5, the incorporation of sweet potato led to significant differences ($p < 0.01$) in the viscosity and syneresis of yogurt samples during cold storage. Among all treatments, yogurt containing sweet potato powder alone (T1) exhibited the lowest viscosity values and the highest syneresis rate. This may be attributed to the modification of the casein network structure due to heat-induced interactions with carbohydrates in sweet potatoes particularly amylose and amylopectin. These components may have disrupted the integrity of the gel matrix, resulting in a more open structure and reduced viscosity. These findings are in agreement with Yang et al. (2025), who reported that high temperatures accelerate starch gelatinization by breaking crystalline regions, and excessive heating can degrade starch molecules, reducing their gel strength and viscosity. In contrast, yogurt treatments fortified with sweet potato pieces (puree or powder) with or without gelatin showed increased viscosity and reduced syneresis compared to the plain yogurt. The treatments containing small pieces of sweet potato, particularly in combination with gelatin, exhibited the highest viscosity values and lowest syneresis rates. This effect may be due to the enhanced interaction between sweet potato particles and casein proteins during the blending and heat treatment processes, which likely improved the structural integrity of the gel matrix. Furthermore, the rheological properties of all yogurt samples improved over the 15-day cold storage period. This could be due to the progressive acidification, which strengthens the protein network. These findings align with those of Walstra et al. (2006), who explained that structural reorganization within the casein network during storage enhances particle–particle interactions and reduces syneresis. As the protein matrix contracts, interstitial fluid is expelled, though syneresis remains an undesirable defect in yogurt products.

Table 4. Counts of *Streptococcus thermophilus* and *Lactobacillus delbrueckii* ssp. *bulgaricus* (log cfu / ml) of flavored yogurt fortified with different kind of sweet potato during cold storage period at 5°C.

Cold storage period (days)	Sample					
	C	T_1	T_2	T_3	T_4	T_5
	Streptococcus thermophiles					
1	$7.27^{b,a}$	$7.31^{b,a}$	$7.72^{ab,a}$	$7.86^{ab,a}$	$7.90^{a,a}$	$7.98^{a,a}$
8	$7.33^{b,a}$	$7.40^{b,a}$	$7.75^{ab,a}$	$7.91^{ab,a}$	$7.95^{ab,a}$	$8.02^{a,a}$
15	$6.98^{b,b}$	$7.02^{b,b}$	$7.41^{ab,b}$	$7.50^{ab,b}$	$7.61^{ab,b}$	$7.65^{a,b}$
	Lactobacillus delbrueckii ssp. *bulgaricus*					
1	$7.58^{b,a}$	$7.61^{b,a}$	$7.59^{ab,a}$	$7.63^{ab,a}$	$7.66^{ab,a}$	$7.67^{a,a}$
8	$7.29^{b,b}$	$7.30^{b,b}$	$7.34^{ab,b}$	$7.39^{ab,b}$	$7.40^{ab,b}$	$7.45^{a,b}$
15	$6.63^{b,c}$	$6.67^{b,c}$	$6.88^{ab,c}$	$6.96^{ab,c}$	$7.08^{ab,c}$	$7.11^{a,c}$

The letters before comma possess the factor of the kind of sweet potato. While those after comma possess storage period. The means with the same letter at any position were not significantly different (P>0.05). C: plain yoghurt, T_1: yogurt with sweet potato powder, T_2: yogurt with sweet potato puree without gelatin, T_3: yogurt with sweet potato puree with gelatin, T_4: yogurt with sweet potato powder without gelatin, T_5: yogurt with sweet potato powder with gelatin.

Table 5. viscosity (cp) and syneresis (%) of flavored yogurt fortified with different kind of sweet potato during cold storage period at 5°C.

Cold storage period (days)	Sample					
	C	T_1	T_2	T_3	T_4	T_5
	Viscosity (cp)					
1	$901^{b,c}$	$872^{c,c}$	$1132^{ab,c}$	$1172^{a,c}$	$1190^{a,c}$	$1198^{a,c}$
8	$1054^{b,b}$	$990^{c,b}$	$1236^{ab,b}$	$1263^{a,b}$	$1292^{a,b}$	$1310^{a,b}$
15	$1178^{b,a}$	$1089^{c,a}$	$1361^{ab,a}$	$1422^{a,a}$	$1416^{a,a}$	$1479^{a,a}$
	Syneresis (%)					
1	$12.39^{ab,a}$	$12.90^{a,a}$	$11.80^{b,a}$	$10.97^{bc,a}$	$11.38^{bc,a}$	$10.81^{c,a}$
8	$11.74^{ab,ab}$	$11.98^{a,ab}$	$11.23^{b,ab}$	$10.52^{bc,ab}$	$10.95^{bc,ab}$	$10.03^{c,ab}$
15	$11.50^{ab,b}$	$11.90^{a,b}$	$11.00^{b,b}$	$10.32^{bc,b}$	$10.81^{bc,b}$	$9.94^{c,b}$

The letters before comma possess the factor of the kind of sweet potato. While those after comma possess storage period. The means with the same letter at any position were not significantly different (P>0.05). C: plain yoghurt, T_1: yogurt with sweet potato powder, T_2: yogurt with sweet potato puree without gelatin, T_3: yogurt with sweet potato puree with gelatin, T_4: yogurt with sweet potato powder without gelatin, T_5: yogurt with sweet potato powder with gelatin.

Texture profile analysis (TPA)

Texture profile analysis (TPA) results comprising parameters such as hardness, adhesiveness, cohesiveness, springiness, and gumminess for various yogurt samples are presented in Table 6. The data indicate that the addition of sweet potato powder (SPo) to milk-based yogurt resulted in significantly lower ($p < 0.05$) values for hardness and gumminess, suggesting a softer and less gummy texture. In contrast, the values for adhesiveness, cohesiveness, and springiness were generally increased. This behavior may be attributed to the high water-holding capacity of sweet potatoes, which influences the gel matrix by enhancing moisture retention and weakening the protein-protein interactions, thereby softening the texture. On the other hand, the addition of sweet potato in the form of pieces (pureed or powdered) led to significantly higher ($p < 0.05$) values for hardness and gumminess, indicating a firmer and more compact gel structure. Meanwhile, the values of cohesiveness, adhesiveness, and springiness were generally reduced in these treatments. This phenomenon can be explained by the formation of a composite gel matrix composed of casein and sweet potato components, which reinforces the gel structure, especially when gelatin is also incorporated. The inclusion of sweet potato pieces likely promotes denser protein–polysaccharide interactions, resulting in a stronger texture. These observations are consistent with findings by Januario et al. (2017), who reported that the incorporation of plant-based materials can modify the microstructure of yogurt, depending on the form and composition of the added ingredients.

Table 6. texture attributes of flavored yogurt fortified with different kind of sweet potato during cold storage period at 5°C.

Cold storage period (days)	Sample					
	C	T_1	T_2	T_3	T_4	T_5
Hardness (N)						
1	$6.1^{b,b}$	$4.2^{c,b}$	$7.7^{ab,b}$	$9.2^{a,b}$	$9.0^{a,b}$	$9.2^{a,b}$
8	$6.2^{b,b}$	$4.3^{c,b}$	$8.0^{ab,b}$	$9.4^{a,b}$	$9.2^{a,b}$	$9.4^{a,b}$
15	$6.2^{b,a}$	$4.3^{c,a}$	$10.4^{ab,a}$	$10.7^{a,a}$	$10.7^{a,a}$	$11.4^{a,a}$
Adhesiveness						
1	$3.05^{a,a}$	$1.28^{b,a}$	$2.58^{ab,a}$	$2.55^{ab,a}$	$2.19^{ab,a}$	$1.34^{b,a}$
8	$3.05^{a,a}$	$1.28^{b,a}$	$2.56^{ab,a}$	$2.09^{ab,a}$	$2.00^{ab,a}$	$1.34^{b,a}$
15	$3.05^{a,a}$	$1.20^{b,a}$	$1.43^{ab,a}$	$1.23^{ab,a}$	$1.30^{ab,a}$	$1.29^{b,a}$
Cohesiveness						
1	$0.52^{ab,a}$	$0.87^{a,a}$	$0.42^{b,a}$	$0.50^{ab,a}$	$0.41^{b,a}$	$0.58^{ab,a}$
8	$0.52^{ab,a}$	$0.87^{a,a}$	$0.41^{b,a}$	$0.49^{ab,a}$	$0.41^{b,a}$	$0.57^{ab,a}$
15	$0.50^{ab,a}$	$0.84^{a,a}$	$0.39^{b,a}$	$0.39^{ab,a}$	$0.40^{b,a}$	$0.38^{ab,a}$
Springiness (mm)						
1	$19.29^{a,a}$	$19.39^{a,a}$	$13.90^{b,a}$	$14.73^{b,a}$	$14.60^{b,a}$	$14.72^{b,a}$
8	$19.28^{a,a}$	$19.38^{a,a}$	$13.90^{b,a}$	$14.72^{b,a}$	$14.00^{b,a}$	$14.72^{b,a}$
15	$19.28^{a,b}$	$19.38^{a,b}$	$10.59^{b,b}$	$10.60^{b,a}$	$10.60^{b,b}$	$10.60^{b,b}$
Gumminess (N)						
1	$3.3^{b,a}$	$3.3^{b,a}$	$3.7^{ab,a}$	$4.7^{ab,a}$	$3.9^{b,a}$	$5.5^{a,a}$
8	$3.3^{b,a}$	$3.3^{b,a}$	$3.7^{ab,a}$	$4.6^{ab,a}$	$3.9^{b,a}$	$4.6^{a,a}$
15	$3.3^{b,a}$	$3.2^{b,a}$	$3.7^{ab,a}$	$4.1^{ab,a}$	$4.0^{b,a}$	$4.2^{a,a}$

The letters before comma possess the factor of the kind of sweet potato. While those after comma possess storage period. The means with the same letter at any position were not significantly different (P>0.05). C: plain yoghurt, T_1: yogurt with sweet potato powder, T_2: yogurt with sweet potato puree without gelatin, T_3: yogurt with sweet potato puree with gelatin, T_4: yogurt with sweet potato powder without gelatin, T_5: yogurt with sweet potato powder with gelatin

Sensory evaluation

Sensory evaluation results for the yogurt samples covering color and appearance, taste and odor, texture, and overall acceptability are presented in Table 7. The findings revealed that yogurt formulated with sweet potato powder (T1) received the lowest sensory scores across most attributes, particularly in color and appearance, texture, and overall acceptability. Panelists showed a preference for yogurt with a brighter color and more appealing appearance, which was significantly influenced by the form of sweet potato used and showed changes over the cold storage period. Sweet potatoes naturally contribute a sweet flavor and creamy mouthfeel to yogurt due to their high carbohydrate content. However, when incorporated as powder (T1), they appear to reduce yogurt viscosity, resulting in a softer texture that was less preferred by panelists. In contrast, yogurt samples containing small pieces of sweet potato, either pureed or powdered, generally received higher sensory ratings, suggesting that the texture and flavor were more acceptable in these formulations. Except for T1, all yogurt formulations received acceptance scores above 6.5 across all sensory parameters, indicating general acceptability and a positive perception by the panelists. This suggests that incorporating small pieces of sweet potato without the need for additional thickening agents or flavor enhancers can produce yogurt with satisfactory sensory characteristics. Notably, the yogurt sample prepared with sweet potato powder pieces and gelatin (T5) achieved the highest overall acceptability score, indicating it was the most preferred by the panel. Sensory attributes for all yogurt samples remained stable ($p < 0.05$) until day 8 of cold storage, after which a gradual decline in sensory scores was observed. Despite being slightly sweeter than plain yogurt, all flavored samples exhibited comparable overall acceptability, which is in line with previous findings by Januario et al. (2017).

Table 7. Mean sensory score of flavored yogurt fortified with different kind of sweet potato during cold storage period at 5° C.

Cold storage period (days)	Sample					
	C	T_1	T_2	T_3	T_4	T_5
Color and Appearance						
1	$8.30^{a,a}$	$7.68^{b,a}$	$8.18^{a,a}$	$8.23^{a,a}$	$8.20^{a,a}$	$8.28^{a,a}$
8	$8.28^{a,a}$	$7.50^{b,a}$	$8.00^{a,a}$	$8.19^{a,a}$	$8.11^{a,a}$	$8.23^{a,a}$
15	$8.07^{a,b}$	$7.13^{b,b}$	$7.80^{a,b}$	$8.00^{a,b}$	$7.88^{a,b}$	$8.01^{a,b}$
Taste and Odor						
1	$8.34^{a,a}$	$7.86^{b,a}$	$8.20^{a,a}$	$8.35^{a,a}$	$8.32^{a,a}$	$8.42^{a,a}$
8	$7.79^{a,a}$	$6.85^{b,a}$	$8.14^{a,a}$	$8.26^{a,a}$	$8.27^{a,a}$	$8.36^{a,a}$
15	$7.28^{a,b}$	$6.53^{b,b}$	$7.99^{a,b}$	$8.17^{a,b}$	$8.20^{a,b}$	$8.22^{a,b}$
Texture						
1	$8.18^{a,a}$	$7.05^{b,a}$	$8.15^{a,a}$	$8.32^{a,a}$	$8.30^{a,a}$	$8.37^{a,a}$
8	$7.95^{a,a}$	$6.80^{b,a}$	$8.00^{a,a}$	$8.28^{a,a}$	$8.22^{a,a}$	$8.30^{a,a}$
15	$7.51^{a,b}$	$6.32^{b,b}$	$7.63^{a,b}$	$7.80^{a,b}$	$7.67^{a,b}$	$7.81^{a,b}$
Overall Acceptability						
1	$8.18^{ab,a}$	$6.52^{b,a}$	$7.96^{ab,a}$	$8.15^{ab,a}$	$8.06^{ab,a}$	$8.26^{a,a}$
8	$8.00^{ab,a}$	$6.44^{b,a}$	$7.85^{ab,a}$	$8.05^{ab,a}$	$7.92^{ab,a}$	$8.13^{a,a}$
15	$7.83^{ab,b}$	$6.31^{b,b}$	$7.80^{ab,b}$	$7.90^{ab,b}$	$7.74^{ab,b}$	$8.01^{a,b}$

The letters before comma possess the factor of the kind of sweet potato. While those after comma possess storage period. The means with the same letter at any position were not significantly different ($P>0.05$). C: plain yoghurt, T_1: yogurt with sweet potato powder, T_2: yogurt with sweet potato puree without gelatin, T_3: yogurt with sweet potato puree with gelatin, T_4: yogurt with sweet potato powder without gelatin, T_5: yogurt with sweet potato powder with gelatin.

4. Conclusion

Two types of yogurt enriched with sweet potato pieces either as puree or powder, particularly when combined with gelatin were successfully developed in this study, demonstrating superior physicochemical, microbiological, and sensory attributes compared to the control. Additionally, the viability of lactic acid bacteria (LAB) and their antioxidant activity were significantly enhanced in the flavored yogurt formulations, suggesting that sweet potato incorporation may positively influence both the functional and nutritional profile of yogurt. The results suggest that sweet potato -enriched yogurt offers a promising alternative product that could diversify consumer choices and potentially boost yogurt consumption, especially among those seeking functional or fortified dairy products. Furthermore, sweet potato powder due to its lower viscosity compared to skim milk powder may be suitable for use in drinkable yogurt formulations. Its thermal stability and functional properties also make it a valuable texture modifier for broader applications in the food industry.

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