



Effects of Basil Seed Mucilage as a Multifunctional Clean-Label Stabilizer on Some Physicochemical, Microbiological and Sensory Properties in Set Yogurt

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Abstract: Set yogurt can develop whey separation and undesirable textural changes during refrigerated storage. This study evaluated basil seed mucilage (BSM) as a clean-label stabilizer in set yogurt, focusing on technological performance and sensory acceptance. Yogurts containing 0, 0.10, 0.20, 0.30, or 0.40% BSM (w/w) were produced in three independent batches and evaluated on days 1, 7, 14, and 21 of storage at 4 ± 1 °C. The mucilage showed a mean Extraction yield of 15.30% and a water-holding capacity of 32.77 g/g across independent extraction batches. Physicochemical composition, syneresis, water-holding capacity, texture, antioxidant properties, microbiological quality, and sensory acceptability were determined, with sensory evaluation performed by 45 untrained panelists. BSM increased total solids, dietary fiber, water-holding capacity, firmness, and antioxidant indices while reducing moisture and syneresis. On day 21, yogurt with 0.40% BSM exhibited higher water-holding capacity (81.54% vs. 64.78%) and lower syneresis (16.31% vs. 31.13%) than the control. It also showed greater firmness (110.85 vs. 87.97 g), total phenolic-reactive content (38.58 vs. 20.80 mg gallic acid equivalents/kg yogurt), 2,2-diphenyl-1-picrylhydrazyl radical-scavenging activity (31.61% vs. 15.98%), and ferric-reducing antioxidant power (200.33 vs. 113.75 $\mu\text{mol Fe}^{2+}$ equivalents/kg yogurt). Yogurt starter counts remained above 7 log CFU/g, while coliforms were not detected. Although 0.40% BSM maximized technological performance, it reduced taste and mouthfeel acceptability. Exploratory correlations among treatment-by-day means were interpreted descriptively rather than causally. Overall, 0.20% BSM provided the most favorable balance between improved stability and sensory acceptance over refrigerated storage.

1. Introduction

Set yogurt contains yoghurt fermented in its final retail container, and the gel is expected to be stable to the end of fermentation, during refrigerated distribution, and during consumption. The quality of the product relies on the establishment of a continuous protein network that holds the aqueous serum phase and also gives it a firm and smooth texture, minimal whey separation, clean acidic taste, and stable appearance [1].

The pH, acidity, syneresis, firmness, and sensory acceptance of the product may change gradually during refrigerated storage, due to post-acidification, casein network structural changes, and redistribution of serum. These modifications render set yogurt a valuable tool to assess stabilizers that affect water immobilization and gel mechanics [2]. The use of hydrocolloids in fermented dairy systems is to raise the viscosity, strengthen serum retention, and minimize visual defects [3]. Minimally processed plant-derived gums and mucilages are increasingly becoming of interest because of their ability to deliver technological functionality while also delivering dietary fiber and bioactive components [4].

For use in the production of set yogurt, a hydrocolloid should be able to reproducibly absorb water when added to milk, be heat stable and acid-tolerant, and be compatible with milk proteins, and yet enhance the stability to the desired degree without causing over-gumminess, adhesiveness, or an unnatural texture. The hydrophilic polysaccharide-rich layer obtained from *Ocimum basilicum* L. seeds after hydration is called basil seed mucilage. It has high swelling and water-binding ability, partial water solubility, and thickening property, which make it suitable for use in high-moisture foods [5-8]. Besides its structural function, basil seed mucilage has been reported to contain phenolic and flavonoid constituents and to exhibit measurable antioxidant and radical-scavenging activity [9, 10]. However, previous basil-seed-gum yogurt research shows that the ingredient can affect the water binding and gel strength [11, 12], and an optimal application level is needed because a higher water binding and gel strength do not necessarily lead to a higher consumer liking [13].

Previous studies have demonstrated that basil seed gum or mucilage can improve selected physicochemical, textural, and sensory properties of yogurt [12, 14]. However, the remaining research gap concerns the concentration-dependent trade-off between technological functionality and consumer acceptance during refrigerated storage. In particular, previous studies have not simultaneously evaluated composition, acidification, serum retention, instrumental texture, antioxidant properties, starter-culture viability, microbiological quality, and sensory acceptance across multiple basil seed mucilage (BSM) concentrations within the same storage experiment. Therefore, the novelty of the present study is not the first application of basil seed mucilage in yogurt, but the integrated evaluation of these responses to determine how BSM concentration influences both technological performance and consumer acceptance throughout refrigerated storage.

Accordingly, this study aimed to evaluate set yogurt containing BSM at 0.00, 0.10, 0.20, 0.30, and 0.40% (w/w) during 21 days of refrigerated storage, with analyses conducted on days 1, 7, 14, and 21. It was hypothesized that intermediate BSM concentrations would enhance water-holding capacity, decrease syneresis, reinforce the yogurt gel, and increase antioxidant activity without significantly decreasing consumer acceptance, whereas the highest concentration would increase adhesiveness and gumminess.

2. Materials and Methods

2.1. Materials

Mucilage was extracted from food-grade sweet basil seeds (*Ocimum basilicum* L.). The seeds were visually uniform, free from insect attack, visible fungal growth, and stored in airtight containers and kept cool and dry until extraction. Yogurt base was fresh pasteurized cow's milk. When necessary, skim milk powder was used to standardize the milk to approximately 1.5% fat and 13% total solids. Within each independent production batch, the same milk and skim milk powder lots were used. No artificial sweetening, flavoring, coloring or preserving added. A commercial direct-vat-set culture of yogurt (*Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus*) was stored and applied following the manufacturer's recommendations. All chemical assay reagents used were analytical grade reagents, such as hydrochloric acid, sodium hydroxide, petroleum ether, methanol, ethanol, Folin-Ciocalteu reagent, gallic acid, 2,2-diphenyl-1-picrylhydrazyl (DPPH), 2,2'-azino-bis(3-

ethylbenzothiazoline-6-sulfonic acid) (ABTS), and other assay-specific reagents. Throughout, water used was de-ionized or distilled water.

2.2. Experimental Design

The experiment was arranged as a 5×4 factorial in a randomized complete-block design, with five BSM concentrations (0.00, 0.10, 0.20, 0.30, and 0.40%, w/w) and four refrigerated-storage periods (1, 7, 14, and 21 days). Three independent yogurt production batches were prepared on separate production days to account for batch-to-batch variation in yogurt manufacture, and each production batch served as a block. All five BSM formulations were produced within each independent batch. Separate yogurt cups were allocated to each treatment $\times$ storage-day combination and to each destructive analysis. Repeated instrumental measurements obtained from the same cup were treated as technical replicates and averaged before statistical analysis; they were not considered independent experimental replicates.

2.3. Extraction of Basil Seed Mucilage

Basil seed mucilage was extracted according to the neutral aqueous extraction method developed previously [5-8]. Dry-cleaned seeds were soaked with deionized water (30 mL/g) and soaked at $50 \pm 1^\circ\text{C}$ for 20 mins with shaking in water bath (100 rpm). The hydrated seeds were mechanically shaken for 30 s, and the mixture was passed through two muslin layers of food grade. The remaining seeds were washed once, and the wash was added to the extract. The clarified mucilage was frozen at -40°C for at least 24 h and then dried in a low-temperature dryer to constant mass. Three separate extraction runs were carried out, and each dried mucilage batch was used in the corresponding yogurt production batch. Until use, the dried mucilage powder was stored at -20°C in airtight, light-protective containers.

2.4. Characterization of Basil Seed Mucilage

The mucilage was extracted independently in three separate extraction runs, and each extraction batch was characterized separately. Laboratory determinations were performed in triplicate as technical replicates, and the three technical readings were averaged to obtain one observation for each independent extraction batch.

2.4.1. Extraction Yield

The extraction yield was calculated using the amount of dried mucilage obtained from the total amount of dry basil seeds used for extraction [5-7]. The dried powder was weighed after being equilibrated in a desiccator.

$$\text{Extraction yield (\%)} = \frac{\text{Mass of dried mucilage (g)}}{\text{Initial mass of basil seeds (g)}} \times 100 \quad (1)$$

2.4.2. Proximate Composition

Moisture, ash, crude protein, and crude fat were measured using validated methods as described in the earlier [15]. Mucilage powder was dried at $105 \pm 2^\circ\text{C}$ until constant weight was reached to determine moisture gravimetrically, and approximately 2.0 g of mucilage powder was used. Ash was determined by incinerating the dry sample at $550 \pm 25^\circ\text{C}$ until the residue was light grey and had a constant mass. Nitrogen was measured using the Kjeldahl procedure [16] and converted to crude protein using a factor of 6.25. Crude fat was extracted using the Soxhlet method with petroleum ether. All composition values are given as-is powders, and dry-basis composition may be reported in addition. Carbohydrate content was determined separately for each replicate of a trial by deducting the values for protein and fat from the total matter obtained. This value represents dietary-fiber polysaccharides and is not to be read as an amount of available carbohydrate.

$$\text{Total carbohydrate (\%)} = 100 - [\text{Moisture (\%)} + \text{Ash (\%)} + \text{Protein (\%)} + \text{Fat (\%)}] \quad (2)$$

2.4.3. Water- and Oil-Holding Capacities

The water-holding capacity (WHC) and oil-holding capacity (OHC) were determined using the centrifugation method described by Hussain *et al.* [7]. The mucilage powder (0.200 g) was weighed, put into a pre-weighed 50-mL centrifuge tube and added to 20.0 mL of distilled water for WHC or density of the refined sunflower oil for OHC. The tubes were vortexed for 30 s, shaken for 60 mins at 25°C, and then centrifuged at $2,500 \times g$ for 30 mins at 25°C. After decanting, the wall of the tube was carefully drained for 5 mins, and the hydrated or oil-bound residue was weighed. A blank sample (water or oil) was processed concurrently.

$$WHC \text{ or } OHC (g/g) = \frac{[\text{Mass of hydrated or oil-bound residue (g)} - \text{dry sample mass (g)}]}{\text{Dry sample mass (g)}} \quad (3)$$

2.4.4. Swelling Capacity

Swelling capacity was determined according to the method described by Neeharika and Vijayalaxmi [16], with minor modifications. Briefly, 1.000 g of mucilage powder was placed in a 50-mL graduated cylinder, and 25.0 mL of distilled water was added. The dispersion was mixed gently to remove dry pockets, covered to avoid evaporation of water, and placed at ambient temperature of $25 \pm 1^\circ\text{C}$ without disturbance. The hydrated volume was measured after 1, 2, 4, 6, and 24 h, and the 24-h value was selected for treatment comparison. Gently tapping the hydrated material without compacting it resulted in the removal of any trapped air.

$$\text{Swelling capacity} \left(\frac{\text{mL}}{\text{g}} \right) = \frac{\text{Hydrated mucilage volume (mL)}}{\text{Dry mucilage mass (g)}} \quad (4)$$

2.4.5. Water Solubility Index

The water solubility index (WSI) was determined according to Neeharika and Vijayalaxmi [16], with minor modifications. Mucilage powder was dispersed in 10.0 mL of distilled water, shaken for 30 mins at 30°C, and centrifuged at $3,000 \times g$ for 15 mins. All the supernatant was transferred to a pre-weighed drying dish and dried to a constant mass at 105°C. Soluble dried solids were weighed after cooling in a desiccator.

$$\text{Water solubility index (\%)} = \frac{\text{Mass of dried supernatant solids (g)}}{\text{Initial dry mucilage mass (g)}} \times 100 \quad (5)$$

2.4.6. Total Phenolic Content

Mucilage powder (0.500 g) was shaken for 60 mins in darkness at room temperature after sonication for 15 min with 80% methanol and centrifuged at $10,000 \times g$ for 10 mins at 4°C to extract phenolics. The above liquor was extracted and kept in amber vials at 4°C for not more than 24 h prior to analysis. The Folin-Ciocalteu method was used to determine the total phenolic content [18]. An extract (0.20 mL) was added to 1.00 mL 10% Folin-Ciocalteu reagent. After 5 mins, 0.80 mL of 7.5% sodium carbonate was added. This was incubated in the dark for 30 mins, and absorbance was measured at 765 nm. A calibration curve was prepared using the validated working range in the same solvent using gallic acid. The results were reported as the mg of gallic acid equivalents per g of dry mucilage (mg GAE/g dry mucilage). A blank containing no Folin-Ciocalteu reagent was used to correct for color and turbidity from mucilage, which is sample specific.

2.4.7. DPPH Radical-Scavenging Activity

DPPH radical-scavenging activity was determined following the method of Brand-Williams *et al.* [19]. A DPPH solution in methanol was freshly prepared and protected from light. The mucilage extract was mixed with DPPH solution at a ratio of 1:39 (v/v), incubated for 30 mins in the dark at room temperature, and the absorbance was measured at 517 nm. The final reaction mixture contained 1.0 mg dry-mucilage equivalent/mL. A DPPH control containing DPPH solution and extraction solvent without

mucilage extract, and a sample blank containing mucilage extract and methanol without DPPH, were prepared concurrently.

$$DPPH \text{ inhibition (\%)} = \frac{1 - (A_{\text{sample}} - A_{\text{blank}})}{A_{\text{control}}} \times 100 \quad (6)$$

where A_{sample} is the absorbance of the DPPH solution containing the mucilage extract, A_{blank} is the absorbance of the mucilage extract without DPPH, and A_{control} is the absorbance of the DPPH solution containing the extraction solvent without mucilage extract. The results were expressed as percentage DPPH inhibition at a dry-mucilage-equivalent concentration of 1.0 mg/mL.

2.5. Experimental Treatments

Five set-yogurt formulations were prepared. BSM concentration was reported as per mass of the final product (w/w) so 0.10% was equivalent to 1.0 g BSM/kg yogurt mix. The amount of final formulation mass, milk fat, milk protein, skim-milk-powder addition, and starter-culture dose was kept constant, and BSM was used to replace an equivalent mass of the standardized milk base (Table 1).

Table 1: Experimental formulations of control and basil seed mucilage-enriched set yogurt.

Treatment	BSM concentration (% w/w)	BSM added (g/kg mix)	Description
Control	0.00	0.0	Set yogurt without BSM
BSM-1	0.10	1.0	Set yogurt containing 0.10% BSM
BSM-2	0.20	2.0	Set yogurt containing 0.20% BSM
BSM-3	0.30	3.0	Set yogurt containing 0.30% BSM
BSM-4	0.40	4.0	Set yogurt containing 0.40% BSM

A preliminary screening trial was performed to validate the range selected for the definitive trial to ensure that the range could be dispersed reproducibly and that the set yogurts had acceptable qualities. The preliminary samples were not used in the final statistical analysis. In the definitive experiment, all five treatments were produced in each independent production batch, thus yielding a randomized complete-block design with the independent production batches as blocks.

2.6. Set-Yogurt Preparation

yogurt was set according to a standardized method modified from published BSG-yogurt research [11, 12]. Milk was standardized to around 1.5% fat and 13% total solids, divided into 5 portions and added with 0-0.40% BSM. The BSM was dry-blended with skim milk powder, then dispersed in milk and mixed under high shear for 2 mins at $45 \pm 2^\circ\text{C}$ before being hydrated for 30 mins with gentle agitation. Control was treated in the same way, except that it was not treated with BSM. Both mixtures were steamed at $90 \pm 1^\circ\text{C}$ for 10 mins, quickly cooled to $43 \pm 1^\circ\text{C}$, and mixed with direct-vat-set starter at the recommended level by the manufacturer, followed by gentle mixing for 1 min.

The inoculated mixtures were all topped with sterile polypropylene cups and incubated at $43 \pm 1^\circ\text{C}$ until pH 4.60 ± 0.05 . The cups were then cooled down to less than 10°C in 1 h and kept at refrigeration temperature ($4 \pm 1^\circ\text{C}$) for 12–18 h prior to the initial analysis. Different unopened cups with the same fill mass, headspace, and shape were assigned to each destructive analysis, treatment, production batch, and storage period.

2.7. Refrigerated Storage and Sampling Schedule

Yogurt cups were kept at $4 \pm 1^\circ\text{C}$ either in the dark or in light protected conditions. A data logger was used to continuously monitor or record the refrigerated temperature at regular time intervals. The 24 ± 2 h after the end of fermentation and cooling was designated as day 1. Storage days 1, 7, 14, and 21 were used for analysis. Samples were only removed from refrigeration immediately before analysis, and the different temperatures/processes required for the different analyses were standardized [20].

2.8. Physicochemical Analyses

All analyses were performed on days 1, 7, 14, and 21 (unless otherwise indicated). Three batches of yogurt that were manufactured independently were used as experimental replicates. Previously unopened cups of each product were allotted to destructive analyses of syneresis, water-holding capacity, texture, microbiology, and antioxidant analyses. Instrumental readings were performed more than once on the same cup and were considered as technical replicates and averaged prior to statistical analysis.

2.9. Chemical Composition

The proximate composition of the yogurt samples was analyzed following standard analytical methods. The total solids were determined by the ISO 13580:2005 [21]. Approximately 5.0 g of the yogurt was placed in a pre-dried dish and dried at $102 \pm 2^\circ\text{C}$ until a constant weight was achieved. The moisture content was determined as follows:

$$\text{Moisture (\%)} = 100 - \text{Total solids (\%)} \quad (7)$$

The protein in the crude protein was analyzed by the Kjeldahl procedure, as described in ISO 8968-1:2014 [16]. The amount of nitrogen was multiplied by the milk-protein conversion factor of 6.38:

$$\text{Protein (\%)} = \text{Nitrogen (\%)} \times 6.38 \quad (8)$$

Fat content was measured using the gravimetric method according to the standard method (ISO 8262-3:2005 [22]). This is an appropriate method for milk products and milk-based foods that include ingredients that can be problematic in direct extraction processes. Ash was determined using the AOAC Official Method 945.46, which involves incinerating the sample in a muffle furnace at $550 \pm 25^\circ\text{C}$ until a light-gray constant mass residue is achieved [23]. The percentages of total carbohydrate were determined by difference:

$$\text{Total carbohydrate (\%)} = 100 - [\text{Moisture} + \text{Protein} + \text{Fat} + \text{Ash}] \quad (9)$$

Dietary fibre was measured separately and available carbohydrate was determined by:

$$\text{Available carbohydrate (\%)} = 100 - [\text{Moisture} + \text{Protein} + \text{Fat} + \text{Ash} + \text{Dietary fiber}] \quad (10)$$

Total dietary fiber was measured using the enzymatic–gravimetric method, as specified by the AOAC Official Method 991.43 [24]. Briefly, the yogurt samples were sequentially treated with heat-stable α -amylase, protease, and amyloglucosidase. Soluble fiber was precipitated with ethanol, and the precipitated residue was adjusted for residual protein and ash. Alternatively, if recovery of low-molecular-weight soluble fiber and/or resistant starch is needed, AOAC Method 2011.25 can be used. Compositional determination was repeated twice for each of the three independent production batches, and the mean of these batches was used to create the statistics.

2.10. PH

The pH of the yogurt samples was measured using a calibrated digital pH meter equipped with a food-penetration combination electrode, following the method described Campos *et al.* [25] with minor modifications. The instrument was calibrated prior to each analytical session with standard buffers at the measurement temperature (pH 4.00 and pH 7.00). Each unopened cup of yogurt was placed in a thermostat-controlled incubator set at $20 \pm 1^\circ\text{C}$, and the electrode was directly inserted into the undisturbed yogurt gel at three positions without stirring. The electrode was washed with distilled water and dried between measurements. The average of the three readings was taken as the pH of the experimental units.

2.11. Titratable Acidity

The titratable acidity was measured following ISO/TS 11869:2012 for fermented milk products, such as yogurt [26]. Carbon-dioxide-free distilled water was added to a 10.00-g sample of yogurt, which was thoroughly stirred, and titrated by adding standardized 0.1000 mol/L sodium hydroxide. The titration was stopped at pH 8.30±0.01 (pH electrode calibrated). The percentage lactic acid was calculated using titratable acidity as follows:

$$\text{Titratable acidity (\% lactic acid)} = \frac{[V \times M \times 90.08 \times 100]}{[m \times 1000]} \quad (11)$$

The volume of sodium hydroxide used (V) is in mL, the molarity of sodium hydroxide (M) is in units of mol/mL, 90.08 is the molecular mass of lactic acid, and m is the mass of the yogurt sample (g). The samples were analyzed for each batch in duplicate.

2.12. Syneresis

Spontaneous syneresis was determined using a standard gravity-drainage method modified from that described by Amatayakul *et al.* [27]. Twenty grams (20.00 g) of undisturbed yogurt was carefully transferred into a glass funnel on Whatman No.1 filter paper. To reduce moisture loss from the funnel, it was covered and kept at 4 ± 1°C for 4 h. The amount of whey collected under the funnel was then measured. The drainage method was chosen to demonstrate spontaneous whey separation without the use of an external centrifugal force. All treatments were carried out under the same conditions, such as the same temperature, sample mass, and drainage time.

$$\text{Syneresis (\%)} = \frac{[\text{Mass of separated whey}]}{[\text{Initial yogurt mass}]} \times 100 \quad (12)$$

Each determination was made from a separate cup of the separate independent batches.

2.13. Water-Holding Capacity

A centrifugation method was used to determine the water-holding capacity. 10.00 g of yogurt sample were placed in a pre-weighed centrifuge tube and centrifuged for 10 mins at 5°C at 5,000 × g. The serum was carefully poured off and weighed. The results were shown as % of water retained in the yogurt gel [28].

$$\text{WHC (\%)} = 1 - \left(\frac{[\text{Mass of expelled serum}]}{[\text{Initial yogurt mass}]} \right) \times 100 \quad (13)$$

The water holding capacity determined by centrifugation is an indication of how much resistance to compaction and forced expulsion of serum the yogurt gel exhibits and thus the amount of relative centrifugal force and temperature applied and the time the samples were centrifuged were kept identical. The relative centrifugal force (× g), not revolutions per minute (RPM), was reported because the force applied is a function of the rotor radius.

2.14. Color Measurement

The instrumental color was determined using a calibrated colorimeter under a D65 illuminant and 10° standard observer in the CIELAB color space. Standard white and black tiles were used to calibrate the instrument prior to measurement. The yogurt samples were examined in the original cups at 10 ± 1°C and at three locations on the surface, avoiding obvious air bubbles and whey pockets. The following coordinates were measured in accordance with ISO/CIE 11664-4:2019 [29]:

L*: lightness, from black to white;

a*: green (–) to red (+);

b*: blue (–) to yellow (+).

Total color difference was calculated relative to the day-1 control yogurt:

$$\Delta E^*ab = \sqrt{[(L^* - L^*_{ref})^2 + (a^* - a^*_{ref})^2 + (b^* - b^*_{ref})^2]} \quad (14)$$

2.15. Apparent Total Soluble Solids

Apparent total soluble solids (ATSS) were measured using a calibrated digital refractometer at 20°C [30]. Clarified serum was used because it was opaque and contained suspended protein and fat particles in the yogurt. This was done by centrifuging approximately 10 g of the yogurt at $5,000 \times g$ for 10 mins at 5°C and adding one or two drops of the serum to the refractometer prism. The results were reported in apparent degrees Brix (°Brix) and interpreted in terms of the relative sugar solids content of the sample.

2.16. Textural Properties

Instrumental textural properties of the set yogurt were evaluated using texture-profile analysis and back-extrusion testing, based on previously reported instrumental methods for yogurt texture characterization [31, 32], with modifications to the test conditions as described below.

2.16.1. Texture-Profile Analysis

Texture profile analysis was carried out at $10 \pm 1^\circ\text{C}$ with a flat-ended cylindrical probe placed in the center of the yogurt [31]. Two compression cycles were performed on samples to 30% of pre-test height at pre-test, test, and posttest speeds of 1.0 mm/s, trigger force of 5 g, and 5 s between cycles. Firmness was defined as the peak positive force from the initial compression, cohesiveness as the ratio of the positive area under the second compression curve to that under the first, and springiness as the recovery of the sample between the two compression cycles. Gumminess was calculated as

$$\text{Gumminess} = \text{Firmness} \times \text{Cohesiveness} \quad (15)$$

2.16.2. Back-Extrusion Test

Consistency and adhesiveness were measured by back extrusion with a disc that was chosen to ensure a constant clearance between the disc and the inside of the cup. The disc was lowered vertically at a speed of 1.0 mm/s in the middle of the yogurt and pulled out at the same rate. The positive area indicated consistency, whereas the negative area indicated adhesiveness during movement down. The positive area indicated consistency, and the negative area indicated adhesiveness during downward movement. All samples underwent the same geometry, penetration depth, speed, and temperature of the sample [33]. Three measurements were taken for each production batch, and the mean was used for each production batch observation.

2.17. Antioxidant Properties

2.17.1. Preparation of Yogurt Extracts

Total phenolic content and antioxidant assays were performed using a common extraction procedure [34]. A 5.00 g yogurt sample was added to 20 mL of 80% methanol. The mixture was homogenized (2 mins), shaken in the dark (30 mins) at room temperature, and centrifuged (10 mins, 4°C , $10,000 \times g$). When necessary, the supernatant was transferred to Whatman No. 1 filter paper and then through a $0.45\text{-}\mu\text{m}$ membrane. Extracts were made fresh before analysis and kept away from light. The same extraction ratio and procedure were used for all treatments to allow valid comparisons. Sample-specific blanks were used to account for turbidity and color from the mucilage of the yogurt and basil seeds.

2.17.2. Total Phenolic Content

The Singleton and Rossi method was used to measure the total phenolic content using the Folin–Ciocalteu method [18]. 0.20 mL of yogurt extract was added to 1.00 mL of 10% Folin–Ciocalteu reagent. At 5 mins 0.80 mL of 7.5% sodium carbonate was added. The mixture was kept in the dark at room temperature for 30 mins, and the absorbance was read at 765 nm. The calibration curve was prepared using gallic acid (0–200 mg/L). Data are reported as mg gallic acid equivalents (GAE)/kg fresh yoghurt:

$$\text{TPC} = (C \times V \times DF)/m \quad (16)$$

where C is the concentration of the gallic-acid-equivalent obtained from the calibration curve, V is the extraction volume, DF is the dilution factor, and m is the mass of the yogurt. The Folin–Ciocalteu result is said to be total phenolic-reactive or reducing capacity because non-phenolic reducing compounds may also react with the reagent.

2.17.3. DPPH Radical-Scavenging Activity

Yogurt extract radical-scavenging activity was determined following the procedure described by Brand-Williams *et al.* with modifications [19]. A 0.10-mL aliquot of yogurt extract was added to 3.90 mL of freshly prepared 0.10 mmol/L DPPH solution in methanol. The reaction mixture was incubated for 30 mins in the dark at room temperature, and the absorbance was read at 517 nm. The following absorbance measurements were obtained:

A-control: absorbance of the DPPH solution containing extraction solvent without yogurt extract;

A-sample: absorbance of the DPPH solution containing yogurt extract;

A-blank: absorbance of the yogurt extract with methanol without DPPH.

The blank-corrected DPPH radical-scavenging activity was calculated as:

$$\text{DPPH inhibition (\%)} = [1 - (A - \text{sample} - A - \text{blank})/A - \text{control}] \times 100 \quad (17)$$

DPPH radical-scavenging activity was reported as blank-corrected percentage inhibition.

2.17.4. ABTS Radical-Cation Scavenging Activity

The radical-cation scavenging activity of ABTS was determined by Re *et al.* [33]. The stock radical solution was prepared by mixing 7.0 mmol/L of ABTS with 2.45 mmol/L of potassium persulfate and leaving it to react in the dark for 12–16 h. The solution was diluted prior to use to obtain an absorbance of 0.700 ± 0.020 at 734 nm. After 6 mins, 3.90 mL of diluted ABTS solution was added to 0.10 mL of yogurt extract, and the absorbance was measured at 734 nm. A sample blank was corrected for the color of yogurt and BSM. The absorbances for the blanks were subtracted, and the blank-corrected absorbances were used to calculate the percentage inhibition.

2.17.5. Ferric-Reducing Antioxidant Power

The measurement methods for ferric-reducing antioxidant power (FRAP) were used by Benzie and Strain [35]. Yogurt extract (0.10 mL) was added to the reagent (acetate buffer, TPTZ solution, FeCl_3 , 10:1:1, v/v/v), which was then heated to 37°C . After 4 mins, the mixture was measured at 593 nm. The results were obtained using a calibration curve with ferrous-sulfate and reported as $\mu\text{mol Fe}^{2+}$ equivalents per kg of yogurt. Three technical readings were taken for each separate batch and then averaged prior to statistical analysis.

2.18. Microbiological Analyses

Microbiological analyses were performed aseptically according to the general requirements of the ISO 7218:2024 [36]. Ten grams (10.0 g) of yogurt was placed in a sterile stomacher bag with 90 mL of sterile 0.1% peptone water or quarter-strength Ringer's solution. The mixture was homogenized for 2 mins, and serial 10-fold dilutions were made with the same diluent.

2.18.1. Enumeration of Characteristic Yogurt Microorganisms

Streptococcus thermophilus and *Lactobacillus delbrueckii* subsp. *bulgaricus* were enumerated according to ISO 7889:2026 [37]. Appropriate decimal dilutions of the yogurt samples were prepared using the diluent described above. *L. delbrueckii* subsp. *bulgaricus* was enumerated on De Man, Rogosa, and Sharpe agar adjusted to pH 5.4 (MRS 5.4), and the plates were incubated anaerobically at 37°C for

72 h. *S. thermophilus* was enumerated on M17 sucrose agar (M17-S), and the plates were incubated under microaerobic conditions at 37°C for 48 h. Colonies showing the characteristic morphology of each organism were counted at appropriate dilution levels, and the results were calculated and expressed as log₁₀ CFU/g of yogurt.

2.18.2. Total Viable Count

The number of aerobic mesophilic microorganisms was determined using Plate Count Agar in accordance with the International Standard ISO 4833-1:2013 and the amendment of the same standard in 2022 [38]. The samples were then diluted to the appropriate level and poured onto plates and incubated at 30°C for 72 h. Log₁₀ CFU/g was used to report results.

2.18.3. Yeast and Mold Count

The number of yeasts and molds was determined according to ISO 21527-1:2008 (products with water activity value > 0.95), including high-moisture dairy products [39]. Dichloran Rose Bengal Chloramphenicol agar or the medium recommended by the adopted standard was used for surface plating, and the plates were then incubated at 25 ± 1°C for approximately 5 days. Counting was performed separately for yeasts and molds if the colony morphology allowed.

2.18.4. Coliform Count

Coliform counts were performed according to ISO 4832:2006 on Violet Red Bile Lactose agar [40]. The plates were in duplicate and allowed to grow for 24 h at 30°C. All presumptive colonies had confirmation when it was required by the standard. The results were presented in log₁₀ CFU/g and below the method detection limit. Values below the detection limit were reported as “not detected” or “<LOD” instead of zero. The detection limit was determined by the minimum dilution and volume plated and inoculated.

2.19. Sensory Evaluation

Consumer acceptance was evaluated according to ISO 11136:2014/Amd 1:2020 in a controlled sensory environment according to ISO 8589:2007, where the orientation of the panelists was done in accordance with ISO 8586:2023 and ISO 6658:2017 [41-44]. A total of 45 untrained panelists, comprising 20 females and 25 males, participated in the sensory evaluation. All participants were regular consumers of yogurt and provided written informed consent prior to participation. Individuals with known milk or basil allergies or other relevant dietary restrictions were excluded. Five treatments were served as 20–25 g portions in the same white cup on each storage day, with the cup covered by a code number of three digits, which varied randomly. The order and randomization of the serving were balanced. The appearance, color, visible whey separation, aroma, taste, sourness, sweetness, smoothness, thickness, mouthfeel, stickiness, aftertaste, and overall acceptability were evaluated using a hedonic scale of 1 to 9 (dislike extremely to like extremely). The acceptability of sourness, thickness, and stickiness were evaluated as a sense of acceptability rather than a sense of intensity. Palate cleansers of water and unsalted crackers were given to prepare the palate, and the samples were tasted individually under standardized conditions.

2.20. Statistical Analysis

Three independent production batches were used as experimental replicates (n = 3). Chemical composition was analyzed using two-factor ANOVA in a randomized complete-block design, with BSM concentration, storage day, and their interaction as fixed effects and production batch as a blocking factor. F-tests used the residual mean square with 38 denominator degrees of freedom. These calculations were performed in Python using NumPy and SciPy. Other yogurt responses were analyzed using linear mixed-effects models with the same fixed effects and production batch as a random effect. Technical replicates were averaged before analysis. Residual normality and variance homogeneity were assessed using Q-Q plots, the Shapiro–Wilk test, and Levene’s test. Tukey-adjusted comparisons were conducted at p < 0.05. Lowercase letters compare treatments within each storage day, and uppercase letters compare storage days within each treatment. Mean values sharing at least one letter are not significantly different

from one another according to Tukey's post hoc test ($p \geq 0.05$). Microbiological counts were $\log_{10}$ -transformed and reported as log CFU/g. Results are presented as mean $\pm$ SD, with SE in parentheses where applicable, on the original measurement scale. Analyses other than the chemical composition ANOVA were performed using OriginPro 2026 SR1, version 10.3.0.197 (OriginLab Corporation, Northampton, MA, USA).

2.20.1. Statistical Treatment of Basil Seed Mucilage Characteristics

For the characterization of basil seed mucilage, three independent extraction batches were considered the experimental units ($n = 3$). Technical replicate measurements performed within each extraction batch were averaged before statistical summarization and were not treated as independent experimental observations. Because each independent extraction batch contributed one batch-level observation for each mucilage characteristic, inferential comparisons among individual extraction batches were not performed using the technical replicates, as this would constitute pseudoreplication. Instead, the reproducibility and between-batch variability of extraction yield, proximate composition, water-holding capacity, OHC, swelling capacity, water-solubility index, total phenolic-reactive content, and DPPH radical-scavenging activity were evaluated descriptively using the mean, standard deviation (SD), and coefficient of variation (CV%). The coefficient of variation was calculated as $CV (\%) = (SD/\text{mean}) \times 100$.

2.20.2. Physicochemical, Textural, Antioxidant, and Microbiological Data

Physicochemical, compositional, color, textural, antioxidant, and microbiological responses were analyzed using a linear mixed-effects model. BSM concentration, storage day, and the BSM concentration $\times$ storage day interaction were included as fixed effects, while production batch was included as a random effect. Technical replicate measurements from the same experimental unit were averaged before analysis. For each response variable, the significance of the main effects of BSM concentration and storage day and their interaction was first evaluated using the fitted linear mixed-effects model. Tukey-adjusted pairwise comparisons were subsequently used to compare treatment $\times$ storage means for presentation in the tables and figures. Lowercase letters were used to compare BSM treatments within the same storage day, whereas uppercase letters were used to compare storage days within the same treatment. Means sharing at least one common letter were considered not significantly different, whereas means with no letter in common differed significantly at Tukey-adjusted $p < 0.05$. The interpretation of the overall treatment $\times$ storage interaction remained based on the mixed-effects model. Model assumptions were evaluated using Q-Q plots and the Shapiro-Wilk test for normality of residuals and Levene's test for homogeneity of variances. Microbiological counts were analyzed after $\log_{10}$ transformation and are reported as log CFU/g. Statistical analyses were performed on transformed data when transformation was required to satisfy model assumptions, whereas the means presented in the tables and figures are reported on the original measurement scale.

2.20.3. Sensory Data

Sensory scores were analyzed using a mixed-effects model with BSM treatment, storage day, and the treatment $\times$ storage day interaction as fixed effects and panelist as a random effect. Tukey-adjusted multiple comparisons were performed at $p < 0.05$ when significant differences were detected. For statistical lettering of sensory means, lowercase letters indicate comparisons among BSM treatments within the same storage day, whereas uppercase letters indicate comparisons among storage days within the same treatment. Different letters indicate significant differences at Tukey-adjusted $p < 0.05$, while means sharing the same letter are not significantly different.

2.20.4. Exploratory Pearson Correlation Analysis

Exploratory Pearson correlation analysis was conducted using nine selected variables representing the principal objectives of the study: BSM concentration, storage day, syneresis, water-holding capacity, firmness, adhesiveness, total phenolic-reactive content, DPPH radical-scavenging activity, and overall acceptability. These variables were selected to represent the relationships among experimental factors, serum retention, instrumental texture, antioxidant properties, and sensory acceptance. The analysis was

limited to these representative variables to provide a focused and interpretable correlation matrix rather than an exhaustive assessment of all measured parameters. Additional physicochemical, textural, antioxidant, microbiological, and sensory parameters were evaluated separately using the statistical models described above. Pearson correlation coefficients were calculated from 20 aggregated treatment $\times$ storage-day means, corresponding to five BSM concentrations and four storage periods. Because these means did not represent independent experimental replicates, correlations were interpreted descriptively without significance testing or causal inference.

3. Results

3.1. Characteristics of Basil Seed Mucilage

The three independent extraction batches showed limited between-batch variability across the measured physicochemical and functional characteristics, with CV values ranging from 0.07 to 7.73% (Table 2). OHC showed the greatest relative between-batch variability (CV = 7.73%), whereas carbohydrate content showed the lowest variability (CV = 0.07%). The mean extraction yield across the three independent batches was 15.30%. The dried mucilage contained 5.93% moisture, 5.24% ash, 1.65% protein, 0.82% fat, and 86.36% carbohydrate. The water-holding and oil-holding capacities were 32.77 and 8.28 g/g, respectively. Swelling capacity was 22.50 mL/g, while the water-solubility index was 26.47%. The total phenolic-reactive content was 3.80 mg GAE/g, and DPPH radical-scavenging activity was 22.77% at a dry-mucilage-equivalent concentration of 1.0 mg/mL.

Table 2: Physicochemical and functional characteristics of basil seed mucilage from three independent extraction batches.

Parameter	Batch 1	Batch 2	Batch 3	Mean $\pm$ SD	CV (%)
Extraction yield (%)	15.12	15.48	15.31	15.30 $\pm$ 0.18	1.18
Moisture content (%)	6.02	5.81	5.95	5.93 $\pm$ 0.11	1.85
Ash content (%)	5.16	5.33	5.24	5.24 $\pm$ 0.09	1.72
Protein content (%)	1.61	1.69	1.65	1.65 $\pm$ 0.04	2.42
Fat content (%)	0.78	0.85	0.82	0.82 $\pm$ 0.04	4.88
Carbohydrate content (%)	86.43	86.32	86.34	86.36 $\pm$ 0.06	0.07
Water-holding capacity (g/g)	31.90	32.80	33.60	32.77 $\pm$ 0.85	2.59
Oil-holding capacity (g/g)	7.62	8.31	8.90	8.28 $\pm$ 0.64	7.73
Swelling capacity (mL/g)	21.80	22.60	23.10	22.50 $\pm$ 0.66	2.93
Water-solubility index (%)	25.70	26.50	27.20	26.47 $\pm$ 0.75	2.83
Total phenolic content (mg GAE/g)	3.72	3.89	3.80	3.80 $\pm$ 0.09	2.37
DPPH inhibition at 1 mg/mL (%)	22.10	23.40	22.80	22.77 $\pm$ 0.65	2.85

3.2. Chemical Composition of Set Yogurt

BSM concentration significantly affected moisture, total solids, ash, carbohydrates, and dietary fiber ($p < 0.001$), whereas protein and fat were not significantly affected by treatment. Storage significantly affected moisture and total solids ($p < 0.001$) and carbohydrates ($p = 0.0085$), but not protein, fat, ash, or dietary fiber ($p > 0.05$). No significant treatment $\times$ storage interactions were detected for any compositional parameter ($p > 0.05$). Moisture content decreased, whereas total solids, carbohydrates, and dietary fiber increased with increasing BSM incorporation (Table 3). On day 21, moisture content decreased from 86.44% in the control to 85.74% in the 0.40% BSM treatment, while total solids increased from 13.56% to 14.26%. Dietary fiber increased from 0.023% to 0.328%. Ash content showed a modest treatment-related increase.

Table 3: Chemical composition of set yogurt containing different concentrations of basil seed mucilage during refrigerated storage.

Parameter	Treatment	Storage period (days)			
		Day 1	Day 7	Day 14	Day 21
Moisture (%)	Control	86.63 ± 0.07 (0.04) ^{aA}	86.58 ± 0.06 (0.03) ^{aA}	86.55 ± 0.05 (0.03) ^{aA}	86.44 ± 0.06 (0.04) ^{aA}
	0.10% BSM	86.45 ± 0.09 (0.05) ^{abA}	86.35 ± 0.10 (0.06) ^{bA}	86.34 ± 0.05 (0.03) ^{aA}	86.30 ± 0.10 (0.06) ^{abA}
	0.20% BSM	86.26 ± 0.05 (0.03) ^{bcA}	86.23 ± 0.11 (0.06) ^{bcA}	86.12 ± 0.14 (0.08) ^{bA}	86.12 ± 0.05 (0.03) ^{bA}
	0.30% BSM	86.06 ± 0.11 (0.06) ^{cA}	86.04 ± 0.04 (0.02) ^{cdAB}	85.84 ± 0.04 (0.03) ^{cB}	85.88 ± 0.06 (0.03) ^{cAB}
	0.40% BSM	85.84 ± 0.11 (0.06) ^{dA}	85.84 ± 0.13 (0.08) ^{dA}	85.68 ± 0.06 (0.04) ^{cA}	85.74 ± 0.17 (0.10) ^{cA}
Total solids (%)	Control	13.37 ± 0.07 (0.04) ^{dA}	13.42 ± 0.06 (0.03) ^{dA}	13.45 ± 0.05 (0.03) ^{cA}	13.56 ± 0.06 (0.04) ^{cA}
	0.10% BSM	13.55 ± 0.09 (0.05) ^{cdA}	13.65 ± 0.10 (0.06) ^{cA}	13.66 ± 0.05 (0.03) ^{cA}	13.70 ± 0.10 (0.06) ^{bcA}
	0.20% BSM	13.74 ± 0.05 (0.03) ^{bcA}	13.77 ± 0.11 (0.06) ^{bcA}	13.88 ± 0.14 (0.08) ^{bA}	13.88 ± 0.05 (0.03) ^{bA}
	0.30% BSM	13.94 ± 0.11 (0.06) ^{abB}	13.96 ± 0.04 (0.02) ^{abAB}	14.16 ± 0.04 (0.03) ^{aA}	14.12 ± 0.06 (0.03) ^{aB}
	0.40% BSM	14.16 ± 0.11 (0.06) ^{aA}	14.16 ± 0.13 (0.08) ^{aA}	14.32 ± 0.06 (0.04) ^{aA}	14.26 ± 0.17 (0.10) ^{aA}
Protein (%)	Control	3.54 ± 0.01 (0.01) ^{aA}	3.56 ± 0.06 (0.03) ^{aA}	3.57 ± 0.04 (0.02) ^{aA}	3.56 ± 0.04 (0.02) ^{aA}
	0.10% BSM	3.57 ± 0.01 (0.00) ^{aA}	3.54 ± 0.03 (0.02) ^{aA}	3.59 ± 0.03 (0.01) ^{aA}	3.58 ± 0.05 (0.03) ^{aA}
	0.20% BSM	3.59 ± 0.05 (0.03) ^{aA}	3.54 ± 0.03 (0.02) ^{aA}	3.56 ± 0.03 (0.02) ^{aA}	3.60 ± 0.04 (0.03) ^{aA}
	0.30% BSM	3.58 ± 0.05 (0.03) ^{aA}	3.58 ± 0.02 (0.01) ^{aA}	3.58 ± 0.01 (0.00) ^{aA}	3.55 ± 0.04 (0.02) ^{aA}
	0.40% BSM	3.55 ± 0.03 (0.02) ^{aA}	3.57 ± 0.03 (0.02) ^{aA}	3.55 ± 0.02 (0.01) ^{aA}	3.55 ± 0.07 (0.04) ^{aA}
Fat (%)	Control	1.51 ± 0.02 (0.01) ^{aA}	1.49 ± 0.01 (0.01) ^{aA}	1.50 ± 0.03 (0.02) ^{aA}	1.50 ± 0.02 (0.01) ^{aA}
	0.10% BSM	1.50 ± 0.01 (0.01) ^{aA}	1.51 ± 0.03 (0.02) ^{aA}	1.50 ± 0.01 (0.01) ^{aA}	1.49 ± 0.02 (0.01)
	0.20% BSM	1.48 ± 0.00 (0.00) ^{aA}	1.49 ± 0.01 (0.01) ^{aA}	1.47 ± 0.04 (0.02) ^{aA}	1.50 ± 0.01 (0.01) ^{aA}
	0.30% BSM	1.51 ± 0.02 (0.01) ^{aA}	1.51 ± 0.01 (0.01) ^{aA}	1.50 ± 0.02 (0.01) ^{aA}	1.51 ± 0.02 (0.01) ^{aA}
	0.40% BSM	1.48 ± 0.01 (0.01) ^{aA}	1.50 ± 0.03 (0.02) ^{aA}	1.46 ± 0.03 (0.02) ^{aA}	1.49 ± 0.06 (0.03) ^{aA}
Ash (%)	Control	0.75 ± 0.01 (0.01) ^{bcA}	0.74 ± 0.02 (0.01) ^{bA}	0.75 ± 0.01 (0.00) ^{aA}	0.75 ± 0.00 (0.00) ^{bA}
	0.10% BSM	0.74 ± 0.02 (0.01) ^{cb}	0.76 ± 0.02 (0.01) ^{abAB}	0.76 ± 0.03 (0.02) ^{aAB}	0.77 ± 0.01 (0.01) ^{abA}
	0.20% BSM	0.77 ± 0.03 (0.02) ^{abcA}	0.75 ± 0.01 (0.01) ^{abA}	0.77 ± 0.02 (0.01) ^{aA}	0.78 ± 0.02 (0.01) ^{aA}
	0.30% BSM	0.78 ± 0.02 (0.01) ^{abA}	0.78 ± 0.01 (0.01) ^{aA}	0.77 ± 0.00 (0.00) ^{aA}	0.77 ± 0.00 (0.00) ^{abA}
	0.40% BSM	0.78 ± 0.01 (0.00) ^{aA}	0.78 ± 0.01 (0.01) ^{aA}	0.77 ± 0.01 (0.00) ^{aA}	0.78 ± 0.01 (0.00) ^{aA}
Carbohydrates (%)	Control	7.57 ± 0.03 (0.02) ^{dA}	7.63 ± 0.08 (0.05) ^{cA}	7.63 ± 0.04 (0.02) ^{dA}	7.76 ± 0.05 (0.03) ^{cA}
	0.10% BSM	7.75 ± 0.11 (0.06) ^{cdA}	7.84 ± 0.15 (0.09) ^{bcA}	7.81 ± 0.04 (0.02) ^{cdA}	7.86 ± 0.15 (0.08) ^{cA}
	0.20% BSM	7.90 ± 0.13 (0.08) ^{bcA}	7.98 ± 0.14 (0.08) ^{bA}	8.09 ± 0.20 (0.12) ^{bcA}	8.00 ± 0.03 (0.01) ^{bcA}
	0.30% BSM	8.07 ± 0.18 (0.11) ^{abA}	8.10 ± 0.06 (0.04) ^{abA}	8.32 ± 0.02 (0.01) ^{abA}	8.30 ± 0.07 (0.04) ^{abA}
	0.40% BSM	8.36 ± 0.14 (0.08) ^{aA}	8.31 ± 0.20 (0.12) ^{aA}	8.54 ± 0.06 (0.03) ^{aA}	8.44 ± 0.30 (0.17) ^{aA}
Dietary fiber (%)	Control	0.008 ± 0.004 (0.003) ^{eA}	0.026 ± 0.012 (0.007) ^{eA}	0.013 ± 0.004 (0.002) ^{eA}	0.023 ± 0.006 (0.004) ^{eA}
	0.10% BSM	0.093 ± 0.016 (0.009) ^{dA}	0.099 ± 0.014 (0.008) ^{dA}	0.108 ± 0.008 (0.004) ^{dA}	0.098 ± 0.009 (0.005) ^{dA}
	0.20% BSM	0.180 ± 0.025 (0.014) ^{cA}	0.163 ± 0.009 (0.005) ^{cA}	0.173 ± 0.027 (0.015) ^{cA}	0.178 ± 0.008 (0.005) ^{cA}
	0.30% BSM	0.256 ± 0.009 (0.005) ^{bA}	0.265 ± 0.007 (0.004) ^{bA}	0.250 ± 0.010 (0.006) ^{bA}	0.249 ± 0.010 (0.006) ^{bA}
	0.40% BSM	0.329 ± 0.025 (0.015) ^{aA}	0.340 ± 0.016 (0.009) ^{aA}	0.330 ± 0.007 (0.004) ^{aA}	0.328 ± 0.018 (0.010) ^{aA}

Values are presented as mean ± SD, with SE in parentheses (n = 3 independent production batches). Within each parameter, different lowercase superscript letters indicate significant differences among BSM treatments within the same storage day, whereas different uppercase superscript letters indicate significant differences among storage days within the same treatment. Means sharing at least one common letter are not significantly different, whereas means with no letter in common differ significantly (Tukey, $p < 0.05$).

3.3. Acidification, Syneresis, Water-Holding Capacity, and Soluble Solids

Treatment and storage significantly affected pH and titratable acidity ($p < 0.001$), whereas the treatment × storage interaction was not significant. Treatment effects were also significant for syneresis, water-holding capacity, and apparent total soluble solids. Progressive post-acidification occurred during refrigerated storage (Figure 1). Mean pH declined from 4.51–4.55 on day 1 to 4.30–4.34 on day 21, whereas titratable acidity increased from 0.82–0.88% to 1.04–1.11% lactic acid. Increasing BSM concentration was associated with a slight decrease in pH and a slight increase in acidity, particularly during later storage periods. Syneresis increased during storage but decreased markedly as BSM concentration increased. On day 1, syneresis was 24.71% in the control and 11.54% in the 0.40% BSM treatment, representing a 53.3% reduction. By day 21, the corresponding values were 31.13% and 16.31%, representing a 47.6% reduction. Water-holding capacity showed the opposite pattern (Figure 2): the 0.40% BSM formulation retained 85.81% on day 1 and 81.54% on day 21, whereas the control retained 67.75% and 64.78%, respectively. Apparent total soluble solids also increased with BSM concentration, reaching 14.32 °Brix in the 0.40% BSM formulation on day 21 compared with 13.57 °Brix in the control.

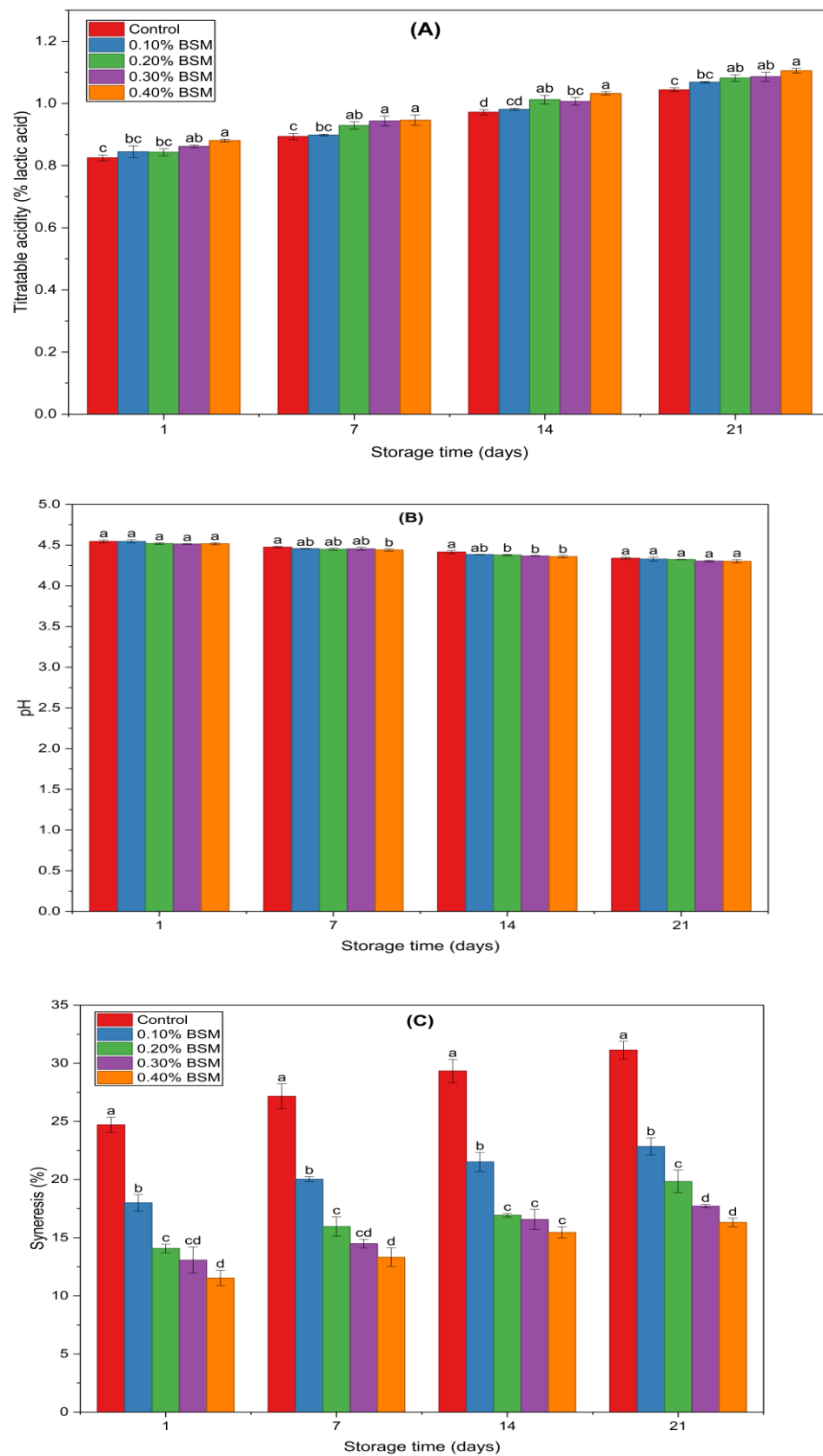


Figure 1: Effects of basil seed mucilage concentration and refrigerated storage on (A) titratable acidity, (B) pH, and (C) syneresis of set yogurt. Values are mean $\pm$ SD of three independent production batches.

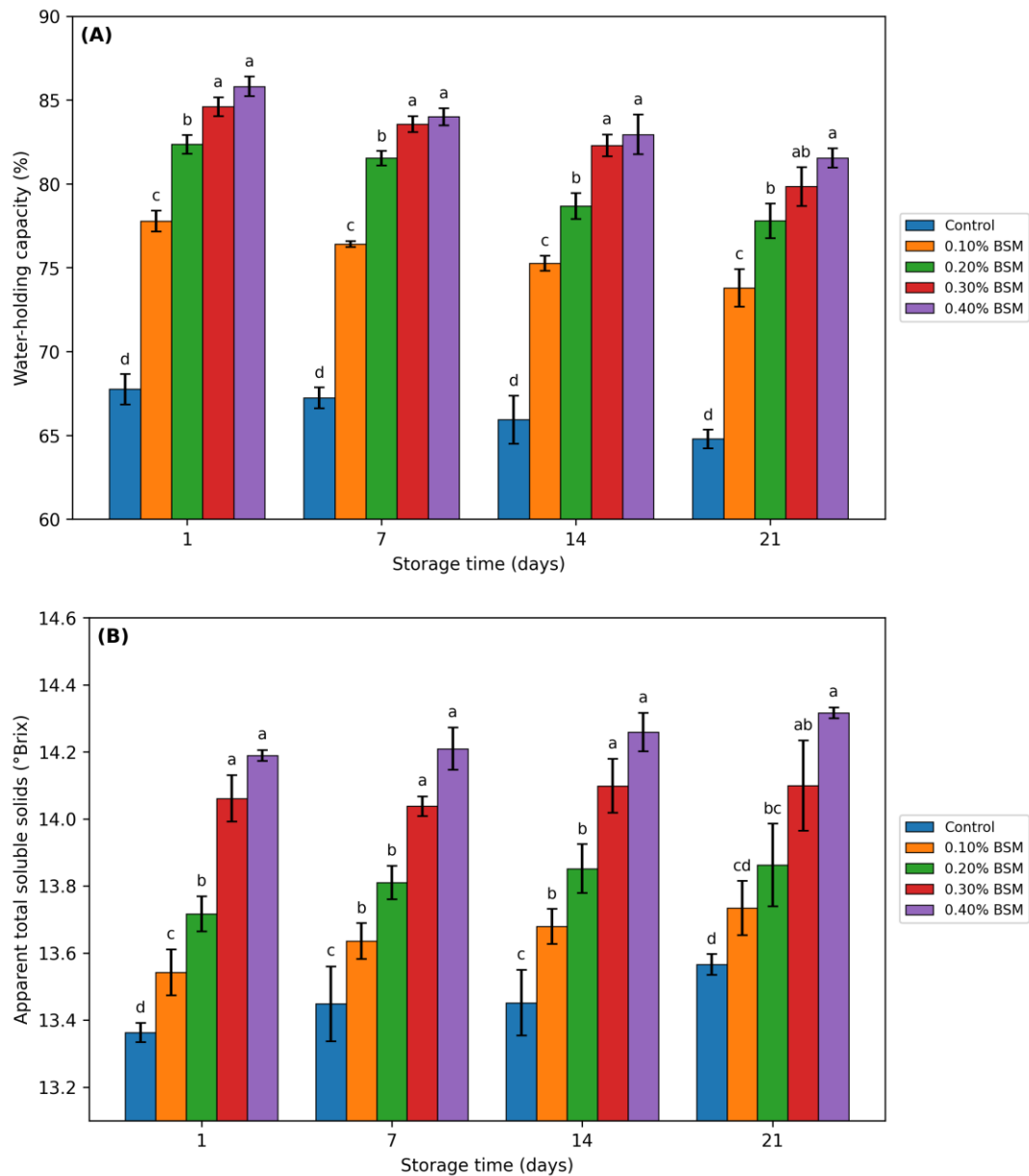


Figure 2: Effects of basil seed mucilage concentration and refrigerated storage on water-holding capacity (A) and apparent total soluble solids (B) of set yogurt. Values are mean $\pm$ SD of three independent production batches. Means sharing the different letters are significantly different according to Tukey test at the level of 0.05.

3.4. Instrumental Color

BSM concentration and storage significantly affected all CIELAB color variables. The treatment $\times$ storage interaction was significant for b ($p = 0.031$), but not for L^* , a^* , or ΔE_{ab} . Lightness (L^*) decreased progressively with increasing BSM concentration; on day 21, L^* decreased from 86.36 in the control to 83.67 in the 0.40% BSM treatment. Increasing BSM concentration was also associated with reduced greenness, reflected by increasing a^* values, and greater yellowness, reflected by increasing b^* values. Total color difference (ΔE^*_{ab}) increased with BSM concentration and storage, reaching 4.40 in the 0.40% BSM formulation on day 21 (Table 4).

Table 4: Instrumental color properties of set yogurt containing basil seed mucilage during refrigerated storage.

Color parameter	Treatment	Day 1	Day 7	Day 14	Day 21
L*	Control	87.11 ± 0.06 (0.04) ^{aA}	86.86 ± 0.05 (0.03) ^{aAB}	86.47 ± 0.18 (0.11) ^{aBC}	86.36 ± 0.19 (0.11) ^{aC}
	0.10% BSM	86.60 ± 0.10 (0.06) ^{bA}	86.28 ± 0.20 (0.11) ^{bA}	85.87 ± 0.39 (0.23) ^{bB}	85.67 ± 0.13 (0.07) ^{bB}
	0.20% BSM	85.85 ± 0.16 (0.09) ^{cA}	85.65 ± 0.18 (0.10) ^{cAB}	85.37 ± 0.34 (0.20) ^{cBC}	85.14 ± 0.16 (0.09) ^{cC}
	0.30% BSM	85.03 ± 0.18 (0.11) ^{dA}	85.02 ± 0.26 (0.15) ^{dA}	84.75 ± 0.04 (0.02) ^{dAB}	84.39 ± 0.06 (0.04) ^{dB}
	0.40% BSM	84.54 ± 0.03 (0.02) ^{eA}	84.17 ± 0.23 (0.13) ^{eAB}	83.81 ± 0.11 (0.06) ^{eBC}	83.67 ± 0.05 (0.03) ^{eC}
a*	Control	-1.43 ± 0.09 (0.05) ^{dA}	-1.45 ± 0.10 (0.06) ^{dA}	-1.35 ± 0.02 (0.01) ^{eA}	-1.33 ± 0.08 (0.05) ^{eA}
	0.10% BSM	-1.29 ± 0.03 (0.02) ^{cdA}	-1.27 ± 0.09 (0.05) ^{eA}	-1.26 ± 0.07 (0.04) ^{bcA}	-1.19 ± 0.07 (0.04) ^{bcA}
	0.20% BSM	-1.13 ± 0.06 (0.04) ^{bcA}	-1.10 ± 0.05 (0.03) ^{bcA}	-1.11 ± 0.05 (0.03) ^{bA}	-1.04 ± 0.09 (0.05) ^{bA}
	0.30% BSM	-1.06 ± 0.07 (0.04) ^{bB}	-0.97 ± 0.07 (0.04) ^{abAB}	-0.86 ± 0.10 (0.06) ^{aA}	-0.81 ± 0.11 (0.07) ^{aA}
	0.40% BSM	-0.86 ± 0.04 (0.02) ^{aA}	-0.90 ± 0.10 (0.06) ^{aA}	-0.81 ± 0.07 (0.04) ^{aA}	-0.76 ± 0.04 (0.02) ^{aA}
b*	Control	9.34 ± 0.05 (0.03) ^{dB}	9.54 ± 0.33 (0.19) ^{cAB}	9.70 ± 0.09 (0.05) ^{dA}	9.77 ± 0.02 (0.01) ^{eA}
	0.10% BSM	9.97 ± 0.34 (0.20) ^{cAB}	9.88 ± 0.18 (0.11) ^{cB}	10.23 ± 0.10 (0.06) ^{cA}	10.26 ± 0.05 (0.03) ^{dA}
	0.20% BSM	10.63 ± 0.07 (0.04) ^{bA}	10.73 ± 0.04 (0.02) ^{bA}	10.67 ± 0.08 (0.05) ^{bA}	10.86 ± 0.13 (0.08) ^{eA}
	0.30% BSM	10.89 ± 0.13 (0.08) ^{bB}	11.05 ± 0.10 (0.06) ^{bB}	11.42 ± 0.06 (0.03) ^{aA}	11.55 ± 0.19 (0.11) ^{bA}
	0.40% BSM	11.85 ± 0.06 (0.03) ^{aAB}	11.55 ± 0.09 (0.05) ^{aB}	11.75 ± 0.18 (0.10) ^{aAB}	11.99 ± 0.15 (0.08) ^{aA}
ΔE*_{ab}	Control	0.09 ± 0.05 (0.03) ^{eB}	0.41 ± 0.13 (0.07) ^{eB}	0.75 ± 0.12 (0.07) ^{eA}	0.88 ± 0.14 (0.08) ^{eA}
	0.10% BSM	0.85 ± 0.22 (0.13) ^{dB}	1.03 ± 0.07 (0.04) ^{dB}	1.56 ± 0.25 (0.14) ^{dA}	1.73 ± 0.08 (0.05) ^{dA}
	0.20% BSM	1.83 ± 0.10 (0.06) ^{cC}	2.04 ± 0.15 (0.09) ^{cBC}	2.23 ± 0.26 (0.15) ^{cAB}	2.52 ± 0.08 (0.05) ^{cA}
	0.30% BSM	2.63 ± 0.14 (0.08) ^{bc}	2.74 ± 0.19 (0.11) ^{bc}	3.20 ± 0.07 (0.04) ^{bB}	3.56 ± 0.16 (0.09) ^{bA}
	0.40% BSM	3.63 ± 0.06 (0.03) ^{bB}	3.72 ± 0.23 (0.13) ^{aB}	4.13 ± 0.17 (0.10) ^{aA}	4.40 ± 0.11 (0.06) ^{aA}

Values are presented as mean ± SD, with SE in parentheses (n = 3 independent production batches). Within each parameter, different lowercase superscript letters indicate significant differences among BSM treatments within the same storage day, whereas different uppercase superscript letters indicate significant differences among storage days within the same treatment. Means sharing at least one common superscript letter are not significantly different, whereas means with no common superscript letter differ significantly (Tukey-adjusted p < 0.05).

3.5. Textural Properties

BSM concentration significantly affected firmness, cohesiveness, gumminess, consistency, adhesiveness, and springiness (p < 0.001), whereas treatment × storage interactions were not significant for any of the six texture variables. All six textural attributes increased with increasing BSM concentration and generally increased during refrigerated storage (Figure 3). The ranking of the treatments was largely maintained throughout storage, with higher BSM concentrations consistently producing firmer, more cohesive, gummier, more consistent, and more adhesive yogurt gels.

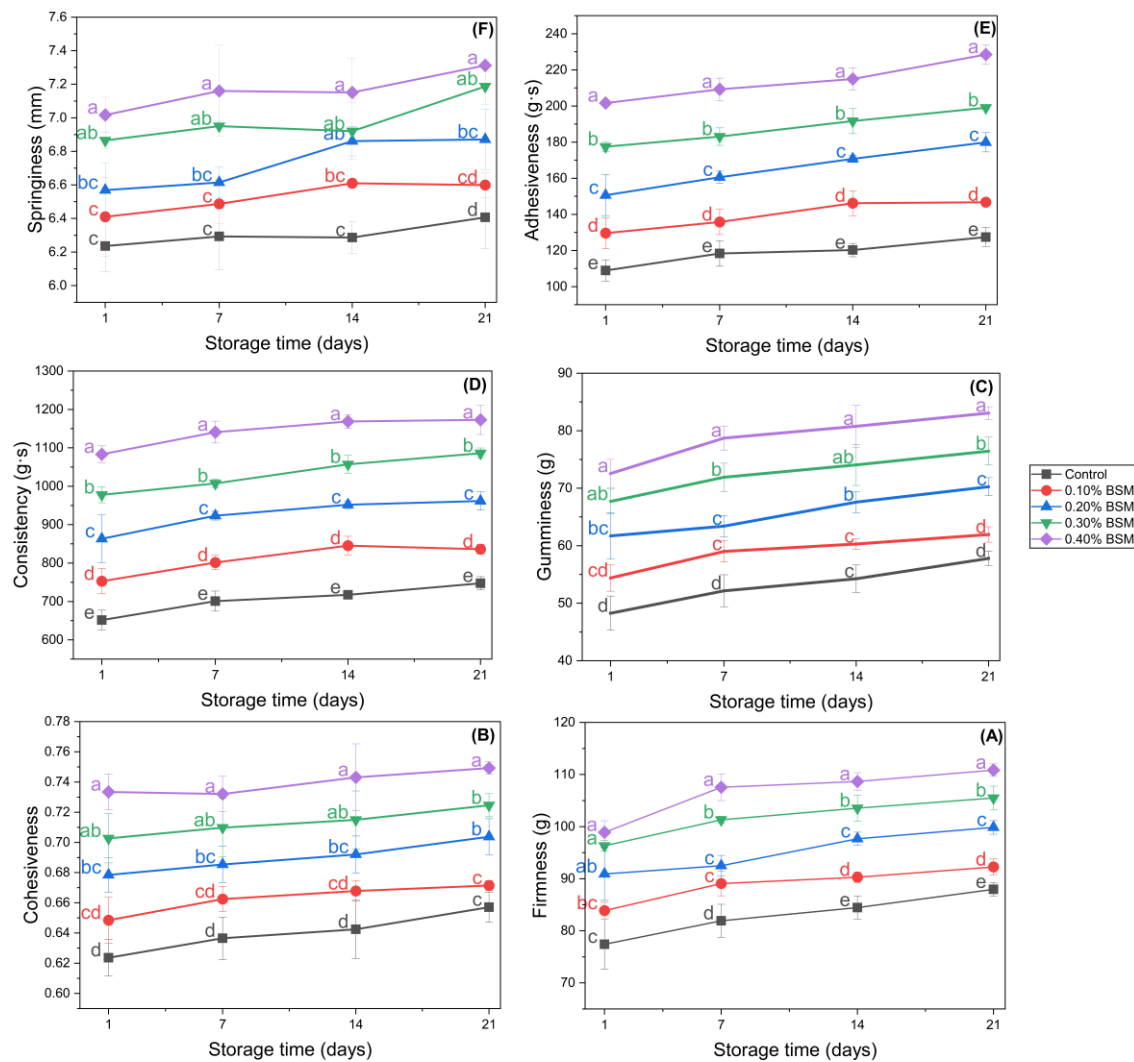


Figure 3: Textural properties of set yogurt containing basil seed mucilage during refrigerated storage. A: Firmness, B: Cohesiveness, C: Gumminess, D: Consistency, E: Adhesiveness, and F: Springiness. Values are the mean $\pm$ SD of three independent production batches. Means sharing at least one common letter are not significantly different, whereas means with no letter in common differ significantly (Tukey-adjusted $p < 0.05$).

3.6. Antioxidant Properties

BSM concentration and storage significantly affected total phenolic-reactive content, DPPH radical-scavenging activity, ABTS radical-scavenging activity, and FRAP ($p < 0.001$), whereas the treatment $\times$ storage interactions were not significant. All antioxidant indices increased with increasing BSM concentration and generally declined during refrigerated storage (Figure 4). On day 1, the 0.40% BSM yogurt showed the highest total phenolic-reactive content (42.10 mg GAE/kg), DPPH radical-scavenging activity (35.06%), ABTS radical-scavenging activity (42.91%), and FRAP value (222.00 $\mu\text{mol Fe}^{2+}$ equivalents/kg). Although these antioxidant indices decreased during storage, the 0.40% BSM formulation remained the highest on day 21, with a total phenolic-reactive content of 38.58 mg GAE/kg, DPPH radical-scavenging activity of 31.61%, ABTS radical-scavenging activity of 38.87%, and a FRAP value of 200.33 $\mu\text{mol Fe}^{2+}$ equivalents/kg. These day-21 values represented increases of approximately 85%, 98%, 81%, and 76%, respectively, relative to the corresponding day-21 control values.

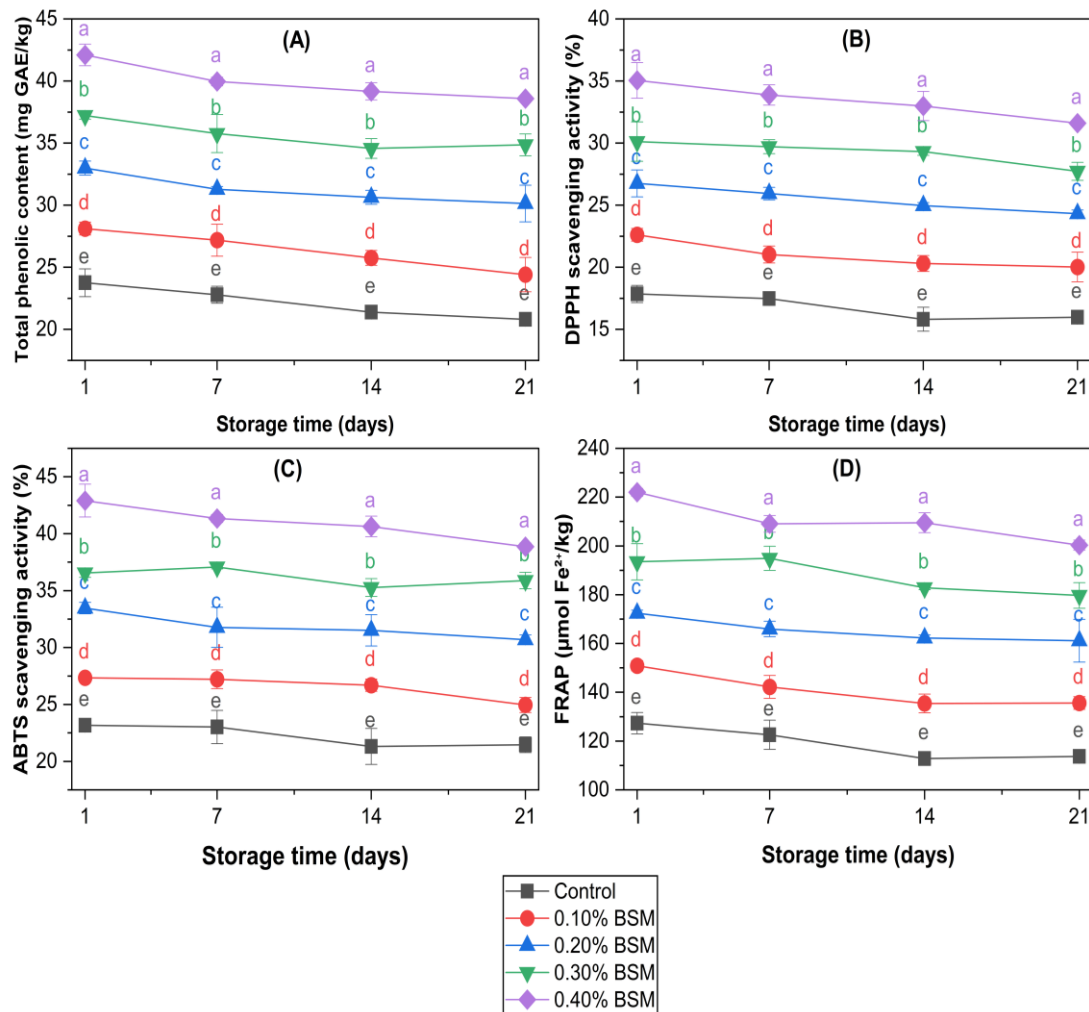


Figure 4: Antioxidant properties of set yogurt containing different concentrations of basil seed mucilage (BSM) during refrigerated storage: (A) total phenolic-reactive content (mg GAE/kg fresh yogurt); (B) DPPH radical-scavenging activity (% inhibition); (C) ABTS radical-cation scavenging activity (% inhibition); and (D) ferric-reducing antioxidant power (FRAP; $\mu\text{mol Fe}^{2+}$ equivalents/kg yogurt). Different lowercase letters indicate significant differences among BSM treatments within the same storage day (p < 0.05).

3.7. Microbiological Quality

Treatment and storage significantly affected *Streptococcus thermophilus*, *Lactobacillus delbrueckii* subsp. *bulgaricus*, and total viable counts (p < 0.001), whereas the corresponding treatment $\times$ storage interactions were not significant. Starter-culture populations declined during refrigerated storage but remained high in all treatments (Table 5). On day 21, *S. thermophilus* counts ranged from 8.03 to 8.25 log CFU/g, while *L. delbrueckii* subsp. *bulgaricus* counts ranged from 7.41 to 7.68 log CFU/g. The highest *S. thermophilus* and total viable counts were generally observed in the 0.20% BSM treatment, whereas *L. bulgaricus* counts tended to be slightly higher in BSM-containing treatments than in the control. Yeast and mold counts increased during storage but remained low, ranging from 1.14 to 1.23 log CFU/g on day 21. Coliforms were not detected in any treatment at any storage period.

Table 5: Microbiological properties of set yogurt containing basil seed mucilage during refrigerated storage.

Microbiological parameter	Treatment	Day 1	Day 7	Day 14	Day 21
Streptococcus thermophilus (log CFU/g)	Control	8.64 ± 0.12 (0.07) ^{bcA}	8.53 ± 0.01 (0.00) ^{abA}	8.24 ± 0.04 (0.02) ^{bB}	8.06 ± 0.05 (0.03) ^{bC}
	0.10% BSM	8.76 ± 0.06 (0.04) ^{abA}	8.56 ± 0.04 (0.02) ^{abB}	8.33 ± 0.03 (0.02) ^{abC}	8.12 ± 0.04 (0.02) ^{bD}
	0.20% BSM	8.79 ± 0.04 (0.02) ^{aA}	8.65 ± 0.07 (0.04) ^{abB}	8.44 ± 0.02 (0.01) ^{aC}	8.25 ± 0.04 (0.02) ^{aD}
	0.30% BSM	8.81 ± 0.07 (0.04) ^{aA}	8.63 ± 0.02 (0.01) ^{abB}	8.35 ± 0.05 (0.03) ^{abC}	8.13 ± 0.02 (0.01) ^{abD}
	0.40% BSM	8.55 ± 0.08 (0.05) ^{cA}	8.43 ± 0.04 (0.02) ^{bbB}	8.25 ± 0.07 (0.04) ^{bC}	8.03 ± 0.06 (0.04) ^{bD}
Lactobacillus delbrueckii subsp. bulgaricus (log CFU/g)	Control	8.21 ± 0.11 (0.06) ^{bA}	7.99 ± 0.04 (0.02) ^{bbB}	7.73 ± 0.10 (0.06) ^{abC}	7.41 ± 0.09 (0.05) ^{bD}
	0.10% BSM	8.37 ± 0.12 (0.07) ^{abA}	8.13 ± 0.10 (0.06) ^{abB}	7.88 ± 0.04 (0.02) ^{abC}	7.68 ± 0.01 (0.00) ^{aD}
	0.20% BSM	8.40 ± 0.03 (0.02) ^{aA}	8.21 ± 0.04 (0.02) ^{abB}	7.90 ± 0.10 (0.06) ^{aC}	7.66 ± 0.10 (0.06) ^{aD}
	0.30% BSM	8.31 ± 0.04 (0.02) ^{abA}	8.13 ± 0.07 (0.04) ^{abB}	7.79 ± 0.07 (0.04) ^{abC}	7.65 ± 0.04 (0.02) ^{aC}
	0.40% BSM	8.21 ± 0.06 (0.03) ^{bA}	8.04 ± 0.02 (0.01) ^{bbB}	7.71 ± 0.06 (0.04) ^{bC}	7.54 ± 0.09 (0.05) ^{abD}
Total viable count (log CFU/g)	Control	8.82 ± 0.06 (0.03) ^{abA}	8.61 ± 0.04 (0.02) ^{abB}	8.34 ± 0.06 (0.03) ^{bC}	8.21 ± 0.08 (0.05) ^{bD}
	0.10% BSM	8.88 ± 0.06 (0.03) ^{abA}	8.69 ± 0.02 (0.01) ^{abB}	8.54 ± 0.08 (0.04) ^{aC}	8.29 ± 0.08 (0.04) ^{abD}
	0.20% BSM	8.93 ± 0.04 (0.02) ^{aA}	8.73 ± 0.05 (0.03) ^{aB}	8.56 ± 0.05 (0.03) ^{aC}	8.37 ± 0.02 (0.01) ^{aD}
	0.30% BSM	8.86 ± 0.06 (0.04) ^{abA}	8.70 ± 0.04 (0.02) ^{abB}	8.54 ± 0.01 (0.01) ^{aC}	8.29 ± 0.06 (0.03) ^{abD}
	0.40% BSM	8.76 ± 0.05 (0.03) ^{bA}	8.60 ± 0.04 (0.02) ^{bbB}	8.40 ± 0.03 (0.01) ^{bC}	8.27 ± 0.03 (0.02) ^{abD}
Yeast and mold (log CFU/g)	Control	0.68 ± 0.10 (0.06) ^{aD}	0.86 ± 0.01 (0.01) ^{abC}	1.06 ± 0.03 (0.02) ^{aB}	1.21 ± 0.08 (0.05) ^{aA}
	0.10% BSM	0.70 ± 0.06 (0.03) ^{aD}	0.88 ± 0.03 (0.02) ^{aC}	1.02 ± 0.04 (0.02) ^{abB}	1.23 ± 0.03 (0.02) ^{aA}
	0.20% BSM	0.61 ± 0.02 (0.01) ^{aD}	0.80 ± 0.07 (0.04) ^{abC}	1.01 ± 0.07 (0.04) ^{abB}	1.21 ± 0.05 (0.03) ^{aA}
	0.30% BSM	0.64 ± 0.03 (0.02) ^{aD}	0.81 ± 0.02 (0.01) ^{abC}	0.93 ± 0.06 (0.03) ^{bbB}	1.15 ± 0.05 (0.03) ^{aA}
	0.40% BSM	0.60 ± 0.00 (0.00) ^{aD}	0.75 ± 0.02 (0.01) ^{bcC}	0.93 ± 0.06 (0.03) ^{bbB}	1.14 ± 0.03 (0.02) ^{aA}
Coliforms (log CFU/g)	Control	ND	ND	ND	ND
	0.10% BSM	ND	ND	ND	ND
	0.20% BSM	ND	ND	ND	ND
	0.30% BSM	ND	ND	ND	ND
	0.40% BSM	ND	ND	ND	ND

Values are presented as mean ± SD, with SE in parentheses (n = 3 independent production batches). Within each microbiological parameter, different lowercase superscript letters indicate significant differences among BSM treatments within the same storage day, whereas different uppercase superscript letters indicate significant differences among storage days within the same treatment. Means sharing at least one common superscript letter are not significantly different, whereas means with no common superscript letter differ significantly (Tukey-adjusted $p < 0.05$).

3.8. Sensory Properties

Treatment and storage significantly affected overall acceptability and most sensory attributes. Treatment × storage interactions were significant for stickiness acceptability and aftertaste, but not for overall acceptability. The 0.20% BSM formulation generally received the highest or near-highest scores for appearance, color, aroma, taste, smoothness, thickness, mouthfeel, aftertaste, and overall acceptability (Figure 5). Overall acceptability for the 0.20% BSM formulation averaged 7.75 across storage and was 7.65 on day 21, compared with 6.83 and 6.68, respectively, for the control. The 0.30% BSM formulation showed the highest acceptability for visible whey separation and maintained acceptable texture, although its overall scores were lower than those of the 0.20% BSM formulation. The 0.40% BSM formulation received the highest score for visible whey separation but the lowest scores for taste, smoothness, thickness, mouthfeel, stickiness acceptability, aftertaste, and overall acceptability, with an overall acceptability score of 6.17 on day 21.

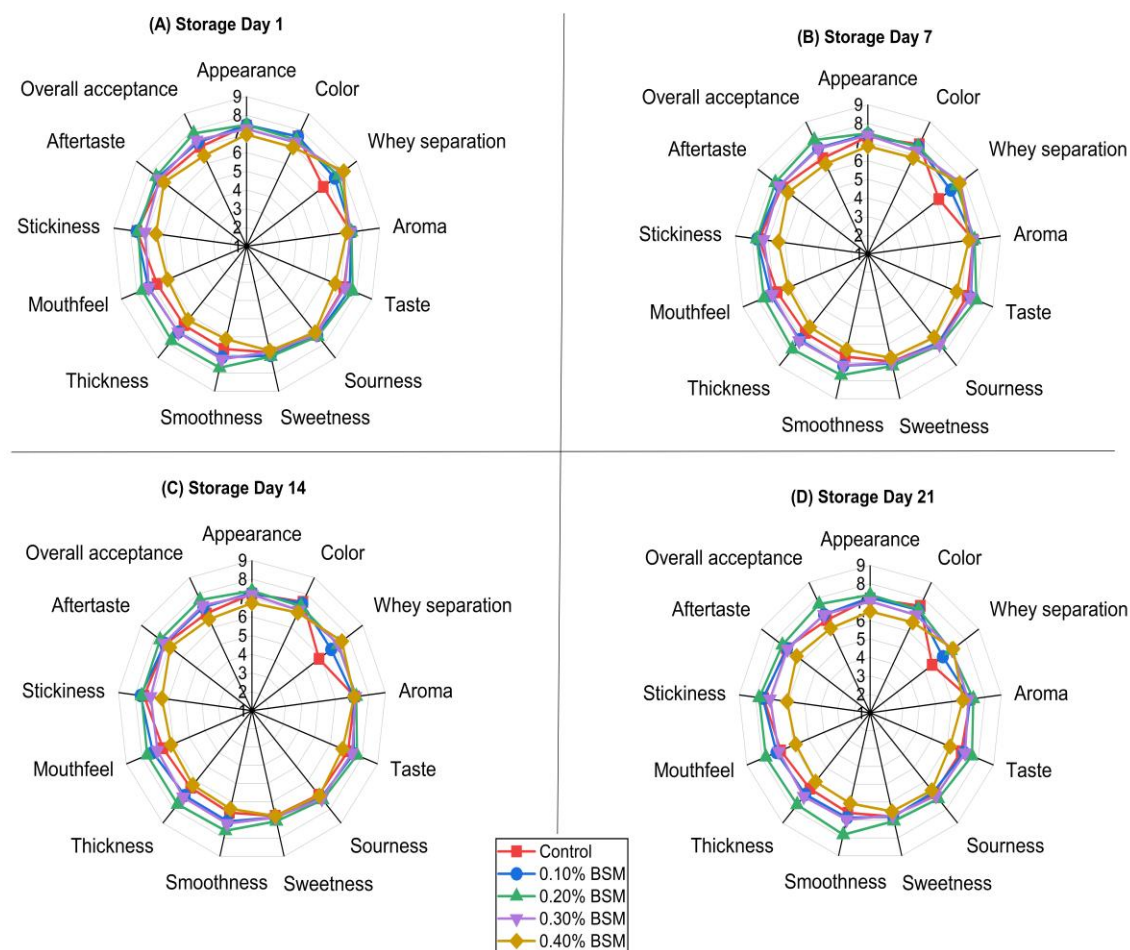


Figure 5: Sensory profiles of set yogurt treatments at different storage times: (A) day 1, (B) day 7, (C) day 14, and (D) day 21.

3.9. Exploratory Correlation Analysis

The exploratory Pearson correlations among the nine selected variables are presented in figure 6. The correlation matrix was designed to illustrate the principal relationships between BSM concentration, refrigerated storage, serum retention, textural properties, antioxidant activity, and overall sensory acceptability. Other measured parameters were not included in this focused matrix because the objective was to illustrate representative relationships directly relevant to the study's main hypotheses rather than to examine every possible pairwise association. The correlation analysis was based on 20 aggregated treatment $\times$ storage-day means (five BSM concentrations $\times$ four storage periods). Nine representative variables were included to focus on the principal relationships relevant to the study objectives. Therefore, these coefficients were interpreted as exploratory descriptive associations without inferential or causal conclusions. BSM concentration showed strong positive descriptive associations with DPPH activity ($r = 0.99$), total phenolic-reactive content ($r = 0.98$), adhesiveness ($r = 0.97$), firmness ($r = 0.91$), and water-holding capacity ($r = 0.90$), and a strong negative association with syneresis ($r = -0.86$). Water-holding capacity and syneresis were strongly inversely associated ($r = -0.98$), whereas firmness and adhesiveness were strongly positively associated ($r = 0.98$). Total phenolic-reactive content and DPPH activity were also nearly perfectly correlated ($r \approx 1.00$ after rounding). Overall acceptability showed only weak linear associations with the selected individual variables ($r \leq 0.30$).

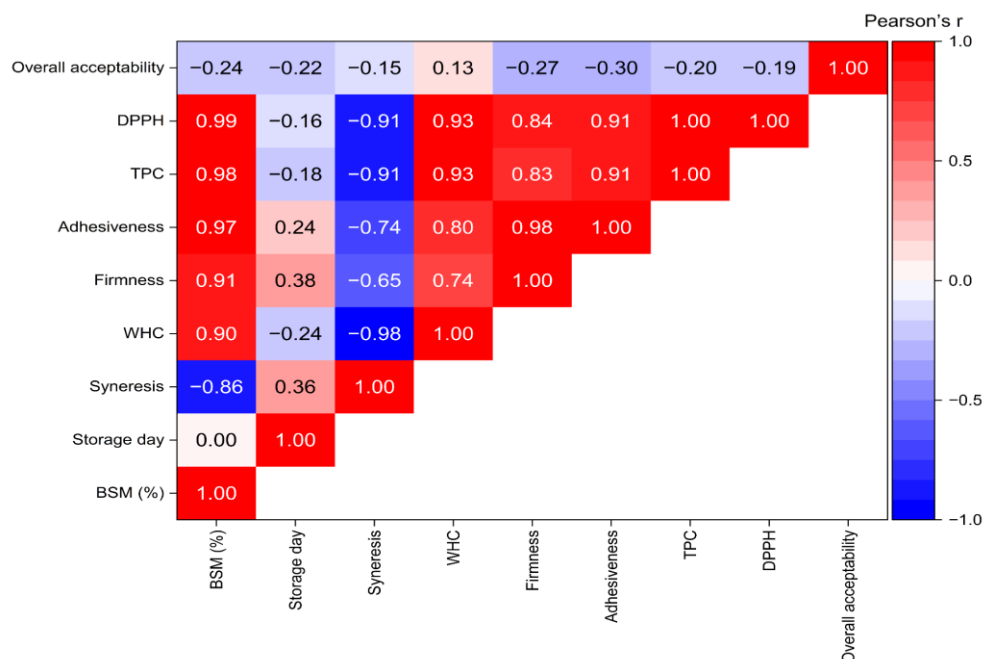


Figure 5: Exploratory Pearson correlation matrix among nine selected experimental, technological, antioxidant, and sensory variables. Variables were selected to represent the principal relationships investigated in the study. Correlation coefficients were calculated descriptively using 20 aggregated treatment $\times$ storage-day means (five BSM concentrations $\times$ four storage periods) and were not subjected to inferential significance testing.

4. Discussion

4.1. Basil Seed Mucilage as a Multifunctional Yogurt Ingredient

The three independent extraction batches showed limited between-batch variability, with CV values ranging from 0.07 to 7.73% across the measured physicochemical and functional characteristics. Extraction yield showed a CV of 1.18%, with a mean value of 15.30%, indicating good consistency of mucilage recovery under the extraction conditions used in this study. This is lower than the yield reported by Salehi *et al.* [45] of 17.95% at optimal conditions of 50 °C, pH 7, and water to seed ratio of 30:1, and the 20.49% reported by Nazir and Wan [6]. However, this value is higher than 11.28% that was achieved by ethanol precipitation by Guan *et al.* [46]. It is reasonable to consider these differences, since the recovery of BSM is highly dependent on the temperature, pH, extraction time, water-to-seed ratio, source of the seeds, and purification/precipitation. In fact, Razavi *et al.* [47] found that the temperature, pH, and water to seed ratio are important factors in the yield of gum, with optimal values of 68.71 °C, pH 8.09, and water to seed ratio of 65.98:1, respectively. The current yield is therefore a measure of the efficiency of recovery under the aqueous conditions used without having to make the recovery more intense.

The recovered material was also found to be mainly polysaccharide, as indicated by its composition. Carbohydrate accounted for 86.36%, whereas protein and fat represented only 1.65% and 0.82%, respectively. The carbohydrate content was found to be higher than the 77.66% previously reported for fractionated BSM by Nazir and Wani [9], and lower than the 93.09% total sugar content previously reported for optimized basil seed gum by Guan *et al.* [46], similarly, the protein level of the present study was lower than the reported value of 2.77%. While the ash content was slightly higher. These differences may be due to the degree of co-extraction of seed proteins, minerals, and other non-polysaccharide components in their purification. The moisture content of 5.93% further implies that the dried mucilage should have a comparatively good shelf-life and hygroscopicity, which however needs to be tested. The high water-holding capacity of 32.77 g/g was found to be comparable to that reported by Nazir and Wani [9] ranging from 35.16 to 38.96 g/g.

The oil holding capacity was significantly less and in the range 8.28 ± 0.64 g/g, which was within their reported range of 5.40–17.38 g/g ranging from 35.16 to 38.96 g/g. The oil holding capacity was significantly less and in the range 8.28 g/g, which was within their reported range of 5.40–17.38 g/g [6].

in contrast. In addition to its large swelling capacity of 22.50 mL/g, these results confirm the high hydrophilic nature of BSM, which is expected to be used as a water-binding, thickening, stabilizing, or texture-modifying agent. Its water-solubility index is $26.47 \pm 0.75\%$, which is also in the range reported earlier (3–30%), and thus suggests partial solubilization, coupled with hydration and swelling to a significant extent.

The phenolics reactive compounds in the mucilage were also 3.80 mg GAE/g with 22.77% inhibition at a concentration of 1 mg/mL for DPPH scavenging assay. The latter one was slightly lower than the antioxidant activity obtained in conventionally extracted BSM (27.01%) [9] and significantly lower than the plasma-activated-water extraction (60.98%) [10]. It indicates moderate antioxidant activity which may be attributed to co-extracted phenolic or other reducing compounds. However, there is no quantitative equivalence that can be made with differences in extraction, DPPH conditions, expression of the number of phenols, and the concentration of the samples. In general, the compositional and hydration properties make this BSM a promising functional hydrocolloid and its antioxidant activity can be considered as an additional rather than main technological property of the BSM [48].

4.2. Chemical Composition of Set Yogurt

The progressive decrease in moisture content and the corresponding rise in total solids confirm that the main effect of BSM on yogurt composition was to incorporate dry, carbohydrate-rich material. Moisture content decreased from 86.44% to 85.74% in the control and yogurt with 0.40% BSM, respectively, on day 21, while there was an increase in total solids from 13.56 % to 14.26%, respectively. Strong treatment effect ($p < 0.001$), generally weak storage effect, and nonsignificant treatment $\times$ storage interaction suggest that these compositional differences were more likely to be due to formulation than progressive changes during refrigeration. This is in accordance with the findings of Roudsari *et al.* [49] who noted an increase in dry matter by increasing the concentration of basil seed gum from 0.1% to 0.2% in low fat probiotic yogurt.

Hydrocolloids extracted from basil have also been found to be promising components for enhancing the technological properties of low-fat yoghurt [50, 51]. This reduction in gravimetrically determined moisture content could be a moisture content reduction resulting from the dry matter contribution of BSM and/or the high moisture absorption capacity of BSM. The hydrophilic polysaccharides in BSM can strongly bind water and may also interact with milk proteins, which could contribute to reduced mobility of water in the yogurt matrix. However, such protein–polysaccharide interactions were not directly measured in the present study. This is in line with the water-binding, thickening, and gel-forming properties of basil seed gum that are well established [6]. However, Kim *et al.* [12] found another moisture response for reduced-fat and nonfat yogurts fortified with 0.5–1.0% BSG. The following apparent discrepancy may result from differences in the level of milk fat, the gum preparation, the concentration, and analytical expression; hence, direct comparisons should take into account the formulation and methodology.

Overall, the hydrocolloid properties in yogurt also depend on the polymer structure, processing parameters, and interactions with the fermented casein network [3]. The progressive increase in carbohydrate content was as expected from day-21 of the control, with BSM, which is mainly polysaccharidic, reaching 8.44% at 0.40% BSM. Most importantly, dietary fiber was raised about fourteenfold (from 0.023% to 0.328%), demonstrating that the fiber was successfully enriched even at the relatively low inclusion rate. This result is in accordance with earlier studies concerning the use of 0.2–0.4% BSG in the probiotic formulation of yogurt [52]. Protein and fat did not significantly change, suggesting that BSM did not significantly alter the main macronutrients of the principal milk feed significantly. The small rise in ash probably is attributable to the mineral matter that was added in with the mucilage. In general, the BSM treatments significantly increased the number of nonfat solids and carbohydrates and dietary fiber and maintained the protein and fat content during 21 days of refrigerated storage.

4.3. Acidification, Syneresis, Water-Holding Capacity, and Soluble Solids

The pH values of all formulations decreased and titratable acidity increased during refrigerated storage. This trend is consistent with post-acidification caused by continued metabolic activity of viable starter cultures and the progressive conversion of residual lactose to organic acids. Table 5 shows that the viable counts of both starter organisms gradually declined during storage, although they remained high in all treatments. Therefore, the continued decrease in pH and increase in titratable acidity do not indicate an increase in starter-cell numbers; rather, they reflect continued acid production by the remaining metabolically active starter population during refrigerated storage. A similar post-acidification trend during yogurt storage was reported by Khalil and Hussain [53].

BSM concentration also affected starter-culture counts, but the response was concentration-dependent rather than uniformly stimulatory or inhibitory. Consequently, the slightly higher acidity and lower pH observed at higher BSM concentrations should not be interpreted as evidence that BSM increased starter growth or exerted a direct prebiotic effect. Basil gum also was reported to have a significant effect on the acidity of yogurts by Noshadi *et al.* [54]. However, the presence of microbiological activity and the level of residual lactose were not determined in this study, so a direct prebiotic action cannot be proven. The nonsignificant treatment $\times$ storage interactions also indicate that the overall level of acidification changed, but not the temporal trend for BSM.

The most significant technological change brought about by BSM was the improvement of serum immobilization. In the BSM 0.40% sample, the amount of syneresis was decreased by 53.3% on day 1 and 47.6% on day 21 as compared to control. Rahmawati *et al.* [55] also found that there was significantly lower syneresis of the yogurt made from hydrated basil seeds than the yogurt made without the seeds. The inverse changes in WHC, from 85.81% at day 1 to 81.54% at day 21, verify that more serum was retained, due to the more water associated with the gel. The improved serum retention is consistent with hydration and expansion of BSM polysaccharides and increased viscosity of the continuous phase. Reinforcement of the casein network and interactions between anionic polysaccharides and milk proteins, including possible calcium-mediated associations, are plausible mechanisms reported for related hydrocolloid-dairy systems. However, these interactions and microstructural changes were not directly measured in the present study and therefore cannot be confirmed from the current data [56].

In the other set yogurt, such as almond-gum set yogurt, where the concentration of gum played a significant role in the WHC and syneresis [57], and fiber-enriched set yogurt, where structural reinforcement was used to increase the WHC to about 84.5% [58], similar behavior was observed. WHC reduced and syneresis increased during storage although BSM was very small. As the pH decreases further, the casein network may rearrange and contract progressively and gradually desorb the weakly immobilized serum. Importantly, centrifugation-based WHC and syneresis measure operationally released water and not all molecular water populations, as Gilbert *et al.* [59] showed that yoghurt contained different types of mobile (operationally released) and bulk and spontaneously separated water. The increase in the apparent soluble-solids values observed with increasing BSM was related to the contribution of the dispersed solid fraction. But the refractometric °Brix measurement should not only be considered as a measure of sugar concentration, since suspended or soluble hydrocolloid materials can affect the measurement. The combination of these results demonstrates that 0.40% BSM is the optimum formulation to retain serum during storage.

4.4. Instrumental Color

By day 21, BSM added 0.40% resulted in a decrease in L^* by 2.69 and an increase in b^* from 9.77 to 11.99 units in set yogurt as compared to control. These changes are likely due to the intrinsic cream to brown color of mucilage after drying and the addition of small quantities of phenolics-reactive materials, mineral, and residue from the seed. Processing is also sensitive to the color of BSM, as shown by Amini *et al.* [60] that the drying conditions in infrared drying changed the CIELAB coordinates and total color difference of BSM significantly. Therefore, differences between yogurt studies at similar addition rates may be caused by differences in type, amount, or purity of mucilage used; drying

methods; and particle size. In addition, BSM can indirectly alter yogurt color by altering its microstructure.

The lightness of the yogurt is highly dependent on light scattering of all fat globules, casein aggregates, serum channels, and particles suspended in the product. Hydration of BSM and its incorporation into the casein matrix might affect the optical homogeneity that brings about the bright-white look of conventional yogurt. This interpretation is supported by reports of a change in the continuity and uniformity of fermented-milk gel networks when the hydrocolloids are added [61, 62]. In the present study, however, no imaging of the microstructures was performed and a change in light scattering may be regarded as a possible, but not a proved, mechanism. The overall color divergence (ΔE_{ab}) increased from 0.09 in day-1 control to 4.40 at 0.40% BSM on day-21, indicating that formulation (0.40% BSM) was the major source of color divergence, and that storage was also giving a significant contribution. A ΔE_{ab} value of about 4.4 would normally be a perceptible difference under controlled viewing conditions and a ΔE_{ab} value of 0.88 is a value that would show limited storage-related difference. However, selected plant nano-mucilage yogurts with color properties similar to the standards (full-fat or skim-milk) were obtained by Tosif *et al.* [63], which indicated that color preservation is influenced by the mucilage source, concentration, purification, and particle sizes.

The large treatment $\times$ storage interaction for b^* (but not for other coordinates) also indicates that the development of yellowness was dependent on the formulation. These could be caused by the oxidation of pigments, changes in the ionization of the pigments due to post-acidification, and redistribution of BSM particles within the gel over time, which would require targeted pigment and microstructure analyses to be distinguished. [64] The different color results obtained for the various seed mucilage's [65] composite BSM-based delivery systems have different structures and corresponding constituents, so these color results should be taken with caution and applied to the specific seed mucilage and delivery system used in this study.

4.5. Textural Properties

For BSM, a dependable concentration-dependent set-yogurt structure reinforcement was observed. For BSM, firmness, consistency, cohesiveness, adhesiveness, gumminess, and springiness increased on the 21st day, by approximately 26.0%, 56.9%, 14.0%, 79.3%, 43.7%, and 14.0%, respectively, compared to the control. The increases in consistency and adhesiveness were particularly high, suggesting that BSM had a significant impact on resistance to initial deformation as well as work to move through and out of the yogurt matrix. Likewise, Sarraf *et al.* [66] reported that the hardness of whey-protein emulsion-gel increased from 1.27 to 3.03 N and the consistency of whey-protein emulsion-gel increased from 11.48 to 25.71 N-s when BSG was increased from 0 to 0.6%. The two studies show excellent mechanical reinforcement of BSG, although it is not possible to compare the absolute values directly because of the differences in matrix and testing geometry. The observed textural strengthening is consistent with increased hydration and viscosity of the serum phase and may also involve physical entanglement or noncovalent associations between BSM polysaccharides and milk proteins, as proposed in related hydrocolloid-protein systems. However, neither protein-polysaccharide interactions nor gel microstructure were directly measured in the present study. Therefore, these explanations should be considered plausible mechanisms rather than experimentally demonstrated mechanisms. BSG has been found to be more effective in developing more compact and uniform structures of dispersed oil droplets in protein gels [66].

In general, hydrocolloids can either interact with milk components or form an interpenetrating network that enhances the firmness and consistency of yogurt [67]. The research on hybrid-yogurt reveals that tighter and finer protein structures have higher hardness, storage modulus, and water retention [68]. Thus, the importance of network architecture is supported. Similarly, the composition of the proteins and the size of the microgel have been directly linked to the firmness of the yogurt and distribution of serum. The textural attributes were enhanced as well during storage. Continued post-acidification may have brought casein particles closer to their isoelectric region, potentially promoting protein-protein association, network rearrangement, and gradual gel contraction. Because these structural changes were not directly measured, this interpretation remains mechanistic rather than

confirmatory. This means that firmness and gumminess could rise even though the release of weakly held serum takes place. Similar changes in size and firmness of microgels have been observed in refrigerated yogurt when stored [69].

More detailed investigations of set yogurt also indicate that both whey separation and structural properties can be lowered by increasing the strength of protein interactions and decreasing the size of the microstructures [70]. The increased cohesiveness and springiness indicate that BSM provided a strengthening effect to the internal structure of the gel, although it did not create a very brittle gel. The nonsignificant treatment $\times$ storage interactions suggest that the structural effect of BSM was developed relatively early on and that subsequent aging took place at similar rates for the various formulations. However, sensory testing is still required as too much firmness, gumminess, or adhesion to the mouth can mean that a product is not accepted by consumers even though the physical stability is good [71, 72].

4.6. Antioxidant Properties

The enhancement effect of BSM did not appear to be limited to a specific reaction mechanism, as there was a consistent concentration-dependent increase across the Folin–Ciocalteu, DPPH, ABTS, and FRAP assays. The day-1 BSM showed a 77% increase with 96%, 85%, and 74% increases for DPPH, ABTS, and FRAP, respectively, compared to the control. Basil seeds have been reported to contain phenolic compounds and radical-scavenging components [6], which are transferred to the isolated mucilage and then to the yogurt. The term “total phenolic content” should be understood as “total Folin-reactive content” as the Folin reagent reacts with nonphenolic reducing substances, such as peptides and other reductants from the dairy matrix. From the phenolic-reactive content measured (3.80 mg GAE/g BSM), it was calculated that 4 g of BSM per 100 g of yogurt would add approximately 15.2 mg GAE/100 g of yogurt. This difference between the 0.40% yogurt and control group was slightly higher at 18.34 mg GAE/kg for day-1. This is not necessarily a sign of antioxidant synergy effect; it might be due to better extraction of matrix-bound compounds, matrix effect in Folin, or to the formation of reducing peptides during fermentation. Extraction temperature, extraction ratio, purification, and processing method can significantly affect the composition and functional performance of BSM [16, 73–75].

The carbohydrate-rich amorphous structure and associated minor phytochemicals could also affect the release of compounds and/or the availability of the assays [75, 76]. The antioxidant indices of the 0.40% formulation were reduced by approximately 8–10% after 21 days, but the formulation showed a significant benefit over the control. This decrease could be caused by oxidation, polymerization, reaction with milk proteins, or structural conversion to products of lower assay reactivity.

Overall reducing and radical-scavenging capacity was reduced during storage, which was further confirmed by the parallel reduction in the activity of these assays, in both DPPH and ABTS and FRAP, and not only in one assay. However, the results of nonsignificant treatment $\times$ storage interactions suggest that BSM did not significantly alter the proportional pattern of losses, but did raise the initial antioxidant content of the product. Overall, 0.40% BSM actually gave the highest and most persistent antioxidant enrichment, but the in-vitro type of these chemical tests is not a direct indicator of the biological antioxidant effects after ingestion.

4.7. Microbiological Quality

The numbers of both the starters of yogurt decreased considerably but were still abundant throughout the storage period. The counts of *S. thermophilus* reduced by 0.54–0.68 log CFU/g during 1–21 d, while *L. delbrueckii* subsp. *bulgaricus* reduced by 0.64–0.80 log CFU/g during 1–21 d. Predicted decreases in the number of cells that can be harvested during refrigeration are due to the continued acidification coupled with cold stress, organic acid accumulation, and nutrient limitation. Similar starter viability losses have been observed in fermented products for which the storage factor is important, but where significant numbers of viable organisms remain [77, 78]. However, the numbers

of both *S. thermophilus* and *L. bulgaricus* remained above 8 log CFU/g and 7.4 log CFU/g, respectively, on day 21, indicating good survival of the starters.

BSM concentration significantly affected starter-culture counts, and the response was concentration-dependent rather than uniformly stimulatory or inhibitory. The 0.20% BSM treatment generally maintained the highest *S. thermophilus* and total viable counts during refrigerated storage, whereas the 0.40% BSM treatment showed significantly lower *S. thermophilus* counts than the 0.20% BSM treatment. However, *S. thermophilus* counts in the 0.40% BSM treatment were not consistently lower than those of the control, and *L. delbrueckii* subsp. *bulgaricus* counts in BSM-containing treatments remained comparable to or higher than those of the control. Therefore, the highest BSM concentration may have partially limited starter-culture performance relative to the intermediate BSM concentration, rather than exerting a general inhibitory effect on the yogurt starter cultures. The lower starter performance at 0.40% BSM may be associated with the higher viscosity and slightly lower pH of this formulation, which could restrict substrate and metabolite diffusion and increase acid stress during refrigerated storage.

The role of mucilages in plant seeds is possibly fermentable carbohydrate fractions, water retention, and physical protection of bacteria in a microenvironment. Chia mucilage has also been noted to enhance viable populations of yogurt organisms during storage [79], and flaxseed mucilage in the survival of the cultures of fermented milk [80]. *Plantago ovata* mucilage has also been found useful as a functional ingredient for yogurt that is capable of changing starter cell micro environments [81].

In the present results, however, given that no measurement of carbohydrate utilization, enzyme activity, or microbiome composition was carried out, there was only an association of the culture supporting effect and not a prebiotic mechanism. This is because of the slight difference in the performances of 0.40% BSM and 0.20% BSM, indicating that the intermediate concentration provided a more favorable balance for starter-culture performance. The higher viscosity of the 0.40% yogurt could reduce the diffusion of substrate and metabolites, and the lower pH of the 0.40% yogurt could enhance the acid stress. This interpretation aligns with reports that fortification of plant-based yoghurt with microorganisms may beneficially increase microbial viability at the right level of fortification but does not necessarily increase benefits as fortification levels increase [82, 83].

The nonsignificant interactions show that the difference in treatments was confirmed in all storage periods and not due to variations in the rate of decrease as storage progressed. The counts of yeast and mold gradually increased and were kept low at 1.14–1.23 log CFU/g on day 21, without any apparent negative impact of BSM. This increase is probably due to slow psychrotrophic growth or less contamination after processing rather than to the lack of fermentation. The total absence of detectable coliforms is indicative of good pasteurization, handling, and prevention of contamination from feces or the environment. Note, however, that the term “not detected” should be taken in relation to the analytical detection limit, which should be given numerically in the Methods. When comparing the overall balance of starter retention with microbiological stability, 0.20% BSM was the most beneficial.

4.8. Sensory Properties

Sensory acceptance was nonlinear with BSM concentration, with 0.20% BSM showing the best sensory acceptance score, based on an improvement in the structure and the preservation of the yogurt-like flavor and mouthfeel. The mean overall acceptability (7.75) was in the category of “like moderately” to “like very much” on the 9-point hedonic scale and was 0.92 points higher than that of the control. This optimal value is similar to the result obtained by Almasi *et al.* [13] who determined that the concentration of 0.20% basil seed hydrocolloid was the best concentration to improve the sensory and physicochemical properties of low-fat yogurt. Similarly, okra pectin at 0.20% has been found to increase the acceptability of yogurt by consumers [84], as a result of it correcting sensory deficits in the product without overwhelming the sensory properties.

The higher rating of 0.20% BSM likely was due to several attributes that are interdependent: less visible whey separation, increased body, smoother consistency, and better coating of the mouth. However, there was no apparent further instrumental strengthening that was observed beyond 0.40% BSM. The highest concentration was the most effective whey separation, but had an adverse effect on

mouthfeel due to its high viscosity, adhesiveness, gumminess, and dark color. The lower scores for taste and aftertaste may also be indicative of the flavor and aftertaste of the seeds becoming evident at the highest concentration. Other mucilage's with similar concentration optima are reported: maximum overall acceptability was obtained with 0.15% flaxseed mucilage in yogurt; higher concentrations of 0.75% (lower) and 0.50% (optimum) showed decreased acceptability [85], maximum overall acceptability was obtained at 0.50% psyllium-mucilage level in yogurt, with higher 0.75% level showing decreased acceptability [86]. Therefore, the assumption of maximum physical stability does not necessarily equate to maximum consumer liking.

The results also account for the high whey-separation and texture scores obtained for the 0.30% formulation when compared to the low overall acceptance scores, as well as why the 0.30% formulation was less acceptable than 0.20% BSM. The appearance, taste, consistency, sticking to the teeth, and aftertaste of a product are not evaluated separately by the consumer. Mousavi *et al.* [87] also found that enriching yogurt with flaxseed increased the yogurt structure but might decrease the overall acceptance of the product at elevated levels. On the other hand, when the concentration of the chia mucilage is such that it can achieve the creaminess and viscosity similar to that of a reference yogurt, the fat can be replaced with it without reducing acceptability [88]. Optimal intermediate levels of psyllium addition (80) have also yielded the best sensory scores for low-fat yogurt [89].

Moderate loss of sensory scores during storage was similar to progressive color, aroma, gel strength, and aftertaste changes, which occurred as a consequence of post acidification. The significant interaction for stickiness acceptability and aftertaste suggests that both of these attributes evolved differently among the different concentrations, and the nonsignificant interaction for overall acceptability suggests that the relative ranking of the treatments remained unchanged. Therefore, 0.20% BSM is the most defensible formulation that can be used in product development, while 0.40% looks technologically effective but sensorially too much.

4.9. Exploratory Correlation Analysis

Two main groups of responses related to BSM concentration were identified based on the correlation matrix. The first group included TPC and DPPH activity, which showed almost a perfect correlation, suggesting that the number of Folin-reactive constituents increased along with the amount of radical-scavenging activity. The second group included WHC, firmness, and adhesiveness, which increased as a group, and syneresis decreased. These relationships are a basis for a coordinated technological response, namely, the enhancement of the serum immobilization and texture, by using BSM hydration and gel reinforcement. This correlation (WHC – syneresis: -0.98) is partially explained with the opposite aspects of serum retention that are measured by both methods and should not be seen as complete evidence. It is not the correlations between overall acceptability and individual variables that are weak, but rather it is sensorially unimportant.

Pearson's coefficient is a summary of linear association and can be close to zero if there is a non-linear association [90, 91]. This was seen as an optimum at 0.20% BSM, and then dropped off in liking, with both less than optimal structure in the control and more than optimal adhesiveness at 0.40% also resulting in a drop in liking. This inverted-U shape relationship between the two variables would be better described by a quadratic regression or a response surface modelling than by one Pearson coefficient. The matrix should be accompanied by scatterplots since the sets of data with similar correlations may have very different response patterns [92]. The following coefficients should, however, be listed as exploratory and descriptive. The 20 observations are means (not individual experimental units) of the treatment $\times$ storage-day interactions. Averaging eliminates the within-batch variation and repeated measurements with different concentrations and storage time do not meet the assumption of independence for ordinary Pearson correlations [93-95]. Furthermore, several highly-correlated relationships may be primarily attributed to their similar monotonic response to 5 BSM levels, not to a specific relationship. Note that the balanced factorial design does not imply mathematical independence of BSM and storage day, but rather the fact that they are not correlated. Similarly, the lack of correlation with storage day in the marginal analysis does not rule out the

existence of strong storage effects in the factorial analysis, as effects of the treatments can overrule effects over time within the treatments. As a result, there is a prohibition on using causal statements.

A more conclusive confirmatory analysis would have included the batch level data in a mixed-effects model with both treatment and storage as fixed effects and production batch as a random effect where the overall acceptability was tested for quadratic terms. A further limitation of the present study is that BSM was compared with an unstabilized control rather than directly with conventional yogurt stabilizers such as pectin, gelatin, or carboxymethyl cellulose. Therefore, the present results demonstrate the concentration-dependent stabilizing functionality of BSM relative to the control formulation, but they do not establish superiority or equivalence to conventional stabilizers. Direct head-to-head comparisons using technologically comparable concentrations and identical processing conditions will be required to determine the relative performance of BSM against established commercial stabilizers.

4.10. Novelty and Practical Implications

The main novelty of this work was the simultaneous evaluation of BSM in both compositional and physicochemical, textural, antioxidant, microbiological, and sensory aspects during a refrigerated storage period. This study illustrates that BSM can be used as a thickener, stabilizer, and to influence the composition of the yogurt, serum retention, gel structure, viability of the starter culture, in-vitro antioxidant activity, and consumer acceptance. The finding of particular interest is that there is a clear difference in the level of concentration that optimized instrumental performance and the level of sensory acceptance. There were only slight differences among the three levels of BSM in the antioxidant response, whereas the technological response was the greatest with 0.40% BSM, and the most acceptable overall sensory profile was obtained with 0.20% BSM.

The non-linear relationship indicates the importance of optimizing the level of hydrocolloid by considering instrumental and sensory parameters. Industrially, the results lead to a practical approach to optimizing the concentration of BSM for the desired product profile. A level of 0.20% is appropriate for a set yogurt that is generally acceptable, fibre-enriched, and has good stability and is suitable for use in most set yoghurt formulations; higher levels can be used in special formulations where water retention, gel strength, or antioxidant enrichment is the higher priority. Because conventional stabilizers were not included as direct comparators, these findings should not be interpreted as evidence that BSM is superior or equivalent to pectin, gelatin, carboxymethyl cellulose, or other established yogurt stabilizers. Prior to commercial use, however, the suitability of the 0.20% BSM level as a preferred formulation should be confirmed through larger consumer studies, pilot-scale production, shelf-life testing under commercial conditions, and regulatory evaluation.

5. Conclusions

Basil seed mucilage demonstrated multifunctional stabilizing effects in set yogurt relative to the unstabilized control during 21 days of refrigerated storage. Its incorporation increased total solids, water-holding capacity, gel strength, and in-vitro antioxidant indices, while decreasing syneresis and maintaining acceptable microbiological quality. Starter-culture response was concentration dependent; the 0.20% BSM treatment generally maintained the highest starter-culture counts, whereas the 0.40% BSM treatment showed somewhat lower counts than the intermediate BSM concentrations, although starter populations remained high throughout storage. The technological benefits of BSM were concentration-dependent and were not directly proportional to sensory acceptance. Although 0.40% BSM provided the highest serum retention, firmness, and antioxidant activity, it also resulted in greater adhesiveness and gumminess and lower scores for taste, smoothness, aftertaste, and overall acceptability. Among the formulations evaluated, 0.20% BSM provided the best balance between technological performance and consumer acceptance. This concentration improved serum stability and textural properties while maintaining high starter-culture counts and consistently high sensory scores during refrigerated storage. Therefore, among the concentrations evaluated, 0.20% BSM represented the most favorable compromise when technological performance and consumer acceptance were considered jointly. Higher BSM concentrations may be considered when greater water binding, firmer

texture, or enhanced in-vitro antioxidant activity is desired; however, formulation optimization is necessary to avoid adverse effects on sensory quality.

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References

- [1] M. Arab, M. Yousefi, E. Khanniri, M. Azari, V. Ghasemzadeh-Mohammadi, and N. Mollakhalili-Meybodi, "A comprehensive review on yogurt syneresis: Effect of processing conditions and added additives," *Journal of Food Science and Technology*, vol. 60, no. 6, pp. 1656-1665, Jun. 2023, doi: 10.1007/s13197-022-05403-6.
- [2] G. K. Deshwal, S. Tiwari, A. Kumar, R. K. Raman, and S. Kadyan, "Review on factors affecting and control of post-acidification in yoghurt and related products," *Trends in Food Science & Technology*, vol. 109, pp. 499-512, Mar. 2021, doi: 10.1016/j.tifs.2021.01.057.
- [3] J. Zang *et al.*, "Hydrocolloid application in yogurt: Progress, challenges and future trends," *Food Hydrocolloids*, vol. 153, p. 110069, Aug. 2024, doi: 10.1016/j.foodhyd.2024.110069.
- [4] I. A. Kassem, T. Joshua Ashaolu, R. Kamel, N. A. Elkasabgy, S. M. Afifi, and M. A. Farag, "Mucilage as a functional food hydrocolloid: Ongoing and potential applications in prebiotics and nutraceuticals," *Food & Function*, vol. 12, no. 11, pp. 4738-4748, Jun. 2021, doi: 10.1039/D1FO00438G.
- [5] S. Naji-Tabasi and S. M. A. Razavi, "Functional properties and applications of basil seed gum: An overview," *Food Hydrocolloids*, vol. 73, pp. 313-325, Dec. 2017, doi: 10.1016/j.foodhyd.2017.07.007.
- [6] S. Nazir and I. A. Wani, "Functional characterization of basil (*Ocimum basilicum* L.) seed mucilage," *Bioactive Carbohydrates and Dietary Fibre*, vol. 25, p. 100261, May 2021, doi: 10.1016/j.bcdf.2021.100261.
- [7] N. Hussain, I. Ishak, M. F. Abdullah, A. Abd Rauh, and N. Azhar, "Water soluble hydrocolloid from basil seed (*Ocimum basilicum* L.) mucilage," *Malaysian Applied Biology*, vol. 48, no. 2, pp. 97-101, May 2019.
- [8] F. Salehi and M. Kashaninejad, "Effect of drying methods on textural and rheological properties of basil seed gum," *International Food Research Journal*, vol. 24, no. 5, pp. 2090-2096, Jan. 2017.
- [9] S. Nazir and I. A. Wani, "Fractionation and characterization of mucilage from Basil (*Ocimum basilicum* L.) seed," *Journal of Applied Research on Medicinal and Aromatic Plants*, vol. 31, p. 100429, Dec. 2022, doi: 10.1016/j.jarmap.2022.100429.
- [10] M. Jafari, Y. Ramezan, B. Tajeddin, and M. R. Khani, "Optimization of plasma-activated water-assisted extraction of basil seed (*Ocimum basilicum* L.) mucilage: Effect on phenols, flavonoids, antioxidant, thermal and morphological properties," *Innovative Food Science & Emerging Technologies*, vol. 99, p. 103876, Jan. 2025, doi: 10.1016/j.ifset.2024.103876.
- [11] A. Afshar Nik, Z. R. Amiri, and S. Hosseini-Parvar, "The effect of basil seed gum as a fat replacer on physico-chemical, micro structural and sensory properties of low-fat set yogurt," *Electronic Journal of Food Processing and Preservation*, vol. 3, no. 2, pp. 23-42, Jan. 2011.
- [12] S. Y. Kim, O. Hyeonbin, P. Lee, and Y.-S. Kim, "The quality characteristics, antioxidant activity, and sensory evaluation of reduced-fat yogurt and nonfat yogurt supplemented with basil seed gum as a fat substitute," *Journal of Dairy Science*, vol. 103, no. 2, pp. 1324-1336, Feb. 2020, doi: 10.3168/jds.2019-17117.
- [13] N. Almasi, J. Mohammadzadeh Milani, and L. Najafian, "Effect of Basil Seed Hydrocolloid on Physicochemical and Sensory properties of low-fat Yogurt," *Journal of Food Science and Technology (Iran)*, vol. 18, no. 121, pp. 1-11, Mar. 2022, doi: 10.52547/fsct.18.121.1.
- [14] M. A. Hesarinejad, A. Arefkhani, A. Rafe, F. Javidi, and A. Sadeghian, "Investigating the qualitative, textural and sensory characteristics of low fat Iranian white cheese containing a mixture of basil seed gum with xanthan or guar," *Iranian Food Science & Technology Research Journal*, vol. 17, no. 4, pp. 583-593, 2021.
- [15] G. W. Latimer, Jr., Ed., *Official Methods of Analysis of AOAC INTERNATIONAL*, 22nd ed. Oxford, U.K.: Oxford University Press, Jan. 2023, doi: 10.1093/9780197610145.001.0001.
- [16] Milk and milk products--Determination of nitrogen content--Part 1: Kjeldahl principle and crude protein calculation, ISO 8968-1:2014 | IDF 20-1:2014, International Organization for Standardization and International Dairy Federation, Geneva, Switzerland, Feb. 2014. [Online]. Available: <https://www.iso.org/standard/61020.html>.

- [17] B. Neeharika and K. Vijayalaxmi, "Optimisation of clove basil and sweet basil seeds mucilages extraction for utilisation as functional ingredients," *Journal of Scientific & Industrial Research*, vol. 82, no. 9, pp. 989-999, Sep. 2023, doi: 10.56042/jsir.v82i9.1937.
- [18] V. L. Singleton and J. A. Rossi Jr, "Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents," *American journal of Enology and Viticulture*, vol. 16, no. 3, pp. 144-158, Jan. 1965, doi: 10.5344/ajev.1965.16.3.144.
- [19] W. Brand-Williams, M.-E. Cuvelier, and C. Berset, "Use of a free radical method to evaluate antioxidant activity," *LWT-Food Science and Technology*, vol. 28, no. 1, pp. 25-30, Jan. 1995, doi: 10.1016/S0023-6438(95)80008-5.
- [20] A. B. Shori, A. Albalawi, A. J. Al Zahrani, O. S. Al-sulbi, and A. S. Baba, "Microbial analysis, antioxidant activity, and sensory properties of yoghurt with different starter cultures during storage," *International Dairy Journal*, vol. 126, p. 105267, Mar. 2022, doi: 10.1016/j.idairyj.2021.105267.
- [21] Yogurt--Determination of total solids content (Reference method), ISO 13580:2005 | IDF 151:2005, International Organization for Standardization and International Dairy Federation, Geneva, Switzerland, May 2005. [Online]. Available: <https://www.iso.org/standard/36878.html>.
- [22] Milk products and milk-based foods--Determination of fat content by the Weibull-Berntrop gravimetric method (Reference method)--Part 3: Special cases, ISO 8262-3:2005 | IDF 124-3:2005, International Organization for Standardization and International Dairy Federation, Geneva, Switzerland, Nov. 2005. [Online]. Available: <https://www.iso.org/standard/42700.html>.
- [23] G. W. Latimer, Jr., Ed., "AOAC Official Method 945.46 Ash of Milk: Gravimetric Method," in *Official Methods of Analysis of AOAC INTERNATIONAL*, 22nd ed. Oxford, U.K.: Oxford University Press, Jan. 2023, doi: 10.1093/9780197610145.001.0001.
- [24] AOAC INTERNATIONAL, "Total, soluble, and insoluble dietary fiber in foods," AOAC Official Method 991.43, in *Official Methods of Analysis of AOAC INTERNATIONAL*, 22nd ed., G. W. Latimer, Jr., Ed. Oxford, U.K.: Oxford University Press, Jan. 2023, doi: 10.1093/9780197610145.001.0001.
- [25] L. Campos, P. Tuma, T. Silva, D. Gomes, C. D. Pereira, and M. H. Henriques, "Low fat yoghurts produced with different protein levels and alternative natural sweeteners," *Foods*, vol. 13, no. 2, p. 250, Jan. 2024, doi: 10.3390/foods13020250.
- [26] Fermented milks--Determination of titratable acidity--Potentiometric method, ISO/TS 11869:2012, International Organization for Standardization, Geneva, Switzerland, Jan. 2012.
- [27] T. Amatayakul, F. Sherkat, and N. P. Shah, "Syneresis in set yogurt as affected by EPS starter cultures and levels of solids," *International Journal of Dairy Technology*, vol. 59, no. 3, pp. 216-221, Aug. 2006, doi: 10.1111/j.1471-0307.2006.00264.x.
- [28] W.-J. Lee and J. Lucey, "Formation and physical properties of yogurt," *Asian-Australasian Journal of Animal Sciences*, vol. 23, no. 9, pp. 1127-1136, Sep. 2010.
- [29] Colorimetry--Part 4: CIE 1976 L*a*b* colour space, ISO/CIE 11664-4:2019, International Organization for Standardization and International Commission on Illumination, Geneva, Switzerland, Jun. 2019.
- [30] M. Greis, T. Sainio, K. Katina, A. A. Nolden, A. J. Kinchla, L. Seppä, and R. Partanen, "Physicochemical properties and mouthfeel in commercial plant-based yogurts," *Foods*, vol. 11, no. 7, p. 941, Mar. 2022, doi: 10.3390/foods11070941.
- [31] Y. Zhao, R. Fu, and J. Li, "Effects of the β -glucan, curdlan, on the fermentation performance, microstructure, rheological and textural properties of set yogurt," *Lwt*, vol. 128, p. 109449, Jun. 2020, doi: 10.1016/j.lwt.2020.109449.
- [32] S. Li, A. Ye, and H. Singh, "Effects of seasonal variations on the quality of set yogurt, stirred yogurt, and Greek-style yogurt," *Journal of Dairy Science*, vol. 104, no. 2, pp. 1424-1432, Feb. 2021, doi: 10.3168/jds.2020-19071.
- [33] R. Re, N. Pellegrini, A. Proteggente, A. Pannala, M. Yang, and C. Rice-Evans, "Antioxidant activity applying an improved ABTS radical cation decolorization assay," *Free Radical Biology and Medicine*, vol. 26, no. 9-10, pp. 1231-1237, May 1999, doi: 10.1016/S0891-5849(98)00315-3.
- [34] A. Yousefvand, Q.-H. Pham, T. M. Ho, S. Amiri, N. Mäkelä-Salmi, and P. E. Saris, "Bifidobacterium animalis subsp. lactis BB12-derived postbiotic powders enhance antioxidant and physicochemical properties of low-fat yoghurt," *Food and Bioprocess Technology*, vol. 17, no. 11, pp. 4354-4370, Nov. 2024, doi: 10.1007/s11947-024-03405-0.
- [35] I. F. Benzie and J. J. Strain, "The ferric reducing ability of plasma (FRAP) as a measure of "antioxidant power": the FRAP assay," *Analytical Biochemistry*, vol. 239, no. 1, pp. 70-76, Jul. 1996, doi: 10.1006/abio.1996.0292.
- [36] Microbiology of the food chain--General requirements and guidance for microbiological examinations, ISO 7218:2024, International Organization for Standardization, Geneva, Switzerland, Jun. 2024.
- [37] Yoghurt--Enumeration of characteristic microorganisms--colony-count technique, ISO 7889:2026, International Organization for Standardization, Geneva, Switzerland, Jan. 2026.
- [38] Microbiology of the food chain--Horizontal method for the enumeration of microorganisms--Part 1: Colony count at 30 °C by the pour plate technique, ISO 4833-1:2013, International Organization for Standardization, Geneva, Switzerland, Sep. 2013; Amd. 1, Jan. 2022.
- [39] Microbiology of food and animal feeding stuffs--Horizontal method for the enumeration of yeasts and moulds--Part 1: Products with water activity greater than 0.95, ISO 21527-1:2008, International Organization for Standardization, Geneva, Switzerland, Jul. 2008.
- [40] Microbiology of food and animal feeding stuffs--Horizontal method for the enumeration of coliforms--Colony-count technique, ISO 4832:2006, International Organization for Standardization, Geneva, Switzerland, Feb. 2006.
- [41] Sensory analysis--Methodology--General guidance for conducting hedonic tests with consumers in a controlled area, ISO 11136:2014, International Organization for Standardization, Geneva, Switzerland, Dec. 2014; Amd. 1, Jan. 2020.
- [42] Sensory analysis--General guidance for the design of test rooms, ISO 8589:2007, International Organization for Standardization, Geneva, Switzerland, Dec. 2007.
- [43] Sensory analysis--Selection and training of sensory assessors, ISO 8586:2023, International Organization for Standardization, Geneva, Switzerland, Apr. 2023.

- [44] Sensory analysis--Methodology--General guidance, ISO 6658:2017, International Organization for Standardization, Geneva, Switzerland, Jul. 2017.
- [45] F. Salehi, M. Kashaninejad, A. Tadayyon, and F. Arabameri, "Modeling of extraction process of crude polysaccharides from Basil seeds (*Ocimum basilicum* L.) as affected by process variables," *Journal of Food Science and Technology*, vol. 52, no. 8, pp. 5220-5227, Aug. 2015, doi: 10.1007/s13197-014-1614-1.
- [46] L. Guan *et al.*, "Extraction of basil seed gum: Optimization and functional properties," *Journal of Applied Research on Medicinal and Aromatic Plants*, vol. 42, p. 100570, Sep. 2024, doi: 10.1016/j.jarmap.2024.100570.
- [47] S. M. Razavi, S. A. Mortazavi, L. Matia-Merino, S. H. Hosseini-Parvar, A. Motamedzadegan, and E. Khanipour, "Optimisation study of gum extraction from basil seeds (*Ocimum basilicum* L.)," *International Journal of Food Science & Technology*, vol. 44, no. 9, pp. 1755-1762, Sep. 2009, doi: 10.1111/j.1365-2621.2009.01993.x.
- [48] L. Guan *et al.*, "The recent progress in the research of extraction and functional applications of basil seed gum," *Heliyon*, vol. 9, no. 9, p. e19302, Sep. 2023, doi: 10.1016/j.heliyon.2023.e19302.
- [49] R. Molaei Roudsari, A. Rahmani, L. Nateghi, and F. Zarei, "Seed gum of basil (*Ocimum basilicum* L.) as a halal hydrocolloid affects technological and organoleptic properties of probiotic low-fat yogurt," *Human, Health and Halal Metrics*, vol. 2, no. 1, pp. 20-26, 2021.
- [50] M. Javed, W. Ahmed, H. M. Shahbaz, S. Rashid, and H. Javed, "Techno-functional assay and quality assessment of yogurt supplemented with basil seed gum powder," *Brazilian Archives of Biology and Technology*, vol. 65, p. e22200814, Sep. 2022, doi: 10.1590/1678-4324-2022200814.
- [51] Z. Shahmoradi, M. Alizadeh Khaledabad, and S. Amiri, "Effect of co-encapsulation of Lactobacillus acidophilus LA5 and selenium in hydrogelated matrix of basil seed mucilage/sodium caseinate on properties of set yogurt," *Food Bioscience*, vol. 55, p. 103039, Oct. 2023, doi: 10.1016/j.fbio.2023.103039.
- [52] Z. Ghasempour, N. Javanmard, A. M. Langroodi, M. Alizadeh-Sani, A. Ehsani, and E. M. Kia, "Development of probiotic yogurt containing red beet extract and basil seed gum; techno-functional, microbial and sensorial characterization," *Biocatalysis and Agricultural Biotechnology*, vol. 29, p. 101785, Oct. 2020, doi: 10.1016/j.bcab.2020.101785.
- [53] I. a. Q. M. Khalil and M. H. Hussain, "Improving the sensory and rheological properties of yogurt using aqueous extract of basil (*Ocimum basilicum* L.)," *Journal of Kerbala for Agricultural Sciences*, vol. 9, no. 4, pp. 76-90, Dec. 2022, doi: 10.59658/jkas.v9i4.1065.
- [54] M. Noshadi, M. Karami, M. Arab, M. Taheri, and V. Ghasemzadeh-Mohammadi, "Effect of propolis extracted and basil gum addition on physicochemical, rheological, sensory, and antioxidant properties of low-fat yogurt," *Journal of Food Science and Technology*, vol. 62, no. 10, pp. 1935-1944, Oct. 2025, doi: 10.1007/s13197-025-06208-z.
- [55] M. A. Rahmawati, K. Patricia, D. R. Adawiyah, and E. Prangdimurti, "pengaruh penambahan biji chia dan selasih terhadap sifat fisikokimia, sensori, dan mikrobiologis yoghurt," *Jurnal Teknologi dan Industri Pangan*, vol. 35, no. 1, pp. 106-118, Jun. 2024, doi: 10.6066/jtip.2024.35.1.106.
- [56] K. D. C. Pamalka, S. S. Munasinghe, D. Weerathilake, and G. S. Liyanage, "Textural properties of yogurts, containing plant stabilizers: a review," *Journal of Food Science and Technology*, vol. 63, no. 3, pp. 430-440, Mar. 2026, doi: 10.1007/s13197-026-06555-5.
- [57] M. B. Mir, S. Rastogi, and S. Haripriya, "Optimization of process variables for the preparation of almond gum incorporated set-yogurt using Box-Behnken response surface model," *Applied Food Research*, vol. 1, no. 2, p. 100016, Dec. 2021, doi: 10.1016/j.afres.2021.100016.
- [58] B. Chen, X. Zhao, Y. Cai, X. Jing, M. Zhao, Q. Zhao, and P. Van der Meeren, "Incorporation of modified okara-derived insoluble soybean fiber into set-type yogurt: Structural architecture, rheological properties and moisture stability," *Food Hydrocolloids*, vol. 137, p. 108413, Apr. 2023, doi: 10.1016/j.foodhyd.2022.108413.
- [59] A. Gilbert, L.-E. Rioux, D. St-Gelais, and S. L. Turgeon, "Characterization of syneresis phenomena in stirred acid milk gel using low frequency nuclear magnetic resonance on hydrogen and image analyses," *Food Hydrocolloids*, vol. 106, p. 105907, Sep. 2020, doi: 10.1016/j.foodhyd.2020.105907.
- [60] G. Amini, F. Salehi, and M. Rasouli, "Color changes and drying kinetics modeling of basil seed mucilage during infrared drying process," *Information Processing in Agriculture*, vol. 9, no. 3, pp. 397-405, Sep. 2022, doi: 10.1016/j.inpa.2021.07.001.
- [61] L. Li *et al.*, "Role and influence mechanism of different concentration of hyaluronic acid on physicochemical and organoleptic properties of yogurt," *Journal of Dairy Science*, vol. 108, no. 1, pp. 218-228, Jan. 2025, doi: 10.3168/jds.2024-25687.
- [62] H. Sıramaz, "Synergistic effect of ultrasound and pectin addition on enhancing yogurt structure," *LWT*, vol. 228, p. 118082, Jul. 2025, doi: 10.1016/j.lwt.2025.118082.
- [63] M. M. Tosif, A. Bains, G. Goksen, M. Z. Rehman, N. Ali, G. Karabulut, and P. Chawla, "A comparative study on utilization of different plant-derived nano-mucilage as a fat replacer in yogurt: Product optimization, physicochemical attributes, shelf-life evaluation, and consumer perception with market orientation," *Food Chemistry: X*, vol. 24, p. 101920, Dec. 2024, doi: 10.1016/j.fochx.2024.101920.
- [64] M. Yousefi, E. Khanniri, and N. Khorshidian, "Effect of Plantago major L. seed mucilage on physicochemical, rheological, textural and sensory properties of non-fat yogurt," *Applied Food Research*, vol. 5, no. 1, p. 100687, Jun. 2025, doi: 10.1016/j.afres.2024.100687.
- [65] Y. Nami, A. Kiani, D. Elieh-Ali-Komi, M. Jafari, and B. Haghshenas, "Impacts of alginate-basil seed mucilage-prebiotic microencapsulation on the survival rate of the potential probiotic Leuconostoc mesenteroides ABRIINW. N18 in yogurt," *International Journal of Dairy Technology*, vol. 76, no. 1, pp. 138-148, Feb. 2023, doi: 10.1111/1471-0307.12909.
- [66] M. Sarraf, S. Naji-Tabasi, A. Beig-Babaei, J. E. Moros, M. C. Sánchez, J. M. Franco, and A. Tenorio-Alfonso, "Improving the structure and properties of whey protein emulsion gel using soluble interactions with xanthan and basil seed gum," *Food Science & Nutrition*, vol. 11, no. 11, pp. 6907-6919, Nov. 2023, doi: 10.1002/fsn.3598.

- [67] A. Behnia, H. Karazhiyan, R. Niazmand, and A. R. M. Nafchi, "Rheological properties of low fat yogurt containing cress seed gum," *Agricultural Sciences*, vol. 4, no. 9, pp. 29-32, Sep. 2013, doi: 10.4236/as.2013.49B005.
- [68] J. Ran, S. Pang, H. Li, R. Zhao, Y. Zhang, Y. Li, and M. Yang, "Gel properties of mung bean protein-sodium caseinate hybrid yogurt: Physicochemical properties, microstructure, and intermolecular interactions," *Food Chemistry: X*, vol. 24, p. 101977, Dec. 2024, doi: 10.1016/j.fochx.2024.101977.
- [69] A. Gilbert, L.-E. Rioux, D. St-Gelais, and S. Turgeon, "Smoothing temperature and ratio of casein to whey protein: Two tools to improve nonfat stirred yogurt properties," *Journal of Dairy Science*, vol. 104, no. 10, pp. 10485-10499, Oct. 2021, doi: 10.3168/jds.2020-20040.
- [70] J. Qing, C. Peng, H. Chen, H. Li, and X. Liu, "Small molecule linoleic acid inhibiting whey syneresis via interact with milk proteins in the fermentation of set yogurt fortified with c9, t11-conjugated linoleic acid," *Food Chemistry*, vol. 429, p. 136849, Dec. 2023, doi: 10.1016/j.foodchem.2023.136849.
- [71] A. Akhi, T. Ahmed, R. Ara, and M. R. Rana, "Response surface optimization of thermo-sonication conditions and taro mucilage concentrations for the preparation of soy yogurt," *Journal of Agriculture and Food Research*, vol. 15, p. 100918, Mar. 2024, doi: 10.1016/j.jafr.2023.100918.
- [72] D. Daniloski, T. Vasiljevic, D. Freitas, T. A. Comunian, A. Brodkorb, and N. A. McCarthy, "Physicochemical and simulated gastric digestion properties of A1/A1, A1/A2 and A2/A2 yoghurts," *Food Hydrocolloids*, vol. 157, p. 110430, Dec. 2024, doi: 10.1016/j.foodhyd.2024.110430.
- [73] M. Shiehnezhad, S. Zarringhalami, and N. Malekjani, "Optimization of microwave-assisted extraction of mucilage from *Ocimum basilicum* var. album (L.) seed," *Journal of Food Processing and Preservation*, vol. 2023, no. 1, p. 5524621, May 2023, doi: 10.1155/2023/5524621.
- [74] H. Maqsood, M. Uroos, R. Muazzam, S. Naz, and N. Muhammad, "Extraction of basil seed mucilage using ionic liquid and preparation of AuNps/mucilage nanocomposite for catalytic degradation of dye," *International Journal of Biological Macromolecules*, vol. 164, pp. 1847-1857, Dec. 2020, doi: 10.1016/j.ijbiomac.2020.08.073.
- [75] S. Mukherjee, D. Avlani, S. B. Majee, and G. Biswas, "Physicochemical and pharmaceutical characterisation of mucilage from sweet basil seed," *International Journal of Applied Pharmaceutics*, vol. 11, Special Issue 2, pp. 12-17, May 2019, doi: 10.22159/ijap.2019v11i3.31312.
- [76] D. Avlani, V. Agarwal, V. Khattri, G. R. Biswas, and S. B. Majee, "Exploring properties of sweet basil seed mucilage in development of pharmaceutical suspensions and surfactant-free stable emulsions," *International Journal of Applied Pharmaceutics*, vol. 11, no. 1, pp. 124-129, Jan. 2019, doi: 10.22159/ijap.2019v11i1.29877.
- [77] M. Ziarno, D. Zareba, I. Ścibisz, and M. Kozłowska, "Comprehensive studies on the stability of yogurt-type fermented soy beverages during refrigerated storage using dairy starter cultures," *Frontiers in Microbiology*, vol. 14, p. 1230025, Aug. 2023, doi: 10.3389/fmicb.2023.1230025.
- [78] M. A. Saadi, S. S. Sekhavatizadeh, H. Barzegar, B. A. Behbahani, and M. A. Mehrnia, "Date yogurt supplemented with *Lactobacillus rhamnosus* (ATCC 53103) encapsulated in wild sage (*Salvia macrosiphon*) mucilage and sodium alginate by extrusion: The survival and viability against the gastrointestinal condition, cold storage, heat, and salt with low pH," *Food Science & Nutrition*, vol. 12, no. 10, pp. 7630-7643, Oct. 2024, doi: 10.1002/fsn3.4304.
- [79] M. Hovjecki *et al.*, "Chia seed mucilage as a functional ingredient to improve quality of goat milk yoghurt: Effects on rheology, texture, microstructure and sensory properties," *Fermentation*, vol. 10, no. 8, p. 382, Jul. 2024, doi: 10.3390/fermentation10080382.
- [80] E. Alhssan, S. Ş. Ercan, and H. Bozkurt, "Effect of flaxseed mucilage and gum arabic on probiotic survival and quality of kefir during cold storage," *Foods*, vol. 12, no. 3, p. 662, Feb. 2023, doi: 10.3390/foods12030662.
- [81] S. Z. Mehrinejad Choobari, A. A. Sari, and A. Daraei Garmakhany, "Effect of *Plantago ovata* Forsk seed mucilage on survivability of *Lactobacillus acidophilus*, physicochemical and sensory attributes of produced low-fat set yoghurt," *Food Science & Nutrition*, vol. 9, no. 2, pp. 1040-1049, Feb. 2021, doi: 10.1002/fsn3.2074.
- [82] H. G. Aziz and S. Hekmat, "Microbial quality and sensory evaluation of probiotic yogurt fortified with functional seeds," *Exploration of Foods and Foodomics*, vol. 3, p. 1010101, Dec. 2025, doi: 10.37349/eff.2025.1010101.
- [83] M. A. Hossain, M. M. Hoque, M. M. Ahmed, and T. Ahmed, "Probiotic yoghurt-like fermented milk product enriched with *Lactobacillus desidius* and *Lactobacillus fermentum*: proximate composition, physicochemical, microbiological, and sensory evaluation during refrigerated storage," *Discover Food*, vol. 4, no. 1, p. 24, Apr. 2024, doi: 10.1007/s44187-024-00093-9.
- [84] M. Tobil, C. Y. Deh, J. K. Agbenorhevi, G. O. Sampson, and F. M. Kpodo, "Effect of okra pectin on the sensory, physicochemical and microbial quality of yoghurt," *Food and Nutrition Sciences*, vol. 11, no. 6, pp. 442-456, Jun. 2020, doi: 10.4236/fns.2020.116032.
- [85] S. Arabshahi-Delouee, S. Rahati Ghochani, and A. Mohammadi, "Effect of flaxseed (*Linum usitatissimum*) mucilage on physicochemical and sensorial properties of semi-fat set yoghurt," *Journal of Food Biosciences and Technology*, vol. 10, no. 2, pp. 91-100, Jul. 2020.
- [86] J. Wyrwiz and P. Pokorski, "The impact of psyllium mucilage as a stabilizer on the physical and sensory properties of vegan yogurt ice cream," *Applied Sciences*, vol. 15, no. 20, p. 11190, Oct. 2025, doi: 10.3390/app152011190.
- [87] M. Mousavi, A. Heshmati, A. Daraei Garmakhany, A. Vahidinia, and M. Taheri, "Texture and sensory characterization of functional yogurt supplemented with flaxseed during cold storage," *Food Science & Nutrition*, vol. 7, no. 3, pp. 907-917, Mar. 2019, doi: 10.1002/fsn3.805.
- [88] S. Ribes, N. Peña, A. Fuentes, P. Talens, and J. M. Barat, "Chia (*Salvia hispanica* L.) seed mucilage as a fat replacer in yogurts: Effect on their nutritional, technological, and sensory properties," *Journal of Dairy Science*, vol. 104, no. 3, pp. 2822-2833, Mar. 2021, doi: 10.3168/jds.2020-19240.

- [89] M. N. Hassan, A. S. Salem, A. A.-m. Hassan, and H. H. Abozied, "Development of functional low-fat yoghurt fortified with psyllium husk mucilage: Quality attributes, microstructure, and antioxidant characteristics," *Acta Scientiarum Polonorum Technologia Alimentaria*, vol. 23, no. 1, pp. 49-64, Mar. 2024, doi: 10.17306/J.AFS.001193.
- [90] N. N. Kachouie and W. Deebani, "Association factor for identifying linear and nonlinear correlations in noisy conditions," *Entropy*, vol. 22, no. 4, p. 440, Apr. 2020, doi: 10.3390/e22040440.
- [91] M. Pividori, M. D. Ritchie, D. H. Milone, and C. S. Greene, "An efficient, not-only-linear correlation coefficient based on clustering," *Cell Systems*, vol. 15, no. 9, pp. 854-868.e3, Sep. 2024, doi: 10.1016/j.cels.2024.08.005.
- [92] F. J. Anscombe, "Graphs in statistical analysis," *The American Statistician*, vol. 27, no. 1, pp. 17-21, Feb. 1973, doi: 10.1080/00031305.1973.10478966.
- [93] J. Z. Bakdash and L. R. Marusich, "Repeated measures correlation," *Frontiers in Psychology*, vol. 8, p. 456, Apr. 2017, doi: 10.3389/fpsyg.2017.00456.
- [94] J. M. Bland and D. G. Altman, "Statistics notes: Calculating correlation coefficients with repeated observations: Part 1--correlation within subjects," *BMJ*, vol. 310, no. 6977, p. 446, Feb. 1995, doi: 10.1136/bmj.310.6977.446.
- [95] J. M. Bland and D. G. Altman, "Calculating correlation coefficients with repeated observations: Part 2--Correlation between subjects," *BMJ*, vol. 310, no. 6980, p. 633, Mar. 1995, doi: 10.1136/bmj.310.6980.633.