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Development of Greek-like yogurt from camel milk fortified with goat whey and sweetened with fig powder

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Introduction: This study was conducted to explore the production of Greek-like yogurt from protein fortified camel milk and to evaluate how compositional and processing modifications could enhance its technological and sensory qualities. The research specifically investigated the effects of protein fortification and trisodium citrate addition as standardization tools, as well as the substitution of sucrose with fig (*Ficus carica* L.) powder as a natural sweetener and functional ingredient.

Methods: Hence, it was conducted in two phases. Initially, various protein powders were tested to enhance fermentation, with goat whey (GW) showing superior results compared to cow whey protein isolate (CWPI). GW was selected for further research.

Results and discussion: In the main phase, GW protein was used to standardize camel milk, replacing sugar with fig powder in treatments labelled GCM-F0 to GCM-F100. Over 15 days, fig-enriched formulations exhibited improved water-holding capacity and lower syneresis. Up to 75% sugar replacement maintained optimal viscosity and stability. The addition of fig powder led to an increase in total phenolic content. However, the antioxidant activity measured on the same day of storage did not show significant changes based on the amount of fig powder used. Notably, the duration of storage had a significant impact at each level of fig powder addition, as it increased the DPPH radical scavenging activity over time. Additionally, the incorporation of fig powder increased the browning index, while reducing sweet and sour taste sensations. The study concluded that natural additives like fig powder can enhance camel milk Greek-like yogurt, appealing to health-conscious consumers.

KEYWORDS

camel milk, fermentation, fig powder, Greek-like yogurt, antioxidant activity, sustainability, food supply

1 Introduction

Fermented dairy products play a vital role in human nutrition by offering a rich source of protein, essential micronutrients, antioxidants, and prebiotics (Danielewicz et al., 2022; Rizzoli and Biver, 2024; Saleem et al., 2024). These components provide various health benefits, including probiotic, prebiotic and postbiotic effects (Savaiano and Hutkins, 2021; Aljutaily et al., 2022). Additionally, fermented dairy products come with diverse sensory profiles and longer shelf lives (Alwohaibi et al., 2023; Hossain et al., 2024; Zhao et al., 2025). The fermentation process not only enhances the bioavailability of nutrients but also introduces beneficial probiotics, which are essential for gut health and immune system support

(Saleem et al., 2024). High-protein fermented dairy products are particularly effective at stimulating muscle protein synthesis, promoting bone density, and increasing feelings of fullness (Rizzoli and Biver, 2024). As a result, they are important for weight management and metabolic health (Danielewicz et al., 2022).

Recent trends show a growing consumer demand for high-protein, low-refined-sugar dairy alternatives (Tao et al., 2024). In April 2026, the U. S. Department of Health and Human Services, alongside the U. S. Department of Agriculture, released the latest Dietary Guidelines for Americans (2025–2030) (U.S. Department of Health and Human Services, and U.S. Department of Agriculture, 2026). These guidelines emphasise the importance of reducing added sugars while encouraging the consumption of nutrient-dense foods. This approach is in harmony with sustainability initiatives aimed at fostering healthier and minimally processed diets. Additionally, reformulating widely consumed dairy products to decrease refined sugar content and enhance nutritional value presents a strategic opportunity to facilitate sustainable dietary transitions. This shift has led to innovations in both the selection of raw materials and formulation strategies to cater to these changing dietary preferences. Recently, dairy products, particularly Greek yogurt, are increasingly gaining market competitiveness. The global Greek yogurt market was valued at approximately USD 8.71 billion in 2024, with projections indicating significant growth, anticipated to reach USD 19.42 billion by 2035. This reflects a compound annual growth rate (CAGR) of 7.56% for the period from 2025 to 2035, according to Market Research Future (2025). Also, one promising alternative milk source is dromedary camel milk (Abou-Soliman et al., 2025; Sakr and Barakat, 2025). Globally, the camel population is estimated at approximately 35 million head, with 492,853 camels reported in Saudi Arabia (FAO, 2020). Among camel species, the dromedary camel (*Camelus dromedarius*) predominates in arid and semi-arid regions and plays a particularly significant role in Saudi Arabia, where it serves as a primary source of both milk and meat (El-Hanafy et al., 2023).

Camel milk is nutritionally rich and has a unique protein profile consisting of casein and whey (Seifu, 2023). Research has linked camel milk to various health benefits, including high levels of certain vitamins, minerals, and bioactive compounds (Redha et al., 2022). This has prompted exploration into value-added camel milk products as functional foods and nutraceuticals (Sakr et al., 2025). Additionally, both fresh and fermented camel milk plays a crucial role in enhancing food security and supporting rural economies in arid regions of North and East Africa, the Middle East, Central Asia, and the Indian subcontinent (Faye and Konuspayeva, 2012). The proteins found in camel milk have been associated with health benefits such as anti-cancer and anti-diabetic effects (Alharbi et al., 2022; Sakr and Barakat, 2025). Furthermore, camel milk is a promising alternative for children feeding as it easy to digest (Abou-Soliman et al., 2020; Al-Nassir and Sakr, 2024) and suitable for whom are allergic to cow's milk, emphasizing its positive impact on health (Kaskous, 2016; Mudgil et al., 2018; Mbye et al., 2020). During droughts, when livestock such as cattle and sheep may become scarce, camels continue to provide a reliable supply of milk, making them an essential resource. This milk not only supports local diets but also enhances food security and strengthens rural economies, particularly in arid and semi-arid regions (Faye and Konuspayeva, 2012).

Regrettably, the commercial processing of camel milk into variable dairy products faces challenges stemming from consumer acceptability and manufacturing issues (Abou-Soliman et al., 2020). One notable difficulty lies in the prolonged coagulation time of camel milk and the weak, poor structure of its fermented products. This characteristic is likely influenced by factors such as the substantial size of casein micelles, the relative distribution of casein fractions, and the absence of beta-lactoglobulin (β -lg) in camel milk when compared to bovine milk. Another contributing factor to the suboptimal structure in fermented camel milk could be attributed to the smaller size of camel milk fat globules. To ensure the effectiveness and consistency of camel milk products production, it is essential to carry out further research and develop a standardized manufacturing protocol. One effective approach may involve modifying camel milk protein by fortifying it with either dairy or non-dairy ingredients and incorporating trisodium citrate (Ali et al., 2026). Among dairy ingredients, whey protein preparations have been shown to enhance the structure and bioactivity of fermented camel milk products, particularly when derived from goat milk. Goat whey typically supports greater antioxidant activity, better survival of probiotics, and a higher concentration of bioactive peptides compared to cow whey in fermented milk products (Dinkçi et al., 2023). In the same context, including plant-based and fruit-derived ingredients in yogurt represents a sustainable approach to food reformulation. Adding fruits not only enhances the nutritional value and flavor but also caters to consumer preferences for functional and clean-label products. This trend aligns with health-focused diets and leverages the bioactive compounds found in fruits to increase product appeal and marketability (Priyashantha et al., 2025). Fig powder, derived from the *Ficus carica* fruit, has been recognized as an effective ingredient in fermented dairy products, particularly yogurt, as reported by Mahmoudi et al. (2021). They reported that when incorporated into yogurt, fig powder significantly enhances its texture, nutritional value, antioxidant properties and sensory appeal. Rich in sugars, dietary fibers, essential minerals, vitamins, and various phytochemicals, fig powder offers numerous health benefits (Rasool et al., 2023). It also increases the counts of lactic acid bacteria, thereby enhancing the probiotic features of yogurt. With its complex flavor profile, which includes various acids and esters, fig powder acts as a natural sweetener and flavor enhancer, providing a healthier alternative to synthetic additives for innovative yogurt varieties (Mahmoudi et al., 2021).

Thus, the current study focuses on the production of Greek-like yogurt from camel milk, which is high in protein. Moreover, modifying camel milk protein either by fortifying it with dried protein preparations or adding trisodium citrate can be a good tool for standardized camel milk. Which make it more suitable for Greek-like yogurt production. Also, the substitution of sugar with fig powder could increase the nutritional value and improve the sensory properties of the final product to ensure the efficacy and consistency of the production of Greek-like yogurt from camel milk. Therefore, the main objective of the current study is to: (1) evaluate the availability of producing Greek-like yogurt from protein fortified camel milk, (2) explore the possibility of incorporating natural fig powder as a flavoring agent and nutritional value enhancer in the final product and (3) optimize manufacturing steps to improve the quality of Greek-like yogurt produced from camel milk. Consequently, it may enhance camel milk supply chains in arid

economies and provide healthier, naturally sweetened yogurt options for health-conscious consumers.

2 Materials and methods

2.1 Materials

Raw camel milk was collected from Wadah species camels, aged 5 to 8 years, at the farms of Al-Sheikh Saleh Al-Sulman, located in the Qassim region of Saudi Arabia, between September and November 2024. The chemical composition of each 100 mL of raw camel milk (CM) was as follows: 88.9 g of water, 3.04 g of protein, 2.75 g of fat, 8.35 g of non-fat solids, 4.56 g of lactose, and 0.75 g of ash. After collection, the milk was refrigerated at a controlled temperature of $4 \pm 1^\circ\text{C}$ and subsequently transported to the laboratory within the Food Science and Human Nutrition Department at the Girls Section, College of Agriculture and Food, Qassim University, for processing and analysis. A commercially available lyophilized culture containing *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus* (YC-381, 200 U, DVS) was obtained from Chr. Hansen Laboratories in Copenhagen, Denmark, through Misr Food Additives (MIFAD) in Badr City, Egypt. Cow whey protein isolate [(CWPI), 395 S. Glen Ellyn Rd. Bloomington, IL 60108, USA: ~89% protein, ~4% carbohydrates and 2% fat] and whey from goat milk [(GW), MT. CAPRA, 517 NW Pacific Ave, Chehalis, WA 98532, USA: 80% protein, 10% carbohydrates and ~3% fat] were purchased online from the iHerb website (ALLMAX Iso Natural, featuring no artificial colors, flavors, or added sugars). High-quality figs were sourced from Ali-Al-Sudari Trade Est. in the Qassim region, Saudi Arabia. White sugar (sucrose) were acquired from a local market in Buraydah, Qassim region. Extra pure β -cyclodextrin was purchased from Ara Chem, a fine chemicals company based in the Netherlands. For microbiological examinations, De Man, Rogosa, and Sharpe (MRS) agar medium, M17 agar, MacConkey agar, malt extract agar, and nutrient agar were sourced from Condalab, located at Calle Forja 9, 28,850 Torrejón de Ardoz, Madrid, Spain. Chemicals used in each experimental method are detailed under their respective analysis methods, described subsequently.

2.2 Preparation methods

For processing different Greek-like yogurt from camel milk, two stages were applied as follows:

2.2.1 Preliminary experiment

A preliminary experiment was conducted in triplicate to identify the most effective protein source and concentration that can reduce fermentation time, enhance gel formation, improve homogeneity and viscosity, and accelerate pH reduction. Thus, it could be used in producing Greek-like yogurt from camel milk. Camel milk was supplemented separately with cow whey protein isolate (CWPI: 2, 3, and 4%) and goat whey protein (GW: 2, 3, and 4%) in the presence of 30 mmol/L TSC. In this preliminary experiment, raw camel milk (pH = 6.61) was warmed to about 55–60 °C before different whey protein types and amounts were added under

continuous blending. Heat treatment (80 °C, 10 min) was then continued, followed by cooling to 45 °C before the addition of 30 mmol/L TSC and inoculation with yogurt starter culture (YC-381, 200 U, DVS). After 12 h of incubation at 42 °C, the pH was recorded, and the fermented camel milk samples were refrigerated ($4 \pm 2^\circ\text{C}$) until the next day for analysis. The selected protein type was then applied in subsequent Greek-like yogurt production experiments.

2.2.2 Preparation of Greek-like yogurt from modified camel milk supplemented with fig powder

Before processing Greek-like yogurt, fig powder was prepared (Khapre et al., 2015). Fresh, clean, organic figs were cut into small pieces and dried in a hot air oven at 60 °C for 20 to 24 h. Once dried, dried figs were ground using an electronic grinder, sieved, and then stored in a sealed glass container under freezing conditions until needed. Also, fresh camel milk was warmed to 40 °C before separated using electric milk separator and the camel milk cream was collected and its fat percent was determined. Then, the cream was heat treated (90 °C/30 min) and use for the Greek-like yogurt processing. For the preparation of the Greek-like yogurt samples, the milk composition was standardized, with particular emphasis on protein and fat contents. To enhance the protein content of camel milk to approximately 7%, a 7% (w/w) supplementation with GW was added. This adjustment aims to match the final formulation with the established protein range for Greek yogurt, which is between 3.33 and 9.94%, as previously reported for full-fat samples (Pappa et al., 2024). This ensures compliance with the necessary compositional standards. Thus, fresh camel milk was first standardized for its Total solids (~25%), protein (~7%) and fat (~4%) to produce modified high-protein camel milk. The pre-modified camel milk was then used to process five different batches of Greek-like yogurt, in which sugar was replaced with varying amounts of fig powder. The formulations are presented in Table 1. Five different Greek-like yogurt batches each from the different camel milk formulations were then processed as presented in Figure 1. First, fresh camel milk for each batch was filtered through muslin and then preheated in a water bath to about 50–55 °C. Then, cream, GW (7%) and β -cyclodextrin (0.5%) were added under continuous blending. Then after, the modified camel milk was differentiated to five batches. The sugar and/or fig powder were then added to each batch at the amounts presented in Table 1 for GCM-F0, GCM-F25, GCM-F50, GCM-F75, and GCM-F100 samples preparation. The heat treatment (80 °C/10 min) was then continued for each batch before fast warming down to about 45 °C. Then, as recommended by Chen et al (2019) and starter culture (YC-381, 200 U, DVS) were added. Finally, different Greek-like yogurt batches were filled and incubated at 45 °C until the pH reached ~4.6. The final product was stored cooled ($4^\circ\text{C} \pm 1$) for analysis at 1, 8 and 15 days.

2.3 Methods of analysis

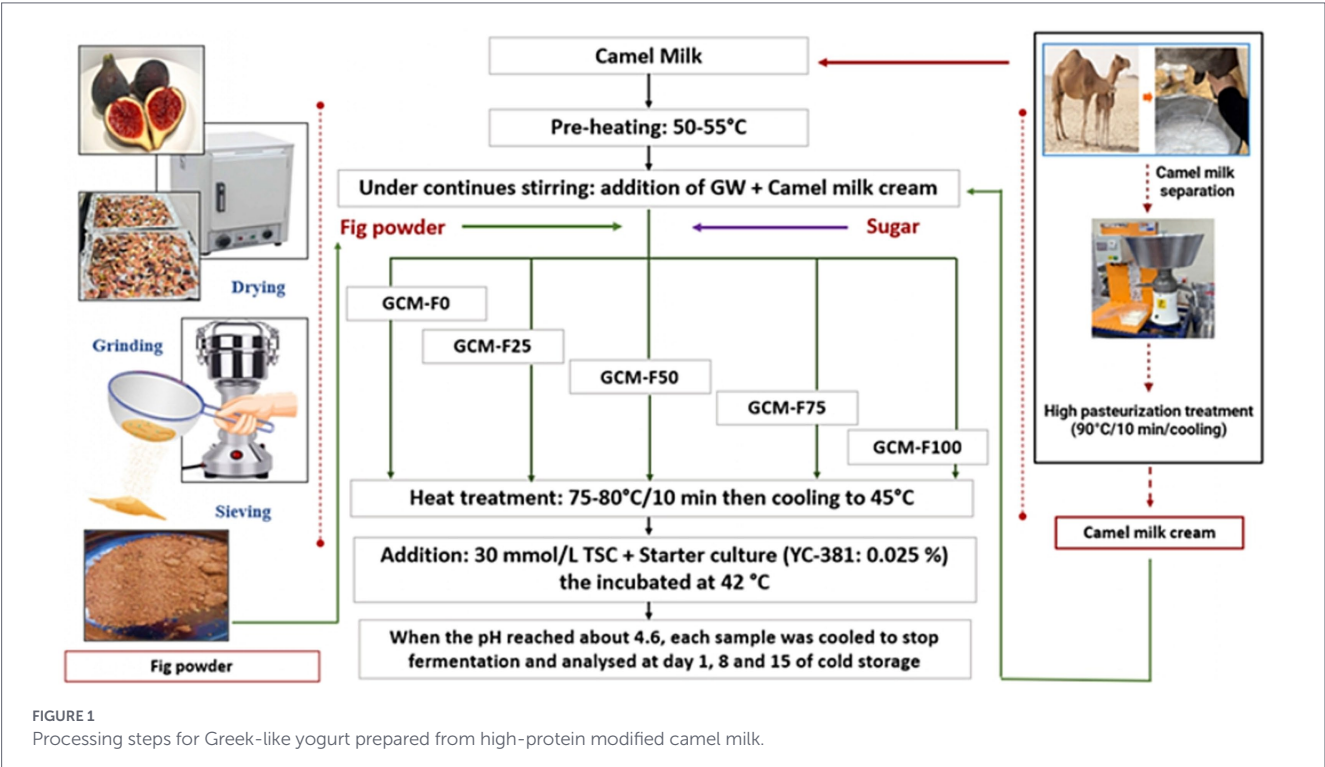
2.3.1 Proximate analysis and pH

The total protein, total solids, and ash contents of different Greek-like yogurt samples were determined according to the methods described in the AOAC methods (AOAC, 2012). Gerber method was applied to

TABLE 1 Different camel milk formulations for Greek-like yogurt processing.

Greek-like yogurt camel milk formula	Ingredients (g/1000 g)				Sugar or fig powder (8%)	
	Camel milk	Camel milk cream	WG	Total	Sugar	Fig powder
GCM-F0	830	100	70	1,000	80	0
GCM-F25	830	100	70	1,000	60	20
GCM-F50	830	100	70	1,000	40	40
GCM-F75	830	100	70	1,000	20	60
GCM-F100	830	100	70	1,000	0	80

GCM-F0 (control without fig powder), GCM-F25 (25% replacement of sugar with fig powder), GCM-F50 (50% replacement of sugar with fig powder), GCM-F75 (75% replacement of sugar with fig powder) and GCM-F100 (100% replacement of sugar with fig powder).



measure fat (%) according to [Ling \(1963\)](#). Specifically, 5 mL of a diluted ammonia solution (1 part concentrated ammonia to 4 parts distilled water) was added to 100 g of the yogurt sample, followed by thorough homogenization before the fat determination. Subsequently, fat content was quantified utilizing Gerber's method, and the percentage of fat in the yogurt samples was calculated using the appropriate formula:

$$Fat\% = \left(fat\ column\ reading\ on\ gerber's\ tube \right) \times (105/100)$$

The amount of total carbohydrates was calculated using the following equation:

$$Carbohydrates\% = \left[Total\ solids - (Fat + Protein + Ash) \right]$$

The pH of different samples was measured in fresh, during fermentation and at the end of fermentation using a digital pH meter (HANNA HI 8314 Portable).

2.3.2 Apparent viscosity

The apparent viscosity in centipoise (cP) of different samples was estimated during 15 days of cold storage ($4 \pm 1^\circ\text{C}$) using the Fungilab Rotational Viscometer. The mean $\pm$ SE of three independent batches, each measured in duplicate, was applied. Each sample was adapted to about 10°C then poured into a glass beaker. Spindle marking No. R5 was lowered perpendicularly into each beaker and rotated at 100 rpm. When stable values were obtained, viscosity measurements were recorded.

2.3.3 Syneresis and water holding capacity (WHC)

The WHC of the fermented milk was determined according to [Akalin et al. \(2012\)](#). The mean $\pm$ SE of three independent batches, each measured in duplicate, was applied. A sample of about 20 g of fermented milk (FM) was centrifuged at $5000 \times g$ for 10 min at 20°C , (Universal 320R, D-78532 Hettich, Germany). The whey expelled

(WE) was removed and weighed as grams. The WHC was calculated as follows:

$$WHC\% = \left[\frac{(FM - WE) \times 100}{FM} \right]$$

Also, Syneresis was calculated according to the following equation:

$$Syneresis = \left(\frac{\text{weight of supernatane}}{\text{weight of yogurt sample}} \right) \times 100$$

2.3.4 DPPH radical scavenging activity

DPPH radical scavenging activity of samples was determined according the modification mentioned by [Mudgil et al. \(2022\)](#). The mean $\pm$ SE of three independent batches, each measured in duplicate, was applied. The decolorization of DPPH free radicals after scavenging was monitored by measuring the absorbance at 517 nm after 30 min of incubation at 37 °C using 96 well microplate reader (Multiskan Sky, Thermo Fisher Scientific, Cambridge, MA, USA). 25 μ L of each soluble nitrogen extracts were mixed with 275 μ L DPPH reagent (0.1 mmol/L in 95% methanol) in a 96 well microplate reader and let in dark for 30 min before the measurement. The radical scavenging activity percent (DPPH radical scavenging activity of extracts %) was calculated as follows:

$$\text{DPPH radical scavenging activity\%} = \frac{(A_0 - A_s)}{A_0} \times 100$$

where A0 is the absorbance at 517 nm of blank (the blank was distilled water); As is the absorbance at 517 nm of extract. Also, a standard curve equation using Trolox was used to utilized in calculating the μ mol Trolox equivalent 100 g⁻¹.

2.3.5 Total phenolic content (TPC)

The TPC values of the prepared extract from each sample was determined using Folin Ciocalteu reagent, according to [Bettaieb et al. \(2010\)](#). The mean $\pm$ SE of three independent batches, each measured in duplicate, was applied. Briefly, in Eppendorf tubes, 150 μ L of the sample was mixed with 300 μ L of Folin–Ciocalteu reagent for 5 min. Then, 300 μ L of an alkali solution (7.5% sodium carbonate solution, Na₂CO₃) was added to stop the reaction. The mixture was incubated in the dark for 60 min at 23 °C, then centrifuged at 10,000 $\times$ g for 10 min at 4 °C, and 120 μ L of supernatant from each Eppendorf was transferred to a new plate; the absorbance was then measured at 760 nm using a microplate reader (BioTek, Winooski, VT, USA). Measurements were compared to the standard curve of gallic acid (GA) solution ($R^2 = 0.99$), and TPC content was expressed as milligrams of gallic acid equivalents per 100 gram sample (mg GAE 100 g⁻¹).

2.3.6 Viable microbial count of different strains in Greek-like yogurt samples

For detecting the microbiological quality of Greek-like yogurt samples during cold storage, coliform bacteria, total mold and yeast, and total bacterial counts were enumerated using MacConkey agar, malt extract agar, and Nutrient agar media, respectively, by

counting colony-forming unit (CFU) after plating serial dilutions according to [Robertson et al. \(1948\)](#). MRS medium detected *Lactobacillus* strains from dilutions 6 through 9. Two layers of medium were poured over diluted samples, left for solidification, and then incubated under anaerobic conditions at 37 °C for 48 h, using an anaerobic jar contained Thermo Oxoid anaerobic bag. The *Streptococcus thermophilus* was detected from the 6th to the 9th dilutions for each sample by enumeration on M17 agar medium, and the plates were aerobically incubated at 37 °C for 24 h. Date was expressed as logarithm colony-forming units per gram (Log₁₀ CFU/g) for Greek-like yogurt sample.

2.3.7 Instrumental color measurement

According to the method described by [Alqahtani et al. \(2023\)](#), the changes in the color of Greek-like yogurt samples during 15 days of cold storage were determined. The mean $\pm$ SE of three independent batches, each measured in duplicate, was applied. The instrumental color determinations were performed using the Hunter Lab Minolta colorimeter with a 20 mm aperture set at illumination D65 and 100 standard observer angles. Before analyzing the measurements for color changes, the initial Hunter color values, including lightness (L*), redness (a*), and yellowness (b*), were calibrated against white and black standard discs. Each sample was carefully prepared by pouring 10 mL of the liquid into a petri dish, resulting in a liquid layer approximately 1 cm high. Three distinct readings at random positions on the sample surface were taken for each analyzed sample. The chroma (C), color changes (ΔE), and browning index (BI) were then calculated according to [Lavelli et al. \(2011\)](#).

2.3.8 Microstructure examination by scanning electron microscope (SEM)

The microstructure of Greek-like yogurt samples was prepared and examined at the central research laboratory of female student campus, King Saud University, Riyadh, Saudi Arabia, according to the fixation method described by [Recio et al. \(2000\)](#). The micrographs of different fresh samples were examined at 6000 $\times$ magnification by SEM (JEOL JEM-2100, USA).

2.3.9 Sensory evaluation

The descriptive sensory analysis of yogurt was conducted utilizing a 10-point scale, with scores ranging from 0 (indicating no perception or low intensity) to 10 (indicating high perception or intense experience). This analysis emphasized texture, aligning with the methodologies described by [Thun et al. \(2022\)](#) and [Swiader and Florowska \(2022\)](#). Ten expert descriptive panel from the Department of Food Science and Human Nutrition at the Faculty of Agriculture and Food, Qassim University, Saudi Arabia, were selected for this study based on their proficiency in sensory analysis of fermented milk products. No additional training was provided to those evaluators. The evaluation focused on ten sensory attributes categorized into appearance (color, syneresis, gel firmness, and ropiness), taste (sweetness, sourness, and bitterness), texture (mouth thickness and mouth coating), and aroma. Samples were labeled with random 3-digit numbers and presented to the evaluators in a random order. To minimize flavor carryover and ensure unbiased assessments, warm distilled water was provided for palate cleansing between samples. It is important to note that the

panelists were not informed about the sugar or fig powder content in the Greek-style yogurt samples prior to their evaluation.

2.4 Statistical analysis

Data are expressed as the mean $\pm$ standard error (SE). The statistical analysis was carried out using SPSS program (ver. 19) with multi-function utility regarding the experimental design and multiple comparisons using Two-way ANOVA carried out according to Steel et al. (1997). Duncan's multiple-range test was employed for pairwise comparisons, and differences were considered statistically significant at $p \leq 0.05$.

3 Results and discussion

3.1 Results and discussion of the preliminary experiment

Research shows that incorporating either bovine whey protein isolate (WPI) or concentrate (WPC) into fermented camel milk improves its texture, water retention, viscosity, and bioactive characteristics compared to those without these additives. The majority of studies have focused on bovine whey protein, indicating that higher levels (up to 6%) enhance texture and antioxidant properties more than traditional bovine milk yogurt (Abou-Soliman et al., 2017; Ali et al., 2023; Ayyash et al., 2025). However, the effect of goat whey protein on fermented camel milk like yogurt has not yet been studied, highlighting a need for further exploration.

Thus, the data obtained from the preliminary experiment were important for identifying additional protein (WG: 2, 3 or 4%; CWPI: 2, 3 or 4%) types and quantities that could improve the properties of camel milk acid gels before further processing. The data presented in Table 2 highlights the decrease in pH values during fermentation, along with the pH values, viscosity, and photos of the cooled fermented camel milk taken the day after processing. It could be seen (Table 2) that both GW (4%) and CWPI (2, 3 and 4%) accelerated fermentation by rapidly decreasing the pH values to about 4.6 after 10 h. compared to the control sample (with no protein supplementation), which took 12 h. The GW supplement samples showed a greater increase in viscosity than the CWPI samples at all supplementation levels. Also, the supplementation of camel milk with 4% GW resulted in the highest viscosity compared to other supplements. Thus, the modification of camel milk with GW was chosen for the rest of the study.

Recent studies suggest that the proteins in camel milk and goat milk may improve nutrient bioavailability and exhibit lower allergenicity compared to cow milk proteins. This quality makes them suitable alternatives for individuals who are sensitive to cow milk (AL Kaisy et al., 2023). As a result, WG was chosen for the remainder of the study. Based on this, a higher concentration of the selected goat whey was added to produce a Greek-like yogurt from camel milk in the main experiment.

Additionally, β -cyclodextrin was added to help mask the characteristic goaty flavor often found in goat milk products. β -Cyclodextrin reduces the goaty flavor in goat milk and yogurt by encapsulating the short- and medium-chain fatty acids responsible for this taste. Studies show that its addition significantly

decreases the goaty flavor intensity, particularly when added before heating and fermentation. In yogurt, β -cyclodextrin enhances consumer acceptance, especially in unsweetened and sweet or vanilla-flavored varieties (Wang et al., 2018; Ma et al., 2023).

3.2 Results and discussion of the main study

3.2.1 Chemical composition

The changes in chemical composition of various Greek-style yogurt samples, which incorporated different amounts of sugar and fig powder, are summarized in Table 3. No significant differences ($P > 0.05$) were observed in moisture percentage, total solids percentage, and fat percentage among all the samples. Our results contrast with findings from previous studies regarding protein percentage and total carbohydrate content. Abd-Eltawab (2019) found that adding larger amounts of fig puree to fermented milk decreased the protein content and increased the total carbohydrate content due to the dilution effect, as figs contain less protein than milk. However, a separate study by Mahmoudi et al. (2021) indicated no significant change in protein content when using fig powder. Additionally, Khapre et al. (2015) reported that fig fruit powder contains 5.26% protein, 61.52% total carbohydrates, 2.48% fat, and 3.9% ash. In our study, the formulation differences led to the greater replacement of sugar with fig powder, resulting in significant increases in protein and ash percentages, along with a decrease in total carbohydrate percentage.

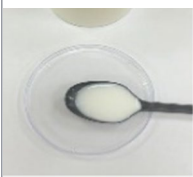
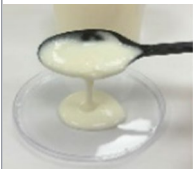
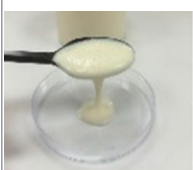
3.2.2 Changes in pH during fermentation

It is clearly observed that the pH values (Figure 2) gradually decreased during fermentation for all samples. There was no substantial difference in total fermentation time among the samples, which ranged from 6 to 7.5 h. The decrease in pH was fastest in the GCM-F75 sample, which reached a pH of 4.66 after approximately 6 h of fermentation. The GCM-F0 sample took 7 h to reach a pH of 4.68. The GCM-F25, GCM-F50, and GCM-F100 samples had the longest fermentation times, with pH values of 4.57, 4.67, and 4.63, respectively, after about 7.5 h of fermentation. This phenomenon may be attributed to the fact that replacing more sugar with fig powder (up to 75%) creates a more favorable environment for the growth of lactic acid bacteria (LAB), which is essential for fermentation and is influenced by enhanced microbial activity (Mahmoudi et al., 2021).

3.2.3 Physico-chemical characteristics

The changes in pH values during the storage period are presented in Figure 3. It could be seen that pH values decreased gradually with increasing storage period for all samples. This pH drop is primarily due to ongoing metabolic activity of LAB, which continue to produce organic acids (mainly lactic acid) even after fermentation, a process known as post-acidification (Li et al., 2019). Additionally, the sample with 75% replacement of sugar with fig powder (GCM-F₇₅) presented the lowest pH value compared to other samples during all storage periods. The results somewhat align with the findings of Abd-Eltawab (2019), who showed that titratable acidity increased over the storage period of stirred fermented milk fortified with fig fruit. This increase in acidity is likely due to the conversion of lactose into lactic acid

TABLE 2 Differences in pH values and viscosity (cP) of fermented camel milk samples supplemented with different amounts of WG or CWPI.

**Camel milk supplementation protein type		pH during fermentation			Properties of the final product after 1 day of cold storage		
		0 h	10 h	12 h	pH	Viscosity (cP)	Product's photo
Control: no supplementation		7.15	5.81	5.17	4.97	147.67 ± 0.6	
GW	2%	6.99	4.72	4.65	4.60	182.00 ± 4.0	
	3%	6.88	4.75	4.69	4.67	360.00 ± 3.0	
	4%	6.82	4.68	-	4.66	1374.33 ± 257.5	
CWPI	2%	6.99	4.68	-	4.68	404.00 ± 59.8	
	3%	6.95	4.68	-	4.65	666.67 ± 15.0	
	4%	6.58	4.63	-	4.64	926.00 ± 34.4	

during storage, as well as the ongoing metabolic activities of the starter culture throughout this time.

Table 4 shows that the WHC% significantly increased ($p \leq 0.05$) as sugar was replaced with fig powder. This improvement can be attributed to the presence of dietary fiber and polysaccharides in figs, which enhance water-binding capacity and reinforce the gel network structure. GCM-F₂₅ and GCM-F₅₀ samples exhibited the highest WHC%, whereas further increases in fig powder concentration (GCM-F₇₅ and GCM-F₁₀₀) resulted in a slight decline. The reduction at higher inclusion levels may be associated with excessive total solids interfering with protein–protein interactions, thereby

weakening the gel network. During refrigerated storage, all samples showed a gradual decline in WHC. However, fig-enriched formulations consistently exhibited higher WHC values than the control (GCM-F₀) throughout the storage period. This finding suggests that fig powder improved the yogurt’s ability to retain moisture and resist syneresis, likely due to the water-binding effect of the fiber matrix and its interaction with casein micelles. Similar trends were reported by Wang et al. (2024), who observed that the addition of high-fiber or fruit-based ingredients to yogurt can either enhance or reduce WHC% depending on fiber solubility and compatibility with milk proteins. When insoluble fibers predominate, they may disrupt the

TABLE 3 Chemical composition (%) of fresh Greek-like yogurt samples.

Greek-like yogurt	Component (g 100 g ⁻¹)					
	Moisture	TS	Protein	Fat	Ash	Total carbohydrates
GCM-F ₀	74.28 ± 0.24 ^{ab}	25.72 ± 0.24 ^{ab}	6.64 ± 0.04 ^b	3.83 ± 0.17 ^b	1.29 ± 0.03 ^c	13.95 ± 0.34 ^{ab}
GCM-F ₂₅	74.42 ± 0.01 ^a	25.57 ± 0.01 ^b	6.37 ± 0.34 ^b	4.00 ± 0.00 ^{ab}	1.39 ± 0.06 ^{bc}	13.81 ± 0.38 ^{ab}
GCM-F ₅₀	73.89 ± 0.03 ^b	26.10 ± 0.03 ^a	6.69 ± 0.26 ^b	4.17 ± 0.17 ^a	1.43 ± 0.04 ^b	13.82 ± 0.46 ^{ab}
GCM-F ₇₅	74.29 ± 0.12 ^{ab}	25.37 ± 3.12 ^b	7.64 ± 0.18 ^a	4.00 ± 0.00 ^{ab}	1.34 ± 0.02 ^{bc}	12.72 ± 0.30 ^c
GCM-F ₁₀₀	73.98 ± 0.00 ^{ab}	26.08 ± 0.00 ^a	7.48 ± 0.08 ^a	4.00 ± 0.00 ^{ab}	1.62 ± 0.01 ^a	12.93 ± 0.09 ^{bc}

^{a,b,c}There is no significant difference ($P > 0.05$) between any two means, within the same column have the same superscript letter for each parameter. GCM-F₀ (control without fig powder), GCM-F₂₅ (25% replacement of sugar with fig powder), GCM-F₅₀ (50% replacement of sugar with fig powder), GCM-F₇₅ (75% replacement of sugar with fig powder) and GCM-F₁₀₀ (100% replacement of sugar with fig powder).

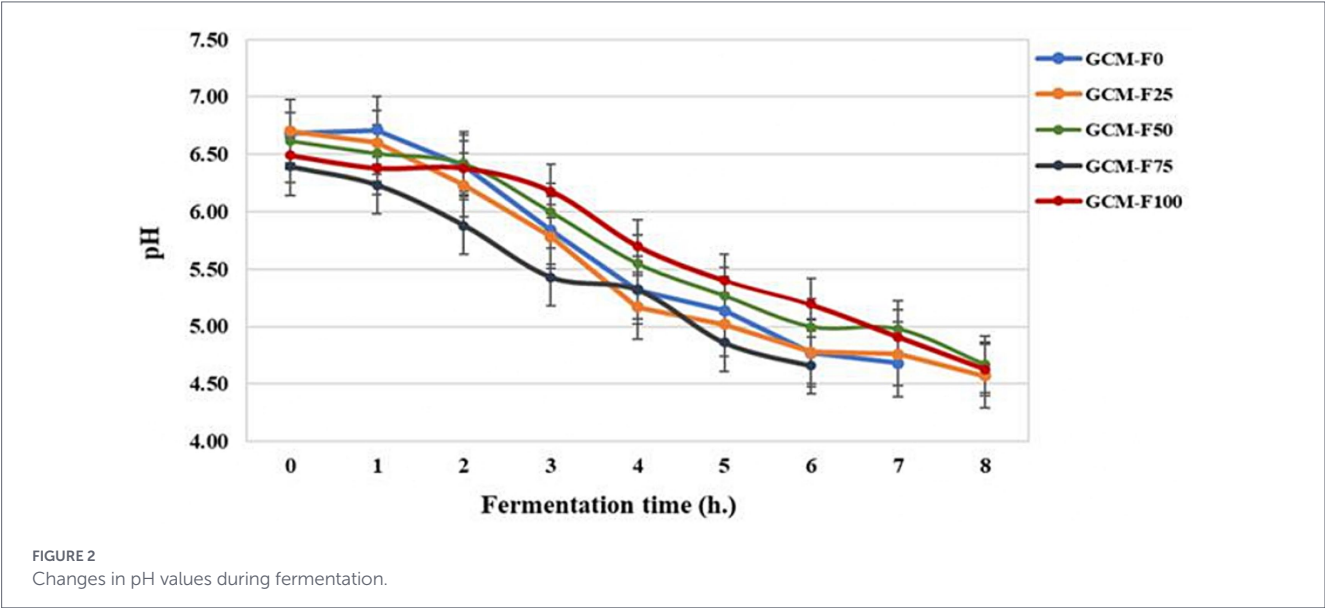


FIGURE 2
Changes in pH values during fermentation.

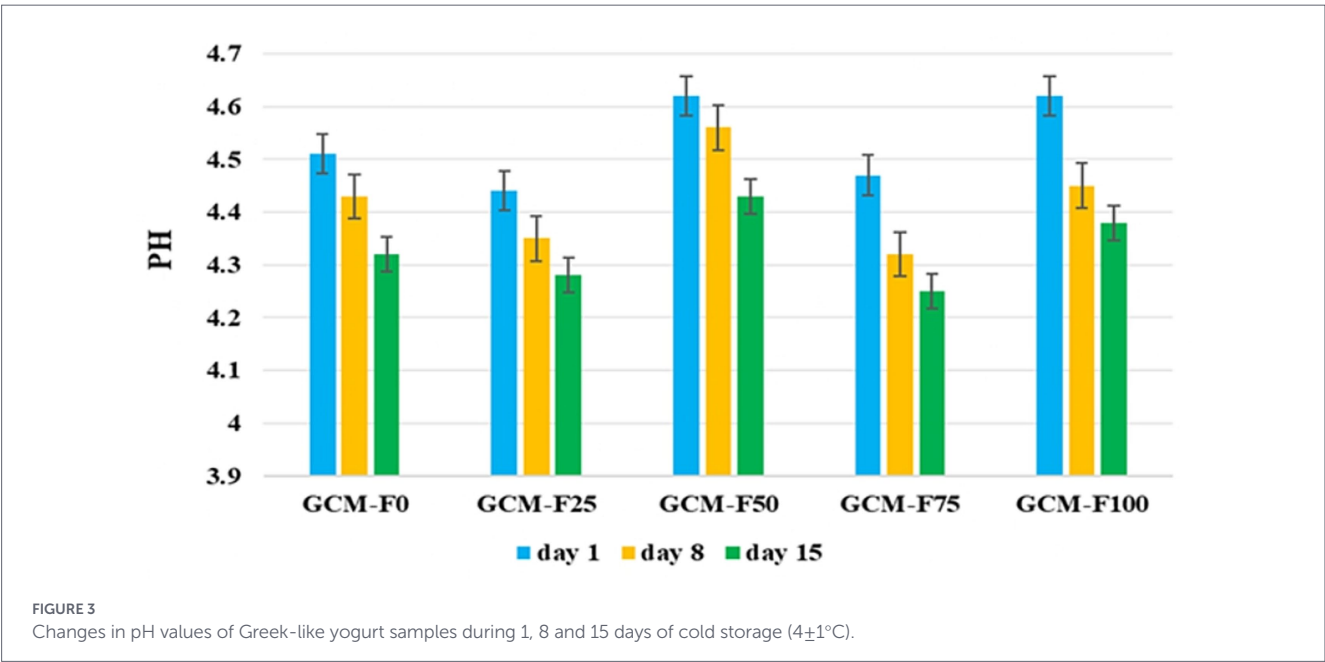


FIGURE 3
Changes in pH values of Greek-like yogurt samples during 1, 8 and 15 days of cold storage (4±1°C).

TABLE 4 Physico-chemical characteristics of Greek-like yogurt samples during 15 days of storage.

Parameter	Storage (days)	Greek-like yogurt sample				
		GCM-F ₀	GCM-F ₂₅	GCM-F ₅₀	GCM-F ₇₅	GCM-F ₁₀₀
WHC (%)	1	64.70 ± 0.67 ^{dA}	73.43 ± 2.05 ^{aA}	73.29 ± 0.77 ^{aA}	68.85 ± 0.61 ^{cA}	70.65 ± 1.02 ^{bA}
	8	64.50 ± 0.60 ^{dA}	73.77 ± 2.18 ^{aA}	73.29 ± 0.77 ^{aA}	68.18 ± 0.61 ^{cA}	70.65 ± 1.02 ^{bA}
	15	62.75 ± 0.24 ^{cB}	64.57 ± 0.39 ^{bB}	66.31 ± 0.46 ^{bB}	63.32 ± 0.04 ^{bcB}	67.40 ± 0.53 ^{aB}
Syneresis (%)	1	35.96 ± 0.34 ^{aB}	27.23 ± 1.93 ^{dB}	27.04 ± 0.69 ^{dB}	31.48 ± 0.51 ^{bB}	29.68 ± 0.96 ^{cB}
	8	35.62 ± 0.58 ^{aB}	27.23 ± 1.93 ^{dB}	27.04 ± 0.69 ^{dB}	31.48 ± 0.51 ^{bB}	29.68 ± 0.96 ^{cB}
	15	37.17 ± 0.23 ^{aA}	35.09 ± 0.20 ^{cA}	33.36 ± 0.32 ^{dA}	36.68 ± 0.04 ^{bA}	32.93 ± 0.41 ^{dA}
Viscosity (cp)	1	1588.00 ± 31.18 ^{dB}	2848.67 ± 179.79 ^{bA}	2270.67 ± 195.01 ^{cB}	3785.33 ± 81.08 ^{aB}	1770.00 ± 10.44 ^{dA}
	8	2599.33 ± 390.57 ^{aA}	1057.00 ± 173.99 ^{bB}	1267.67 ± 202.31 ^{bc}	793.67 ± 100.09 ^{cA}	780.33 ± 129.37 ^{cB}
	15	2374.67 ± 329.92 ^{dA}	1087.00 ± 272.71 ^{cB}	2790.00 ± 234.59 ^{cA}	359.33 ± 23.59 ^{bB}	504.33 ± 12.86 ^{cC}

^{a,b,c,d,e}There is no significant difference ($P > 0.05$) between any two means, within the same column have the same superscript letter for each parameter. ^{A,B,C}There is no significant difference ($P > 0.05$) between any two means, within the same row have the same superscript letter for each parameter. GCM-F₀ (control without fig powder), GCM-F₂₅ (25% replacement of sugar with fig powder), GCM-F₅₀ (50% replacement of sugar with fig powder), GCM-F₇₅ (75% replacement of sugar with fig powder) and GCM-F₁₀₀ (100% replacement of sugar with fig powder).

TABLE 5 Total phenolic content (mg GAE 100 g⁻¹) and DPPH radical scavenging activity (μmol TE 100 g⁻¹) in Greek-like yogurt samples during 15 days of storage.

Parameter	Storage (days)	Greek-like yogurt sample				
		GCM-F ₀	GCM-F ₂₅	GCM-F ₅₀	GCM-F ₇₅	GCM-F ₁₀₀
TPC (mg GAE 100 g ⁻¹)	1	5.94 ± 0.97 ^{dB}	8.85 ± 0.24 ^{cC}	8.36 ± 0.82 ^{cC}	24.21 ± 0.29 ^{bC}	29.86 ± 0.56 ^{aC}
	8	5.99 ± 0.19 ^{cB}	11.61 ± 0.54 ^{dB}	16.11 ± 0.22 ^{cB}	28.21 ± 0.72 ^{bB}	31.77 ± 0.62 ^{aB}
	15	7.02 ± 0.05 ^{cA}	13.66 ± 0.26 ^{dA}	28.54 ± 0.18 ^{cA}	45.45 ± 1.27 ^{bA}	56.3 ± 1.28 ^{aA}
DPPH (μmol TE 100 g ⁻¹)	1	102.97 ± 7.24 ^{aC}	109.05 ± 0.32 ^{aA}	44.00 ± 0.58 ^{cC}	91.49 ± 3.59 ^{bB}	86.97 ± 4.79 ^{bC}
	8	117.95 ± 8.56 ^{aB}	91.96 ± 3.34 ^{bB}	56.86 ± 13.24 ^{dB}	93.19 ± 1.71 ^{cB}	106.28 ± 1.2 ^{bB}
	15	129.31 ± 0.81 ^{aA}	95.33 ± 7.13 ^{cB}	90.92 ± 12.58 ^{cA}	107.87 ± 2.14 ^{bA}	119.19 ± 4.89 ^{abA}

^{a,b,c,d,e}There is no significant difference ($P > 0.05$) between any two means, within the same row have the same superscript letter for each parameter. ^{A,B,C}There is no significant difference ($P > 0.05$) between any two means, within the same column have the same superscript letter for each parameter. GCM-F₀ (control without fig powder), GCM-F₂₅ (25% replacement of sugar with fig powder), GCM-F₅₀ (50% replacement of sugar with fig powder), GCM-F₇₅ (75% replacement of sugar with fig powder) and GCM-F₁₀₀ (100% replacement of sugar with fig powder).

casein network, leading to increased syneresis and reduced WHC%. Consistent with the observed WHC% behavior, the degree of whey separation represented as syneresis % showed an inverse trend (Table 5). After 1 day of cold storage ($4^{\circ}\text{C} \pm 1$), the control sample (GCM-F₀) exhibited the highest syneresis, whereas all fig-enriched yogurts recorded lower values. This inverse relationship between WHC% and syneresis% confirms that fig powder enhanced water retention by strengthening the gel matrix. Throughout storage, the lowest syneresis values were observed in treatments GCM-F₂₅ and GCM-F₅₀, indicating that moderate fig incorporation (20–40%) provided the most stable gel structure. In contrast, higher fig concentrations (GCM-F₇₅ and GCM-F₁₀₀) led to a progressive increase in syneresis during storage, likely due to excessive solids and reduced sugar content interfering with the gel network and weakening its structural integrity.

In general, fig-enriched yogurts exhibited improved resistance to whey separation compared with the control (GCM-F₀). The slight increase in syneresis at higher fig levels supports the hypothesis that excessive fig particulates and sugars may reduce gel compactness, facilitating serum release during storage. These findings align with the observations of Mudgil et al. (2018), who reported that camel milk yogurt inherently forms a weaker gel due to its lower κ -casein content, and those additional solids can intensify whey expulsion. Collectively, These results suggest that moderate levels of fig powder enhance the

textural stability and overall quality of Greek-like camel milk yogurt during storage.

The variations observed in WHC% and syneresis% among the different formulations are consistent with the corresponding changes in texture and microstructure. Thus, the achievement of optimal water-holding capacity and minimal syneresis in high-protein camel milk Greek-like yogurt, replacing 25–50% of sugar with fig powder, is the most effective application according to the results of the current study. Since both parameters are closely related to the gel matrix integrity and moisture distribution, further examination of the microstructural features was undertaken to better understand the effect of fig powder incorporation on the Greek-like yogurt samples physical stability and network organization.

Viscosity values varied significantly throughout the storage period (Table 4). Initially, the control sample (GCM-F₀) exhibited the lowest viscosity, which gradually increased during storage. In contrast, fig-fortified samples displayed different viscosity patterns depending on the level of fig incorporation. Treatments GCM-F₂₅ and GCM-F₅₀ showed moderate viscosity after 1 day of cold storage, followed by a gradual decline with increasing storage time. At moderate inclusion levels (25–50%), fig powder appeared to enhance texture through its fiber and sugar components, which contribute to water retention and gel strengthening. However, at higher concentrations (GCM-F₇₅ and GCM-F₁₀₀), the excessive solid content and dilution of milk proteins

likely interfered with network formation, resulting in decreased viscosity. A slight decline in viscosity over time was observed across all treatments, a trend commonly reported in fermented dairy products and attributed to slow proteolytic activity and gel structure rearrangement during storage.

Overall, the data suggest that replacement of sugar up to 75% with fig powder (GCM-F₇₅) maintained optimal viscosity and physical stability, while higher substitution levels may impair textural uniformity. The initial increase in viscosity observed at moderate fig concentrations, followed by a decline at higher levels, indicates that limited amounts of fig powder can improve gel structure through mild thickening, whereas excessive levels hinder network uniformity. A comparable trend was reported by Mahmoudi et al. (2021) in goat milk yogurt fortified with fig powder, where moderate addition enhanced viscosity and texture, whereas excessive fortification caused phase separation and reduced WHC%.

3.2.4 Total phenolic content and DPPH radical scavenging activity

The total phenolic content (TPC: mg GAE 100 g⁻¹) and DPPH (μmol TE 100 g⁻¹) radical scavenging activity of the Greek-like yogurt samples made from camel milk are presented in Table 5. Overall, the amounts of fig powder added and the duration of storage significantly influenced their values. As shown in Table 5, increasing the amount of sugar replaced by fig powder enhanced the TPC during the 1, 2, and 15 days of cold storage at 4 ± 1 °C. As previously reported, figs are rich in phytochemicals, including polyphenols, carotenoids, and anthocyanins (Rasool et al., 2023; Sandhu et al., 2023). Various studies show that adding plant powders to milk or yogurt before fermentation significantly increases the TPC compared to control samples. This enhancement is both dose-dependent and consistent across different plant sources and types of dairy products, highlighting the strong influence of phytochemical incorporation on the phenolic profiles in fermented dairy products (Simonetti et al., 2021; Milincic et al., 2024). The highest radical scavenging activity percentage (RSA%) was observed in the GCM-F100 sample (~58%) at day 15 of cold storage, while the lowest RSA% was found in the GCM-F25 sample (~45%) at the same day of storage with no significant difference ($P > 0.05$) between them. Although the enhanced antioxidant effects are likely linked to the higher amount of fig powder incorporated into the final products, which remain active in the yogurt matrix as previously explained (Mahmoudi et al., 2021), our results indicated an opposite trend, even with the significant increase in TPC.

Recent studies have highlighted the vigorous DPPH scavenging activity of fig powder, yet a closer examination of fig-milk systems reveal a complex interplay between processing conditions and antioxidant efficacy. Notably, higher milk temperatures and prolonged storage can lead to a decrease in antioxidant activity, as measured by DPPH assay, despite an increase in TPC (Mahmoudi et al., 2021; Teruel-Andreu et al., 2024; Zare et al., 2024). This discrepancy raises essential questions about the relationship between TPC and antioxidant activity. It appears that certain components in the milk matrix or by-products from fermentation may inhibit the antioxidant potential of phenolics. For instance, interactions between proteins and phenolics can result in the formation of complexes that decrease the bioavailability of phenolics, resulting in a slight reduction in DPPH scavenging activity (Simonetti et al., 2021; Zare et al., 2024). Moreover, the processes of fermentation and storage can cause degradation or

transformation of key bioactive compounds, which may further reduce antioxidant potential. Therefore, it is not just the total phenolic content that matters, but the specific phenolic profile within these products that fundamentally influences their antioxidant capabilities. Understanding the nuances of how processing conditions affect antioxidant activity can lead to improved formulations that better retain beneficial properties (Li et al., 2019; Teruel-Andreu et al., 2024; Zare et al., 2024).

In contrast, our results indicate that the fermentation process, along with the activity of the starter culture on milk components during cold storage, enhanced the antioxidant properties by the end of the storage period compared to day one across all samples. Moreover, antioxidant activity typically increases during the first one to two weeks of cold storage, often peaking before declining due to peptide breakdown (Loghman et al., 2022; El-Sayed et al., 2024; Shori, 2024). Thermal pre-treatment at 90 °C before fermentation significantly enhances antioxidant capacity. While raw milk demonstrates the highest radical scavenging activity, its use is limited by microbiological safety concerns (Abou-Soliman et al., 2025). The fortification of Greek-like yogurt with plant-based or fractionated additives significantly improves phenolic and antioxidant profiles over storage, offering a robust strategy for developing functional dairy products with superior health-promoting properties and shelf stability.

3.2.5 Viable bacterial count

Analysis of the microbiological quality of various Greek-like yogurt samples showed no presence of viable coliforms, molds, or yeasts. This may be due to effective heat treatment of milk that inhibits vegetative cells, as well as proper sanitation during manufacturing (Abd-Eltawab, 2019). The enumeration of viable bacteria was performed using TC, MRS, and M17 media, and the resulting colony counts are presented in Table 6. The data in Table 6 indicates that the logarithm value of viable count (log₁₀) of starter culture strains was significantly affected ($p < 0.05$) by the amounts of fig powder used as a sugar replacement and by the duration of cold storage (1, 8, and 15 days). As the amount of sugar replaced with fig powder increased, the enumeration of bacterial strains also showed a positive increase during each storage period. This was particularly evident for the *S. thermophilus* strain values on M17 medium, which demonstrated a positive linear relationship with the amount of fig powder used in the Greek-like yogurt samples. In contrast, the log₁₀ values of *L. bulgaricus* on MRS medium were highest in the GCM-F25 sample, which contained 25% of sugar replaced by fig powder, compared to the other samples.

The data presented in Table 6 clearly demonstrate the impact of the storage period on the viability of bacterial strains. In this regard, it could be said that the Greek-like yogurt samples under the current study are under the specification of the Food and Drug Administration (FDA) regulations. In which the FDA guidelines (2021) reported that the active starter culture in yogurt remains above the recommended levels (greater than 7 log CFU g⁻¹) during refrigeration, consistently meeting this requirement throughout a 15-day storage period at 4 °C. Replacing sugar with 25% fig powder (GCM-F25) exhibited the highest counts of *L. bulgaricus*, with 8.44 ± 0.06 Log CFU g⁻¹ on day 1 and 8.49 ± 0.06 Log CFU g⁻¹ on day 8. In contrast, the free of fig powder sample (GCM-F0) showed the lowest *L. bulgaricus* count, starting at 6.53 ± 0.09 Log CFU g⁻¹ on day 1 and decreasing further by day 15. For *S. thermophilus*, Samples GCM-F50, GCM-F75, and

TABLE 6 Viable count (Log CFU g⁻¹) of different bacterial groups in Greek-like yogurt samples during 15 days of storage.

Medium	Storage (days)	Greek-like yogurt sample				
		GCM-F ₀	GCM-F ₂₅	GCM-F ₅₀	GCM-F ₇₅	GCM-F ₁₀₀
TC	1	6.76 ± 0.07 ^{aA}	7.41 ± 0.22 ^{bA}	7.75 ± 0.09 ^{aA}	6.62 ± 0.14 ^{cB}	7.78 ± 0.03 ^{aA}
	8	6.73 ± 0.05 ^{aA}	7.08 ± 0.03 ^{bB}	7.86 ± 0.02 ^{aA}	7.84 ± 0.03 ^{aA}	7.82 ± 0.06 ^{aA}
	15	6.80 ± 0.07 ^{aA}	6.79 ± 0.15 ^{aC}	6.71 ± 0.26 ^{aB}	6.57 ± 0.35 ^{abB}	6.40 ± 0.09 ^{bB}
MRS	1	6.53 ± 0.09 ^{dA}	8.44 ± 0.06 ^{aA}	7.55 ± 0.16 ^{cB}	8.18 ± 0.10 ^{bB}	7.63 ± 0.13 ^{aA}
	8	6.66 ± 0.03 ^{aA}	8.49 ± 0.06 ^{aA}	7.73 ± 0.02 ^{bdA}	7.89 ± 0.06 ^{bA}	7.67 ± 0.10 ^{dA}
	15	5.51 ± 0.11 ^{cB}	5.63 ± 0.11 ^{bcB}	5.71 ± 0.12 ^{abC}	5.82 ± 0.13 ^{aC}	5.59 ± 0.13 ^{bcB}
M17	1	8.34 ± 0.06 ^{bA}	8.76 ± 0.05 ^{aB}	8.79 ± 0.08 ^{aA}	8.82 ± 0.10 ^{aA}	8.86 ± 0.03 ^{aA}
	8	8.23 ± 0.01 ^{aA}	9.23 ± 0.02 ^{aA}	5.97 ± 0.02 ^{dC}	8.92 ± 0.02 ^{bA}	8.32 ± 0.44 ^{cB}
	15	7.35 ± 0.02 ^{bB}	7.37 ± 0.05 ^{bcC}	7.41 ± 0.05 ^{bbB}	7.67 ± 0.03 ^{aB}	7.63 ± 0.07 ^{acC}

^{a,b,c,d,e}There is significant difference ($P \leq 0.05$) between any two means, within the same raw have the different superscript letter for each parameter. ^{A,B,C}There is significant difference ($p \leq 0.05$) between any two means, within the same column have the different superscript letter for each parameter. GCM-F₀ (control without fig powder), GCM-F₂₅ (25% replacement of sugar with fig powder), GCM-F₅₀ (50% replacement of sugar with fig powder), GCM-F₇₅ (75% replacement of sugar with fig powder) and GCM-F₁₀₀ (100% replacement of sugar with fig powder).

GCM-F100 recorded the highest counts after one day of cold storage, with 8.79 ± 0.01 , 8.82 ± 0.10 , and 8.86 ± 0.03 Log CFU g⁻¹, respectively. Overall, lactic acid bacteria (LAB) populations in Greek-like yogurt exceeded 10^7 CFUg⁻¹, particularly in GCM-F50 and GCM-F100 samples by the eighth day of refrigerated storage. Our results were in parallel with those of Abd-Eltawab (2019). They reported that adding fig puree enhances *L. acidophilus* growth, thereby boosting the probiotic activity of fermented milk.

3.2.6 Instrumental color parameters

The instrumental color values (Table 7) showed clear differences among the treatments as the concentration of fig powder increased. The lightness (L*) values decreased significantly ($p < 0.05$) with higher fig supplementation levels (GCM-F75–GCM-F100), indicating a darker appearance of the yogurt compared with the GCM-F0 (control). This reduction in brightness could be attributed to the natural brown pigments and phenolic compounds in fig powder, which led to masking the inherent whiteness which impart brownish hues to the Greek-like yogurt matrix (Teruel-Andreu et al., 2024). A similar decrease in L* value was reported by Mahmoudi et al. (2021) in goat-milk yogurt fortified with fig powder, where the color darkened proportionally with increasing fig concentration. The redness (a*) and yellowness (b*) values increased gradually in treatments containing fig powder, reflecting the presence of anthocyanins, carotenoids, and Maillard-reaction pigments derived from the fruit solids. These findings are consistent with those of Rashwan et al., (2023), who noted that fortifying yogurt with plant-based powders rich in phenolics and sugars enhances reddish-yellow tones due to both natural pigments and thermal browning during pasteurization or storage.

The chroma (C) values showed an upward trend, especially in GCM-F75, suggesting higher color saturation and vividness in yogurts with moderate fig levels. However, excessive addition (GCM-F100) led to non-uniform pigment dispersion and slight dullness, possibly caused by pigment–protein interactions or phase separation. Meanwhile, the hue angle (H°) slightly decreased in fortified samples, implying a shift toward a red–yellow hue, which visually corresponds with the observed reddish coloration of fig-fortified yogurt. Color difference (ΔE) values increased notably compared with the control, confirming perceptible visual changes even after storage. Overall,

these results demonstrate that the incorporation of fig powder significantly affects the chromatic attributes of camel-milk Greek-like yogurt, mainly by introducing fruit-derived pigments and altering light scattering due to higher total solids. The darker and warmer tones may enhance consumer acceptance by giving the product a more natural, fruit-based appearance, as observed in previous fruit-fortified yogurt studies (Mahmoudi et al., 2021; Rashwan et al., 2023).

3.2.7 Microstructure observation

The scanning electron micrographs ($\times 6,000$) of various Greek-like yogurt samples made from camel milk are illustrated in Figure 4. Incorporating dairy ingredients improved the protein matrix density in fermented camel milk gels (Abou-Soliman et al., 2017; Fang and Guo, 2019). However, SEM analysis revealed distinct microstructural variations among the samples in the current study. These differences were particularly noticeable when comparing the control sample (GCM-F0) to the other Greek-style yogurt formulations. These differences were primarily due to an increased compactness of the protein matrix and a corresponding decrease in both the number and size of void spaces containing the aqueous phase (indicated by the white arrows) within the gel network. As sugar was progressively replaced with fig powder, a more compact and continuous protein matrix was formed, resulting in a significant decrease in both the number and size of void spaces related to the aqueous phase in the gel network. This may explain the observed increase in mouthfeel thickness and mouth coating, as illustrated in Figure 5C. Additionally, the fat's bright spherical structures, seen in the micrographs of the GCM-F0 and GCM-F25 samples (shown by yellow arrows), became more compacted (indicated by blue arrows) in the networks of the other samples (GCM-F50, GCM-F75, and GCM-F100) and lost their prominent spherical shape. As reported by Wang et al. (2025), plant-derived ingredients, like lentil flour, can change the gel structure through interactions with the starch or proteins in the milk matrix. Additionally, pectin from plant powders can fill internal voids by forming a compact colloidal network, which enhances the gel's elasticity while reducing its hardness. This behavior differs from the thickening and stabilizing mechanism provided by starch in lentil flour, underscoring the distinct textural effects of various functional ingredients in yogurt. Furthermore, the gelling properties of pectin found in fig powder have also been examined

TABLE 7 Instrumental color measurements of Greek-like yogurt samples during 15 days of storage.

Color parameter	Storage (days)	Greek-like yogurt sample				
		GCM-F ₀	GCM-F ₂₅	GCM-F ₅₀	GCM-F ₇₅	GCM-F ₁₀₀
L*	1	90.92 ± 0.04 ^{aA}	82.02 ± 0.19 ^{bA}	78.66 ± 0.02 ^{cA}	74.48 ± 0.05 ^{dA}	69.84 ± 0.11 ^{eB}
	8	90.72 ± 0.03 ^{aA}	81.49 ± 0.09 ^{bb}	78.67 ± 0.07 ^{cA}	74.95 ± 0.02 ^{dA}	70.57 ± 0.09 ^{eA}
	15	89.01 ± 0.06 ^{aB}	79.83 ± 0.17 ^{bc}	77.75 ± 0.36 ^{cA}	74.06 ± 0.21 ^{dA}	69.81 ± 0.15 ^{eB}
a*	1	−2.06 ± 0.51 ^{dA}	0.61 ± 0.04 ^{cA}	1.34 ± 0.04 ^{bb}	2.38 ± 0.17 ^{aA}	2.76 ± 0.26 ^{aA}
	8	−2.46 ± 0.09 ^{eB}	0.83 ± 0.06 ^{dA}	1.51 ± 0.16 ^{cAB}	2.40 ± 0.03 ^{bA}	2.94 ± 0.23 ^{aA}
	15	−2.32 ± 0.12 ^{cAB}	0.80 ± 0.30 ^{dA}	1.84 ± 0.42 ^{cA}	2.24 ± 0.46 ^{bA}	3.06 ± 0.28 ^{aA}
b*	1	6.44 ± 0.06 ^{dC}	12.81 ± 0.26 ^{cA}	13.13 ± 0.02 ^{cB}	14.32 ± 0.14 ^{bb}	15.05 ± 0.20 ^{aB}
	8	7.06 ± 0.05 ^{cA}	12.35 ± 0.02 ^{dB}	13.52 ± 0.12 ^{cA}	14.74 ± 0.02 ^{bA}	16.34 ± 0.17 ^{aA}
	15	6.71 ± 0.10 ^{eB}	11.36 ± 0.27 ^{dC}	13.13 ± 0.34 ^{cB}	14.41 ± 0.39 ^{bb}	16.22 ± 0.21 ^{aA}
C	1	36.91 ± 0.33 ^{aC}	28.62 ± 1.85 ^{aC}	28.43 ± 0.67 ^{aC}	32.69 ± 0.50 ^{aC}	30.97 ± 0.93 ^{aC}
	8	91.15 ± 0.03 ^{aB}	82.45 ± 0.19 ^{aB}	79.02 ± 0.01 ^{aB}	74.93 ± 0.05 ^{aB}	70.26 ± 0.12 ^{aB}
	15	1588.00 ± 31.18 ^{cA}	2848.67 ± 179.79 ^{bA}	2270.67 ± 195.01 ^{cA}	3785.33 ± 81.08 ^{aA}	1770.00 ± 10.44 ^{dA}
H°	1	269.42 ± 0.00 ^{aA}	269.35 ± 0.00 ^{aA}	269.32 ± 0.00 ^{aA}	269.28 ± 0.00 ^{aA}	269.22 ± 0.00 ^{aA}
	8	118.82 ± 7.53 ^{dC}	211.48 ± 1.62 ^{cC}	233.27 ± 0.75 ^{bC}	247.05 ± 1.53 ^{aC}	249.80 ± 1.92 ^{aC}
	15	261.22 ± 0.09 ^{bb}	265.58 ± 0.09 ^{aB}	265.69 ± 0.01 ^{aB}	266.05 ± 0.04 ^{aB}	266.24 ± 0.05 ^{aB}
BI	1	5.51 ± 0.46 ^{eB}	17.15 ± 0.45 ^{dA}	19.12 ± 0.00 ^{cB}	23.26 ± 0.04 ^{bb}	26.70 ± 0.03 ^{aC}
	8	5.91 ± 0.04 ^{cA}	16.81 ± 0.08 ^{dB}	19.86 ± 0.01 ^{cA}	23.80 ± 0.03 ^{bA}	28.88 ± 0.02 ^{aB}
	15	5.72 ± 0.01 ^{eAB}	15.74 ± 0.22 ^{dC}	19.85 ± 0.12 ^{cA}	23.42 ± 0.09 ^{bb}	29.15 ± 0.02 ^{aA}
ΔE	1	0 ± 0 ^{cA}	11.40 ± 0.31 ^{dA}	14.51 ± 0.01 ^{cA}	18.89 ± 0.04 ^{bA}	23.39 ± 0.09 ^{aA}
	8	0 ± 0 ^{cA}	11.18 ± 0.09 ^{dB}	14.28 ± 0.05 ^{cB}	18.25 ± 0.02 ^{bb}	22.88 ± 0.07 ^{aB}
	15	0 ± 0 ^{cA}	10.72 ± 0.17 ^{dC}	13.60 ± 0.27 ^{cC}	17.41 ± 0.13 ^{bC}	22.06 ± 0.10 ^{aC}

^{a,b,c,d,e}There is significant difference ($P \leq 0.05$) between any two means, within the same row have the different superscript letter for each parameter. ^{A,B,C}There is significant difference ($P \leq 0.05$) between any two means, within the column have the different superscript letter for each parameter. GCM-F0 (control without fig powder), GCM-F25 (25% replacement of sugar with fig powder), GCM-F50 (50% replacement of sugar with fig powder), GCM-F75 (75% replacement of sugar with fig powder) and GCM-F100 (100% replacement of sugar with fig powder).

(Mishra et al., 2025). Pectin, a soluble fiber present in figs and other fruits, interacts with casein micelles in milk. Depending on the type and concentration of pectin, this interaction can either encourage or inhibit gelation. At specific concentrations, pectin promotes the aggregation of casein micelles, altering the structure and strength of the gel network. Electron microscope images from various studies indicate that pectin accumulates around casein micelles. This accumulation thickens the protein network and enlarges the void spaces within the gel. As a result, the structure becomes more cohesive, although it may sometimes appear more porous. The degree of porosity is influenced by the type and concentration of pectin used (Mishra et al., 2025; Zhang et al., 2025).

3.2.8 Sensory evaluation

Nine sensory attributes were identified and defined for Greek-like yogurts. The sensory lexicon developed included 4 appearance, 3 basic taste and 2 textural attributes (Figure 5). The Greek-like yogurt samples presented in Figure 5A were evaluated based on their color, syneresis, gel firmness, and ropiness. According to the evaluators, the control sample (GCM-F0: no fig powder added) consistently received the highest scores throughout all storage days. Additionally, the color of the samples with added fig powder diminished after 15 days of storage compared to the first day in cold storage. This observation may be related to the results of the Browning Index (BI) presented in Table 7.

The BI data indicated that the intensity of browning significantly increased ($p \leq 0.05$) as the storage period extended. This increase can be attributed to the solubility of pigments in fruit products during storage, as previously discussed (Mahmoudi et al., 2021; Wang et al., 2025). Thus, it can be concluded that sensory evaluators favored a colorless appearance. The syneresis and gel firmness was in the same line for each sample. The more the syneresis increased the more the firm of the gel increased.

It is clearly appeared (Figure 5A) that the more the storage period increased the more the syneresis and firmness decreased. These findings may be influenced by several factors, including the protein composition, processing conditions, and the choice of starter cultures. Generally, an increase in gel firmness -an important characteristic of fermented milk products- is linked to higher levels of syneresis, also known as wheying-off. This occurs particularly when the gel network becomes more compact, which reduces its ability to retain water (Jaros et al., 2010; El Bouchikhi et al., 2019). Regarding ropiness, sensory panels define it as the degree to which a strand forms when the product is pulled with a spoon or in the mouth, often accompanied by increased mouth thickness and creaminess (Priyashantha et al., 2019). After the first day of cold storage, the ropiness property was highest for the GCM-F0 sample. This property increased as the sugar was replaced with fig powder and decreased as the storage period increased. Ropiness in fermented milk can be significantly affected by the addition of pectin, particularly when it comes from dried fruits or

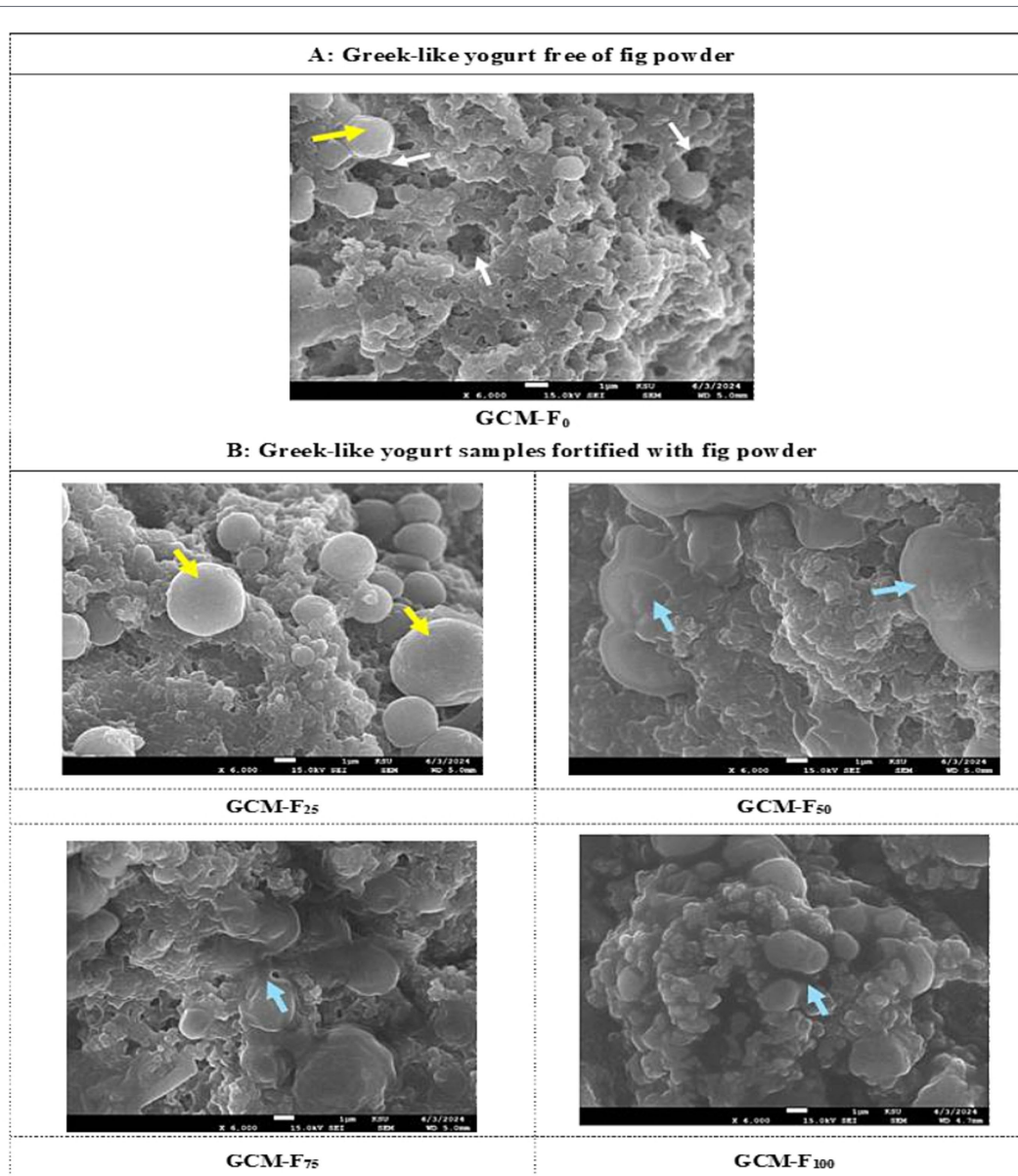


FIGURE 4

Scanning electron micrographs (x6000) of different Greek-like camel-milk yogurt samples fortified with fig powder. GCM-F0 (control without fig powder), GCM-F25 (25% replacement of sugar with fig powder), GCM-F50 (50% replacement of sugar with fig powder), GCM-F75 (75% replacement of sugar with fig powder) and GCM-F100 (100% replacement of sugar with fig powder).

fruit-derived fibers (Arioui et al., 2017). Pectin is a water-soluble fiber found in fruits that serves as a gelling and thickening agent, which increases the viscosity of fermented milk and contributes to a more noticeable ropy or stringy texture (Kieserling et al., 2019). It interacts with casein micelles and whey proteins, forming complexes that stabilize the protein gel network. This interaction enhances both viscosity and ropiness (Yu et al., 2025). The effects become more pronounced as the pectin content increases, particularly with higher additions of fruit powder (Kieserling et al., 2019).

Different taste attributes, including sweet, sour, and bitter flavors, are illustrated in Figure 5B. The sensation of both sweet and sour tastes diminished as the amount of sugar was replaced with fig powder throughout all storage periods. Additionally, the bitter taste was the most prominent sensory attribute in all Greek-style yogurt samples, and it tended to gradually decrease with an increasing amount of fig powder added. As shown in Figure 5C, both mouthfeel thickness and

mouth coating were more pronounced when sugar was replaced by 25 and 50% fig powder in the GCM-F₂₅ and GCM-F₅₀ samples, respectively.

When introduced via dried fruit or fruit-derived fibers (Arioui et al., 2017). Pectin, a water-soluble fiber found in fruit, acts as a gelling and thickening agent in fermented milk, increasing viscosity and contributing to a more pronounced ropy or stringy texture (Kieserling et al., 2019). Pectin interacts with casein micelles and whey proteins, forming complexes that stabilize the protein gel network, further enhancing viscosity and ropiness (Yu et al., 2025) which lead to an increase in viscosity and ropiness, with the effect being more pronounced as the pectin content rises by increasing the amounts of fruit powder addition (Kieserling et al., 2019). Different taste attributes, including sweet, sour, and bitter flavors, are illustrated in Figure 5B. The sensation of both sweet and sour tastes diminished as the amount of sugar was replaced with fig powder throughout all

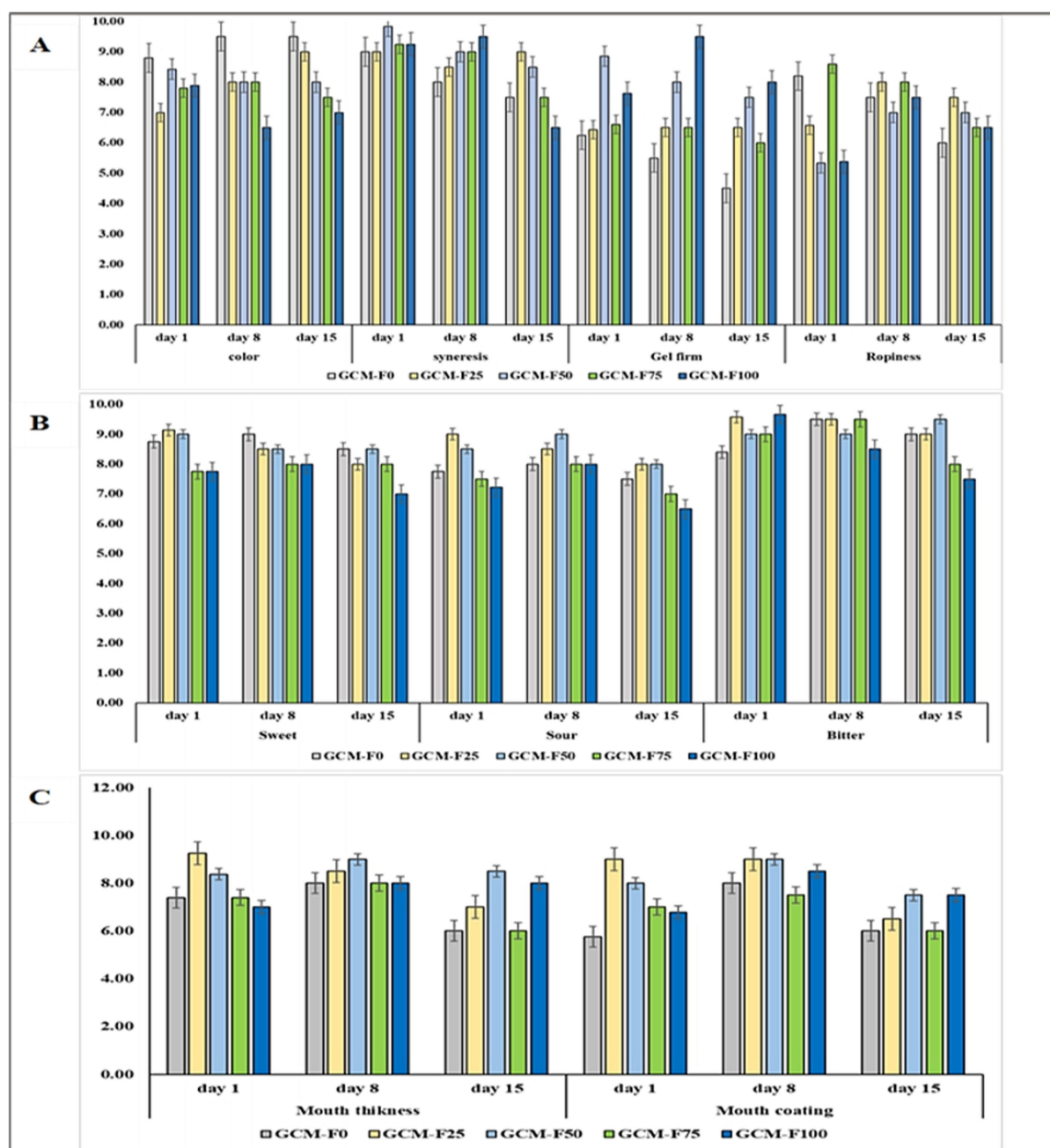


FIGURE 5

Descriptive sensory attributes of different Greek-like camel milk yogurt samples during 15 days of cold storage ($4^{\circ}\text{C}\pm 1$). While (A) Appearance (color, syneresis, gel-firm and ropiness), (B) Taste (sweet, sour and bitter) and (C) (mouth thickness and mouth coating).

storage periods. Additionally, the bitter taste was the most prominent sensory attribute in all Greek-style yogurt samples, and it tended to gradually decrease with an increasing amount of fig powder added. As shown in Figure 5C, both mouthfeel thickness and mouth coating were more pronounced when sugar was replaced by 25 and 50% fig powder in the GCM-F₂₅ and GCM-F₅₀ samples, respectively.

4 Conclusion

In conclusion, the present study provides valuable insights into the technological feasibility of producing high-quality Greek-like

yogurt from camel milk. Standardisation of camel milk with GW and TSC, and replacing sugar with fig powder as a natural sweetener for Greek-like yogurt production, can improve the nutritional, texture and sensory qualities of the final product. Moreover, the replacement of sugar with fig powder (up to 75%) not only improved nutritional value by increasing fibre and antioxidant content but also positively influenced sensory attributes, especially the balance of sweetness and overall acceptability. Future research should focus on scaling up production, evaluating shelf life under various storage conditions, and investigating the viability of probiotics, as well as the *in vivo* postbiotic effects of these products. This work is integral to expanding the applications of camel milk and fostering innovations in sustainable dairy practices.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

SA: Methodology, Formal analysis, Writing – original draft, Investigation. AA: Writing – original draft, Writing – review & editing, Formal analysis, Methodology, Visualization, Investigation. SS: Supervision, Data curation, Methodology, Writing – review & editing, Conceptualization, Investigation, Writing – original draft, Software, Formal analysis, Visualization, Project administration.

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