

Effect of microbial transglutaminase and banana peel powder on the structure and oxidative potentiality of camel milk yoghurt during cold storage

REHAB S. ALSULAMI, ELFADIL E. BABIKER*, ISAM A. MOHAMED AHMED,
TAWFIQ S. ALSULAMI, FAHAD Y. AL-JUHAIMI

Department of Food Science and Nutrition, College of Food and Agricultural Sciences, King Saud University, Riyadh, Saudi Arabia

*Corresponding author: ebabiker.c@ksu.edu.sa

Citation: Alsulami R.S., Babiker E.E., Mohamed Ahmed I.A., Alsulami T.S., Al-Juhaimi F.Y. (2025): Effect of microbial transglutaminase and banana peel powder on the structure and oxidative potentiality of camel milk yoghurt during cold storage. Czech J. Food Sci., 43: 365–375.

Abstract: The current investigation was done to study the impact of adding banana peel powder (BPP) and treatment with microbial transglutaminase (MTGase) on the structure, physicochemical, antioxidant, and sensory qualities of yoghurt prepared from camel milk powder during cold storage. BPP analysis showed that it contained high amounts of total phenolics, which were accompanied by strong antioxidant activity. When employed alone or with BPP, MTGase polymerises yoghurt proteins, forming a structure with a high molecular weight above the stacking gel and lacking pores. The levels of protein, total phenolic compounds (TPC), total solids, ash, and antioxidant activity (DPPH – 2,2-diphenyl-1-picrylhydrazyl) increased after the addition of BPP to yoghurt, even after 21 days of storage. Adding BPP to yoghurt initially decreased thiobarbituric acid reactive substances (TBARS) levels, which then increased with the storage time. Yoghurt made with BPP and treated with MTGase was more stable with enhanced physicochemical, antioxidant, and sensory qualities during storage when compared to yoghurt made with MTGase alone. The results of the study demonstrated that MTGase is capable of cross-linking yoghurt proteins and that BPP can be applied as a stabiliser, antioxidant, and functional component in yoghurt production.

Keywords: transglutaminase; antioxidant; composition; protein; total soluble solids

As a nutritious substitute to cow's milk, camel milk has been used for a long time in dry areas where other dairy products are not available. It is also quite popular among people because it has unique taste and health benefits (Ait El-Alia et al. 2025). Benmeziiane-Derradji (2021) reported that camel milk products are rich in minerals (Ca, Fe, and Mg) and vitamins such as C and B. Healthy fats, mainly unsaturated fatty acids were found in camel milk, which are found to decrease cholesterol levels and stop plaque from building up in the arteries (Swelum et al. 2021). Due to its lower level of lactose,

camel milk plays a role in overcoming metabolic diseases, such as lactose intolerance, and is a better choice for the stomach compared to cow's milk (Ho et al. 2022a). In a study conducted by Khan et al. (2021), camel milk contains lysozyme and immunoglobulins, which have antimicrobial and immunological regulating effects. The low coagulation power of camel milk makes it difficult to produce yoghurt and other fermented food products due to lower lactose content (Ait El Alia et al. 2023) and the yoghurt produced has a thin consistency, more whey separation, and an unappealing texture, making it less

Supported by the Ongoing Research Funding Program (ORFFT-2025-051-1), King Saud University, Riyadh, Saudi Arabia.

© The authors. This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0).

attractive and less likely to be accepted by customers (Khalifa and Zakaria 2019). The consumers' attractiveness, taste, and acceptability of yoghurt are highly affected by its texture properties (Al-Zoreky and Al-Otaibi 2015). To overcome low consistency and high syneresis of camel milk yoghurt, various attempts have been made by blending camel milk with milk from other animals (Khalifa and Zakaria 2019; Kamal-Eldin et al. 2020).

Nevertheless, blending camel milk with milk from other mammals will reduce its natural benefits, features, and other attributes (Ho et al. 2022b). Moreover, other attempts have investigated the use of hydrocolloids and stabilisers to make more consistent camel milk yoghurt, such as gelatine (Mudgil et al. 2018; Ho et al. 2022a), and banana fibre mixed with peel fibre (Safdari et al. 2021). In the study by Mudgil et al. (2018), the addition of gelatine to camel milk yoghurt improved the microstructure and decreased syneresis. Additionally, Alia et al. (2023) found that the addition of persimmon pulp and gelatine to camel milk yogurt improves its rheological, sensory, and physicochemical properties. Fazilah et al. (2018) reported that people prefer yoghurt incorporated with fruit, which could shed light on the ongoing practice of adding different types of fruits to yoghurt. Ahmad et al. (2022) observed that the addition of fruits improves the taste of yoghurt and provides the added value of fruits, mainly sugars and pectin, which give yoghurt a thicker, creamier texture and a more satisfying mouthfeel.

As an agricultural by-product, banana (*Musa* spp.) peel, like many agricultural by-products, is frequently wasted. Banana peels can be converted into functional foods, as they have been traditionally used in various regions globally for both food and medicinal purposes (Zaini et al. 2022). Annually, approximately 36 million tonnes of banana peels are generated, with current disposal methods resulting in economic losses and adverse environmental impacts (Gomes et al. 2022). Pectin derived from banana peels has the potential to be an effective gelling agent for various applications (Rasidek et al. 2021). Banana peel possesses antibacterial, antimicrobial, and antioxidant characteristics, and is rich in dietary fibre and bioactive compounds, including anthocyanins, catechin, epicatechin, gallic acid, and tannins (Sidhu and Zafar 2018).

MTGase (microbial transglutaminase) in food systems has been applied to improve the protein functional properties (Akbari et al. 2021), which will help overcome the problems related to camel milk yoghurt processing using a similar technique to that used for bovine milk. According to Mostafa (2020), MTGase

cross-links the lysine residue and the glutamine residue in a protein, resulting in a protein with a network structure that makes the protein solutions thicker and forms a firm gel. Moreover, Bulca and Büyükgümüş (2024) demonstrated that MTGase enhances the texture of yoghurt and prevents it from becoming watery during storage. They showed that MTGase treatment cross-linked yoghurt proteins, resulting in improved physicochemical, microstructural, sensory, and fragrance qualities. Food formulations with a high concentration of banana peel are expected to enhance phytochemical and antioxidant potency. Nonetheless, this may result in food products exhibiting inadequate physicochemical properties and sensory qualities that are unacceptable (Zaini et al. 2022). This research aimed to produce camel milk yoghurt treated with MTGase and enriched with banana peel powder (BPP), followed by an evaluation of its quality attributes.

MATERIAL AND METHODS

Material. In April 2025, the Riyadh vegetable market in Saudi Arabia was the source of fresh bananas (*Musa* spp.) that were free from pesticides and other harmful chemicals. After being peeled by hand, the fruits were rinsed three times with water and then left to soak in a citric acid solution containing 1% (w/v) for 5 min to avoid any colour change. Then, the peels were freeze-dried. Sigma-Aldrich (St. Louis, USA) provided all of the chemicals, which were of standard grade.

Yoghurt preparation. Before starting this study, we optimised the primary factors, specifically BPP and MTGase concentrations, as well as the MTGase reaction time. Nonetheless, camel milk containing only BPP or lacking both BPP and MTGase did not undergo coagulation; thus, we utilised milk treated with MTGase alone as a control. Camel milk yoghurt preparation was performed using the method outlined by Zhang et al. (2019), with minor modifications. Camel milk powder (6.2 g) was dissolved in 50 mL of distilled water to maintain a total soluble solids concentration between 10% and 15%, similar to that of fresh milk. The mixture was pasteurised at 85 °C for 30 min and subsequently cooled to room temperature. Then, 1% BPP was incorporated into pasteurised milk, followed by homogenisation for 5 min and heating in a water bath until the temperature reached 55 °C. Subsequently, MTGase (6 U·g⁻¹) at a 0.6% concentration was incorporated into the mixture and allowed to react for 20 min. Afterward, the mixture was cooled to 42 °C and inoculated with a commercial yoghurt culture comprising *Lactobacil-*

<https://doi.org/10.17221/100/2024-CJFS>

lus delbrueckii subsp. *bulgaricus* and *Streptococcus thermophilus* (YF-L903, CHR Hansen, Denmark). The mixture was subsequently incubated at 42 °C for 5 h until complete coagulation occurred, maintaining a pH of 4.6. Then, the yoghurt was kept at 4 °C for 21 days with a sampling interval of 7 days.

Yoghurt extract preparation. As described by Zhang et al. (2019), the yoghurt supernatant extract was produced by centrifuging 10 g yoghurt samples (5 000 × g for 20 min at 4 °C), re-centrifuging the supernatants (5 000 × g for 20 min at 4 °C), collecting and combining the clear supernatants, and storing them at –80 °C for later use.

Gel electrophoresis. According to Laemmli's method (1970), SDS-polyacrylamide gel electrophoresis (SDS-PAGE) was performed using a 12% acrylamide separating gel and a 4% acrylamide stacking gel, both of which contained 0.1% SDS. Electrophoresis was performed in a Tris-Glycine buffer containing 0.1% SDS, with currents of 10 mA for 1 h followed by 20 mA for 2 h. Thereafter, the gel sheets were dyed with 0.2% Coomassie Brilliant Blue R-250 and destained in a solution of 10% acetic acid and 20% methanol for 18 h.

Scanning electron microscopy (SEM). A Dynavac Engineering FD3 freeze-drier, sourced from Belmont, Australia, was used to freeze-dry the yoghurt samples. Scanning electron microscopy (JSM-6360A, JEOL, Japan) was used to analyse the yoghurt powders. The microscope was used to capture the images, which were magnified at 500× and 600×. Coating samples with a 10–12 nm thick layer at a 20 kV working voltage for 1.5 min was done before imaging.

Yoghurt's chemical composition and total solid content determination. The ash, protein, and moisture content of treated yoghurt samples were examined during storage (AOAC 2005). The fat content in yoghurt during storage was determined according to Badertscher et al. (2007). After deducting 100% from the sample moisture, the total solid content was calculated.

Yoghurt's pH and titratable acidity determination. The pH of yoghurt during storage was evaluated using an electronic pH meter (Universal Motion, model H1-1131B, Mumbai, India) following calibration with standard buffers. Titration acidity (TA) during storage was measured as a percentage, using phenolphthalein as an indicator and titration with 4 mg·mL^{–1} of NaOH. The data were presented as a percentage of lactic acid.

Yoghurt's total phenolic content (TPC) determination. TPC in yoghurt extract during storage was determined using the method described by Hernández-Carranza et al. (2016) and the Folin-Ciocalteu rea-

gent. At 765 nm, the absorbance of gallic acid, BPP, and yoghurt extract was measured using a Lambda EZ 150 spectrophotometer (PerkinElmer, USA), and TPC was expressed as mg gallic acid equivalent (GAE)·(100 g)^{–1}.

Yoghurt's DPPH antiradical activity determination. The method described by Hernández-Carranza et al. (2016) was applied to measure the DPPH (2,2-diphenyl-1-picrylhydrazyl) antiradical activity of BPP and camel yoghurt extract during storage. The absorbance at 517 nm for both the sample and the control (without the extracts) was measured using a Lambda EZ 150 spectrophotometer (PerkinElmer, USA). According to the following equation, the percent DPPH was determined:

$$\text{DPPH scavenging (\%)} = \frac{\text{Absorbance of blank} - \text{Absorbance sample}}{\text{Absorbance of blank}} \times 100 \quad (1)$$

Determination of thiobarbituric acid reactive substances (TBARS). The procedure outlined by Rosmini et al. (1996) was used to calculate the level of TBARS in camel yoghurt extract during storage by determining the oxidation products of malonaldehyde (MDA). The MDA (mg MDA·kg^{–1}) was calculated as absorbance (532) multiplied by 7.8.

Sensory evaluation. A group of 37 males and females, aged 20 to 35, who are either professionals or students at King Saud University's College of Food and Agriculture, was requested to rate the sensory characteristics of the yoghurt during storage. The method provided by Dantas et al. (2016) was applied to determine sensory attributes. Before the sample examination, the panellists received three training sessions to familiarise themselves with the sensory features that would be examined. Panellists evaluated the yoghurt product's sensory qualities during storage. Colour, texture, flavour, sourness, and overall acceptability were all evaluated using a 9-point hedonic scale. Ethical permission was not required because all the ingredients used in the yoghurt's formulation are of food grade, and appropriate protocols were followed to protect the rights of the panellists. After providing a clear explanation of the experiments, written informed consent forms were obtained from all of them. The well-established ethical guidelines, guaranteeing full compliance with participant rights and privacy preservation, were strictly followed throughout this study.

Statistical analyses. An analysis of variance (ANOVA) was done on data from three replicates using IBM SPSS Statistics 23.0 software (SPSS Inc., USA). The re-

sults were shown as means $\pm$ SD. To determine if the means were statistically significant, Duncan's multiple range tests were used. For statistical purposes, a *P*-value of 0.05 or less was considered significant.

RESULTS AND DISCUSSION

SDS-PAGE. The MTGase polymerised milk proteins were assessed using SDS-PAGE (Figure 1). The polymerisation of camel milk yoghurt protein via MTGase led to the emergence of new polymer fractions (Figure 1, lanes 4 and 5) above the stacking gel and a reduction in the monomeric fraction of intact protein in both MTGase-treated and MTGase-with-BPP yoghurt samples, relative to the control and fermented milk samples (Figure 1, lanes 2 and 3). Protein molecules underwent cross-linking through a transfer process involving an amide group in a glutamine-bound protein and an ϵ -amino group in a lysine side chain,

potentially catalysed by MTGase. The addition of BPP to yoghurt did not influence the MTGase response. Bulca et al. (2022) examined the influence of MTGase on yoghurt prepared from camel milk and observed results that agree with those of the present finding. Abou-Soliman et al. (2017) found that the gel electrophoresis pattern of MTGase-treated yoghurt exhibited a notable decline in the intensities of casein and monomeric whey protein bands relative to control samples. The variations in the bands were linked to a significant quantity of aggregates that failed to infiltrate the stacking gel. The observed alterations were attributed to the activity of MTGase, which facilitated chemical cross-links and promoted the formation of high-molecular-weight, covalently bonded polymers.

Scanning electron microscopy (SEM). Figure 2 presents the scanning electron microscopy images of yoghurt samples produced with the addition of MTGase with or without BPP. Yoghurt samples were lyophilised one day post-production. The yoghurt treated with MTGase, either alone (Figure 2A) or with BPP (Figure 2B), was found to have a denser, compact structure, a smoother microstructure, and a more homogeneous protein matrix. These changes can be due to the proteins cross-linking by MTGase. It has been reported that milk proteins, particularly caseins, are recognised as the most suitable substrates for MTGase (Velazquez-Dominguez et al. 2023). The structure and texture of fermented camel milk are less than ideal, owing to smaller fat globules and larger micelles of camel milk casein compared to milk of other animals. However, the results imply that the protein concentrate is a suitable substrate for MTGase. Therefore, the yoghurt had the most excellent structural distribution and the highest interaction density. The results also showed that BPP did not affect the action of MTGase. Similarly, Bulca et al. (2022) found that camel milk yoghurt protein matrices subjected to MTGase treatment were more compact compared to the controls, owing to the impact of MTGase on the microstructure, which causes aggregates to form a denser matrix, thereby helping to form a finer mesh network. The changes in protein matrices make the gel harder by creating small pores and reducing syneresis (Gharibzahedi and Chronakis 2018). It has been reported that adding whey protein concentrate and beta-lactoglobulin to yoghurt, followed by MTGase treatment, resulted in a yoghurt microstructure that showed homogeneity with smaller clusters and a stronger network than samples that were not enriched (Abu Suleiman et al. 2017).

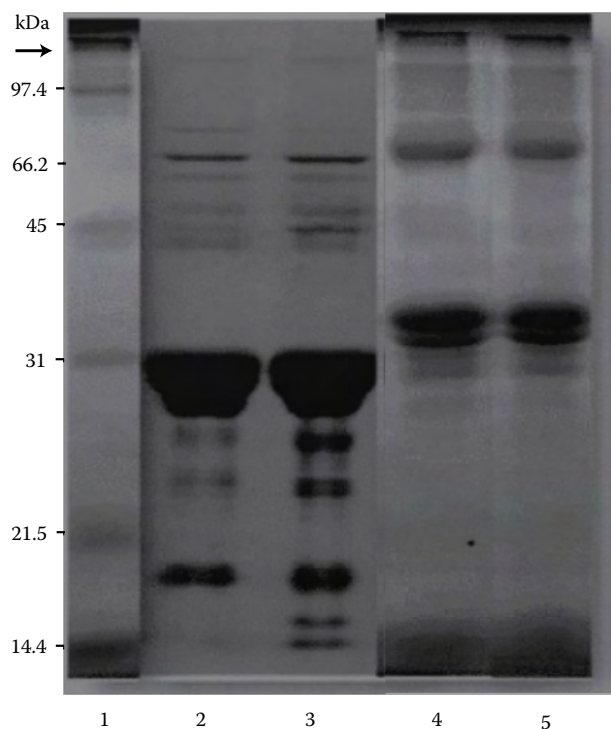


Figure 1. SDS-PAGE pattern of camel milk powder yoghurt prepared using MTGase with and without BPP

Lane 1: molecular marker; lane 2: camel milk; lane 3: fermented camel milk; lane 4: camel milk + MTGase; lane 5: camel milk + MTGase + BPP. Arrows indicate the boundary between stacking (upper) and separating (lower) gels; MTGase – microbial transglutaminase; BPP – banana peel powder

<https://doi.org/10.17221/100/2024-CJFS>

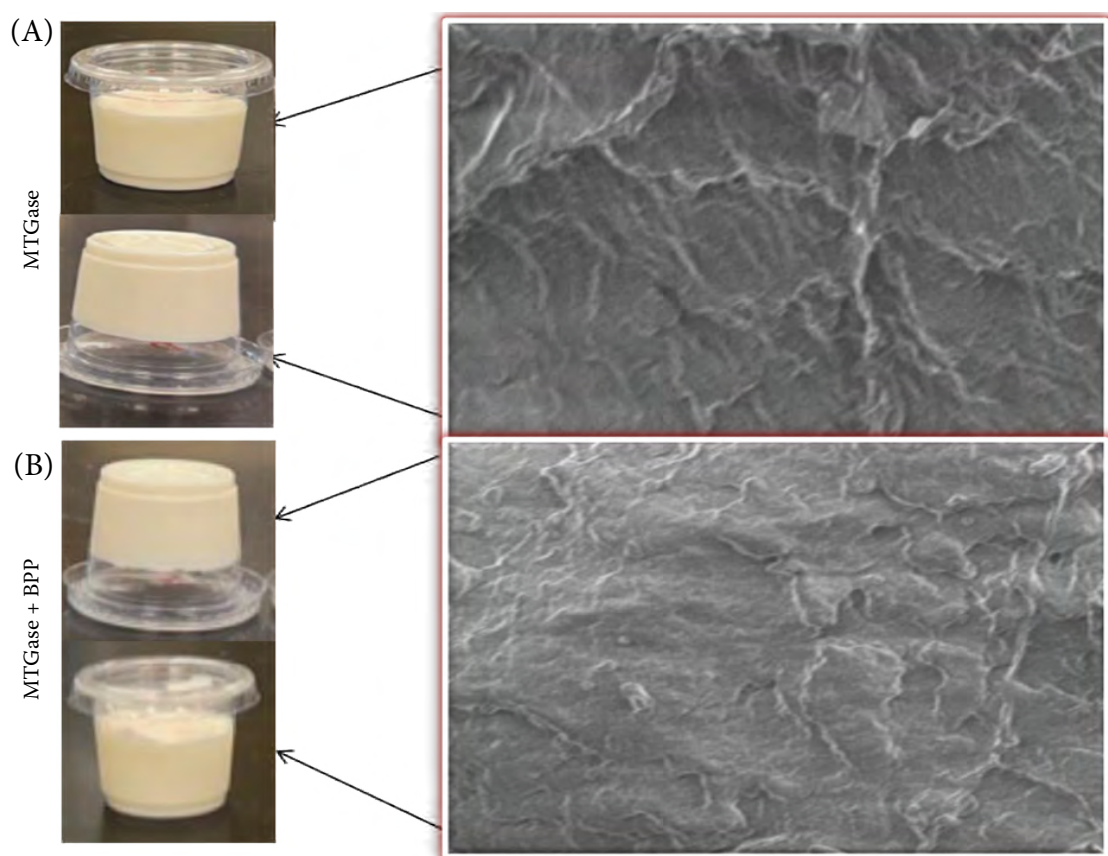


Figure 2. Scanning electron micrographs of camel milk yoghurts fortified with BPP and treated with MTGase. A) MTGase; B) MTGase + BPP

MTGase – microbial transglutaminase; BPP – banana peel powder

Changes in the chemical composition of yoghurt during storage. The data obtained for yoghurt composition treated with MTGase with and without BPP during cold storage are displayed in Table 1. MTGase treatment with and without BPP did not alter the composition of yoghurt during cold storage, except in a few cases. Adding BPP to treated yoghurt, as opposed to MTGase-treated yoghurt, significantly ($P \leq 0.05$) dropped the moisture content, along with a significant ($P \leq 0.05$) increase in total solids and other yoghurt components over the storage period. The rise in total solids following BPP addition may account for the reduction in yoghurt moisture content, suggesting that BPP possesses a significant water-holding capacity (Alam et al. 2020). Almusallam et al. (2021a) reported a comparable rise in total solids and a reduction in moisture content in yoghurt with date palm spikelet extract. The low moisture level in MTGase-treated yoghurt may result from MTGase's role in facilitating the formation of new bonds between milk proteins,

primarily caseins, and in generating larger and more robust protein networks through cross-linking, which effectively entraps moisture within the structure. The enhancement of protein-protein cross-linking fortifies the stability of the yoghurt gel, thereby diminishing syneresis and improving texture and viscosity (Mohamed et al. 2022). The integration of BPP resulted in elevated protein and ash levels in the manufactured yoghurt, with significant impacts noted during the latter storage phase. The substantial concentrations of protein, fat, and ash in BPP (Zaini et al. 2022) may result in elevated quantities of these components in the formed yoghurt. The fat content remained unaffected by the incorporation of BPP or the storage time, primarily due to BPP's low fat composition. Almusallam et al. (2021a) documented an elevation in protein and fat levels in yoghurt enhanced with date palm spikelet extract, corroborating our results. Lactose is initially high but decreases over time due to conversion to lactic acid, as described by Barros et al. (2019).

Table 1. Chemical composition (%) of camel skim milk yoghurt during storage prepared using MTGase with and without BPP

Treatment/storage period (days)	Composition (%)				lactose	total solids
	moisture	protein	ash	fat		
MTGase						
1	84.11 ± 0.11 ^{aA}	3.59 ± 0.46 ^{aB}	0.94 ± 0.02 ^{aB}	3.48 ± 0.72 ^{aA}	4.35 ± 0.66 ^{aA}	15.89 ± 0.54 ^{aB}
7	84.02 ± 0.35 ^{bA}	3.41 ± 0.61 ^{aB}	1.15 ± 0.09 ^{aB}	3.62 ± 0.51 ^{aA}	4.68 ± 0.83 ^{aA}	15.98 ± 0.79 ^{aB}
14	84.39 ± 0.08 ^{aA}	3.31 ± 0.35 ^{aA}	0.96 ± 0.02 ^{aB}	3.76 ± 0.47 ^{aA}	4.11 ± 0.49 ^{aA}	15.61 ± 0.89 ^{aB}
21	84.11 ± 0.07 ^{aA}	2.77 ± 0.26 ^{bC}	0.99 ± 0.01 ^{aA}	3.72 ± 0.32 ^{aA}	3.58 ± 0.38 ^{aB}	15.89 ± 0.93 ^{bB}
MTGase + BPP						
1	83.02 ± 0.13 ^{aB}	4.64 ± 0.59 ^{aB}	0.99 ± 0.11 ^{bB}	3.98 ± 0.56 ^{aA}	4.41 ± 0.59 ^{aA}	16.98 ± 0.47 ^{bA}
7	82.85 ± 0.09 ^{aB}	4.52 ± 0.61 ^{aB}	1.84 ± 0.07 ^{aA}	3.58 ± 0.71 ^{aA}	4.91 ± 0.63 ^{aA}	17.15 ± 0.53 ^{aA}
14	82.74 ± 0.27 ^{aB}	3.59 ± 0.77 ^{bC}	1.06 ± 0.02 ^{bB}	3.89 ± 0.47 ^{bB}	3.55 ± 0.75 ^{bB}	17.26 ± 0.38 ^{aA}
21	82.36 ± 0.03 ^{aB}	3.55 ± 0.69 ^{bC}	1.07 ± 0.03 ^{bB}	3.45 ± 0.68 ^{bB}	3.67 ± 0.65 ^{bB}	17.64 ± 0.49 ^{aA}

Values are means of three samples ± SD; ^{a,b}different letters denote significant difference ($P \leq 0.05$) within treatment, ^{A–C}different letters denote significant difference ($P \leq 0.05$) between treatments; MTGase – microbial transglutaminase; BPP – banana peel powder

Changes in pH and titration acidity of camel yoghurt during storage. Figure 3 illustrates the pH and titration acidity levels of yoghurt subjected to MTGase treatment, both with and without BPP. Initially, the pH (Figure 3A) of yoghurt treated with MTGase was elevated and significantly ($P \leq 0.05$) decreased after 7 days, after which it remained stable; however, following the addition of BPP, a further decrease was observed. The pH progressively decreased with extended storage time, ultimately reaching a minimum of 4.07 for MTGase with BPP yoghurt after the storage period. The most significant reduction in pH occurred with MTGase in BPP yo-

ghurt. The incorporation of BPP resulted in a minor decrease in pH, from 4.51 to 4.01, in yoghurt during storage, indicating that BPP effectively regulates the metabolic activity of LAB, thereby stabilising bacterial counts during the storage period. Results similar to our finding have been found in yoghurt with jujube pulp (Feng et al. 2019) and with date palm spikelet extract (Almusallam et al. 2021a). During the storage time, the titration acidity (Figure 3B) of MTGase-yoghurt with BPP increased steadily, reaching its highest point at the end of the 21 days (1.23%). The pH drop and titration acidity rise during storage are likely due to the increased metabolic activity of lactic acid

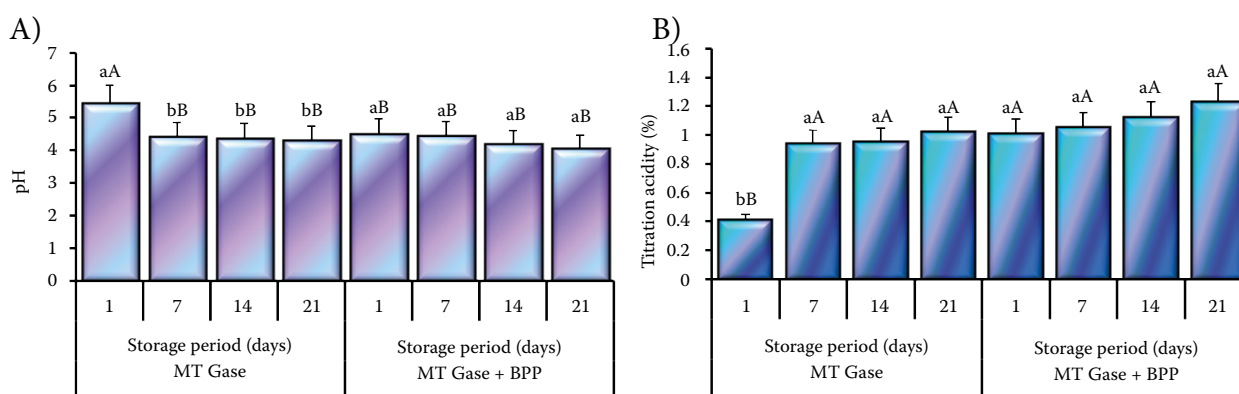


Figure 3. pH (A) and titration acidity (B) of camel skim milk yoghurt during storage prepared using MTGase with and without BPP

^{a,b}different letters denote significant difference ($P \leq 0.05$) within treatment, ^{A,B}different letters denote significant difference ($P \leq 0.05$) between treatments; MTGase – microbial transglutaminase; BPP – banana peel powder

<https://doi.org/10.17221/100/2024-CJFS>

bacteria (LAB), which produce lactic acid through enzymatic hydrolysis of lactose, fatty acids, and fibre, thereby lowering the pH and raising the titration acidity of yoghurt samples. Yoghurt containing date palm spikelets extract (Almusallam et al. 2021b), moringa leaf extract (Zhang et al. 2019), and jujube pulp (Feng et al. 2019) all showed similar changes in pH and titration acidity during storage.

Oxidative characteristics of yoghurt during cold storage. Figure 4 shows the total phenolic content (TPC), DPPH radical scavenging activity, and thiobarbituric acid reactive substances (TBARS) in camel milk powder yoghurt treated with MTGase, with and without BPP, stored under cold conditions. The total phenolic content (Figure 4A) of yoghurt treated with MTGase was measured at $55.98 \text{ mg GAE} \cdot (100 \text{ g})^{-1}$, corresponding to a DPPH value of 37.41%. A high drop ($P \leq 0.05$) was observed over the storage period, reaching a minimum TPC of $46.87 \text{ mg GAE} \cdot (100 \text{ g})^{-1}$ and a DPPH value of 19.64% by the end of storage. The addition of BPP to treated yoghurt caused a significant upsurge ($P \leq 0.05$) in TPC to $109.44 \text{ mg GAE} \cdot (100 \text{ g})^{-1}$, accom-

panied by a DPPH (Figure 4B) value of 79.52%. However, during storage time, the amount of TPC dropped significantly ($P \leq 0.05$) to $92.89 \text{ mg GAE} \cdot (100 \text{ g})^{-1}$, and the DPPH value decreased to 75.47%. According to the results obtained, adding BPP to yoghurt significantly ($P \leq 0.05$) increased TPC levels, which was accompanied by an increase in DPPH. The increase in TPC and DPPH activity in yoghurt containing BPP was noted, as BPP exhibited $18.67 \text{ mg GAE} \cdot \text{g}^{-1}$ sample and a DPPH value of 89.67% (data not shown), which agrees with studies reporting that BPP exhibits significantly higher levels of TPC and antioxidant activity (Sidhu and Zafar 2018; Zaini et al. 2022). The elevated level of TPC in BPP explained the upsurge in TPC and DPPH of yoghurt when BPP was added. An investigation conducted by Alenisan et al. (2017) showed that elevated concentrations of natural antioxidants caused a significant upsurge in TPC and DPPH radical scavenging activity in yoghurt. During storage, however, the TPC declined and was accompanied by a reduction in DPPH. The decrease in DPPH and TPC of yoghurt during cold storage may result from interactions

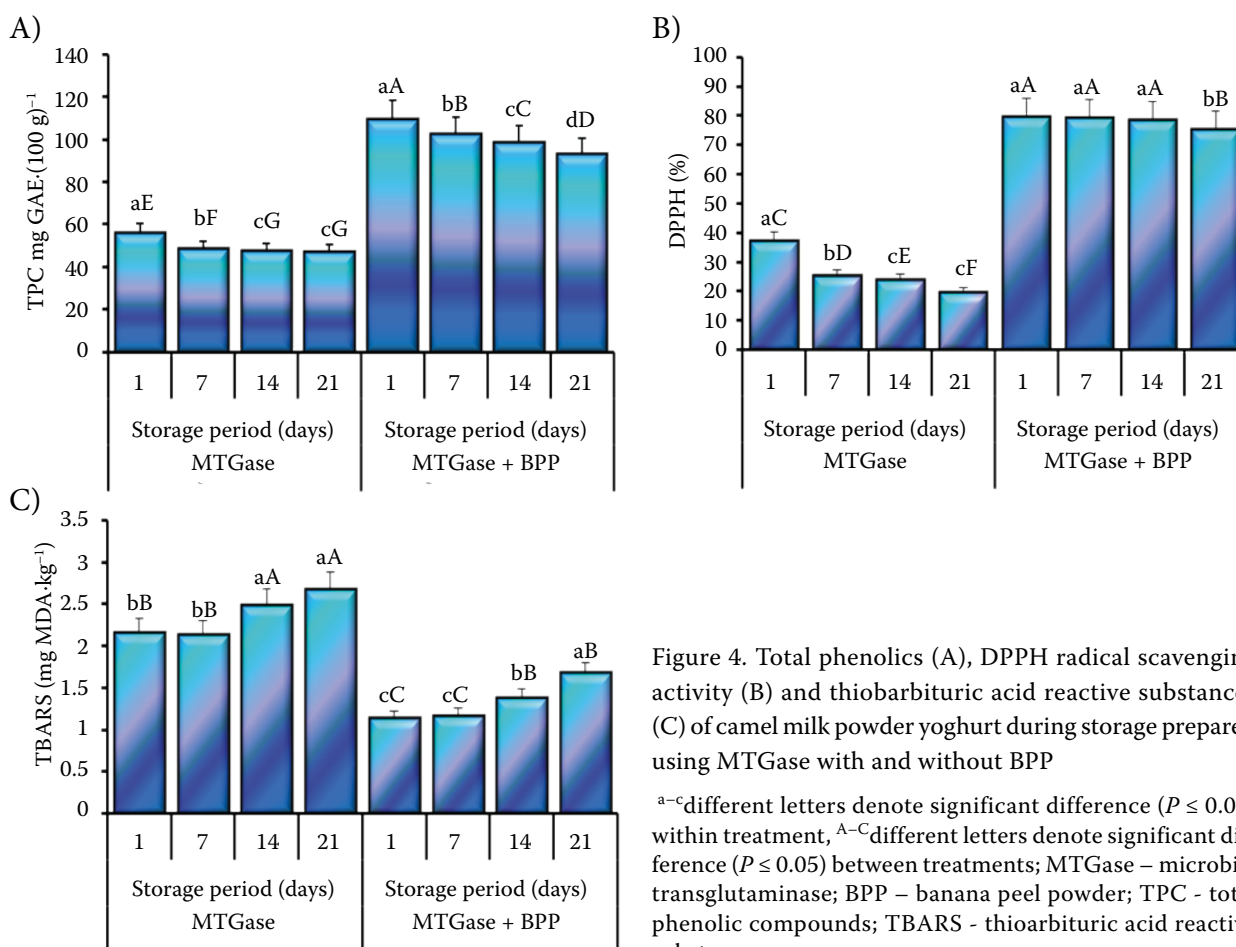


Figure 4. Total phenolics (A), DPPH radical scavenging activity (B) and thiobarbituric acid reactive substances (C) of camel milk powder yoghurt during storage prepared using MTGase with and without BPP

^{a-c}different letters denote significant difference ($P \leq 0.05$) within treatment, ^{A-C}different letters denote significant difference ($P \leq 0.05$) between treatments; MTGase – microbial transglutaminase; BPP – banana peel powder; TPC – total phenolic compounds; TBARS – thiobarbituric acid reactive substances

with other ingredients that mitigate oxidative rancidity (Caipo et al. 2021). Pascariu et al. (2025) observed a high initial total phenolic content, but this decreased with increasing storage duration, attributing the decline to the minor degradation of polyphenolic compounds over time. However, Kim et al. (2019) noted a rising trend in total phenolic content throughout the 7-day storage period of yoghurt, irrespective of the inclusion of lotus leaf. The rise was attributed to the decomposition of milk proteins by proteases, resulting in the liberation of amino acids with phenolic side chains. The authors also stated that microbial metabolism may have contributed to the formation of new phenolic acids, thereby increasing the overall levels of polyphenols.

TBARS data (Figure 4C) showed that adding BPP to yoghurt lowered lipid peroxidation. The MTGase-yoghurt showed $1.13 \text{ mg MDA} \cdot \text{kg}^{-1}$, whereas the one treated with MTGase alone showed $2.16 \text{ mg MDA} \cdot \text{kg}^{-1}$. The results indicated that BPP improves the lipid oxidation stability of yoghurt compared to non-formulated yoghurt. The TBARS levels of the MTGase sample augmented significantly over the storage period, reaching a peak of $2.67 \text{ mg MDA} \cdot \text{kg}^{-1}$ at the last day of storage (day 21). On the other hand, the BPP-formulated yoghurt had a maximum TBARS amount of $1.67 \text{ mg MDA} \cdot \text{kg}^{-1}$ after being stored. The significant increase in TBARS values of MTGase-yoghurt and the moderate increase in TBARS values of MTGase-yoghurt fortified with BPP during storage indicate lipid oxidation and aldehyde formation in the Yoghurt (Almusallam et al. 2021a). The antioxidant components

in BPP-fortified yoghurt enhanced the storage stability and prolonged the shelf life of the yoghurt compared to that treated with MTGase alone. Previous research has also shown that adding Argel leaf extract (Mohamed Ahmed et al. 2021) and date palm spikelet extract (Almusallam et al. 2021a) to yoghurt lowered TBARS levels and made the fortified yoghurts more stable during cold storage.

Sensory evaluation of camel yoghurt during cold storage. Table 2 presents the sensory parameters, including colour, taste, texture, sourness, and general acceptability, of MTGase-yoghurt with and without BPP. The addition of BPP to yoghurt formulations demonstrated diverse influences on the sensory parameters of the products. The colour was diminished, yet other quality parameters, such as texture, flavour, sourness, and overall acceptability, were enhanced compared to MTGase-yoghurt. The sensory properties scores for yoghurt with BPP were better than those for yoghurt with MTGase. This acceptability is likely due to BPP's flavouring ingredients and high water-binding capacity. All sensory qualities increased with storage duration, with the lowest scores at the end of 21 days, and a slight decrease in yoghurt with BPP. The scores for all of the yoghurts' sensory qualities stayed above the cut-off score of 5 throughout the storage period. Consistent with our findings, prior studies indicate that the addition of pomegranate juice powder (Pan et al. 2019), Argel leaf extract (Mohamed Ahmed et al. 2021), and date palm spikelet extract (Almusallam et al. 2021a) improved the sensory attributes of yoghurts and maintained quality during cold storage. The incorporation

Table 2. Sensory attributes of camel skim milk yoghurt during storage prepared using MTGase with and without BPP

Treatment/Storage period (days)	Sensory attributes					
	colour	texture	taste	flavour	sourness	overall acceptability
MTGase						
1	$7.81 \pm 0.67^{\text{bA}}$	$6.02 \pm 2.27^{\text{abB}}$	$6.71 \pm 2.16^{\text{cA}}$	$6.71 \pm 2.01^{\text{aA}}$	$6.45 \pm 1.96^{\text{aB}}$	$6.64 \pm 1.56^{\text{aA}}$
7	$8.09 \pm 1.17^{\text{abA}}$	$5.85 \pm 1.95^{\text{bB}}$	$6.65 \pm 1.46^{\text{cA}}$	$6.85 \pm 2.03^{\text{bA}}$	$6.35 \pm 1.35^{\text{aA}}$	$6.61 \pm 1.17^{\text{aA}}$
14	$8.06 \pm 0.89^{\text{abA}}$	$6.29 \pm 1.89^{\text{aB}}$	$6.65 \pm 2.21^{\text{aA}}$	$6.71 \pm 1.49^{\text{aA}}$	$6.41 \pm 1.94^{\text{aA}}$	$6.82 \pm 1.44^{\text{aA}}$
21	$8.32 \pm 0.68^{\text{aA}}$	$6.42 \pm 1.84^{\text{aB}}$	$6.21 \pm 2.35^{\text{bB}}$	$6.42 \pm 1.98^{\text{aA}}$	$6.32 \pm 1.83^{\text{aA}}$	$6.74 \pm 1.34^{\text{aA}}$
MTGase + BPP						
1	$7.82 \pm 1.12^{\text{aA}}$	$7.35 \pm 1.66^{\text{abA}}$	$7.13 \pm 1.22^{\text{aA}}$	$7.35 \pm 1.47^{\text{aA}}$	$7.25 \pm 1.28^{\text{aA}}$	$7.29 \pm 1.71^{\text{aA}}$
7	$6.75 \pm 1.55^{\text{bB}}$	$6.95 \pm 1.39^{\text{bA}}$	$6.91 \pm 1.25^{\text{bA}}$	$6.95 \pm 1.36^{\text{bA}}$	$6.65 \pm 1.27^{\text{bA}}$	$6.84 \pm 1.16^{\text{bA}}$
14	$6.94 \pm 1.67^{\text{bB}}$	$7.42 \pm 1.63^{\text{abA}}$	$6.71 \pm 1.99^{\text{bA}}$	$7.01 \pm 1.62^{\text{abA}}$	$7.02 \pm 1.62^{\text{abA}}$	$6.95 \pm 1.69^{\text{bA}}$
21	$7.05 \pm 1.61^{\text{abB}}$	$7.32 \pm 1.53^{\text{aA}}$	$6.79 \pm 1.81^{\text{bA}}$	$7.11 \pm 1.45^{\text{abA}}$	$6.95 \pm 1.81^{\text{bA}}$	$7.04 \pm 1.45^{\text{abA}}$

Values are means of three samples $\pm$ SD; ^{a,b}different letters denote significant difference ($P \leq 0.05$) within treatment, ^{A,B}different letters denote significant difference ($P \leq 0.05$) between treatments within the same storage period; MTGase – microbial transglutaminase; BPP – banana peel powder

<https://doi.org/10.17221/100/2024-CJFS>

of BPP in yoghurt did not affect the action of MTGase and improved sensory quality, which was maintained during cold storage. According to Abou-Soliman et al. (2020), the addition of MTGase to camel milk had no significant impact on colour, flavour, or taste in both untreated and MTGase-treated cheese samples. Moreover, Abou-Soliman et al. (2017) observed that MTGase-treated camel milk yoghurts had average sensory attribute scores, an acceptable appearance, overall acceptability, a uniform structure, and no free water on the surface throughout the storage duration. Bulca et al. (2022) also stated that the sensory characteristics of yoghurt prepared from camel milk improved with increased concentration of MTGase.

CONCLUSION

MTGase, a protein-crosslinking enzyme, and banana peel powder, a source of antioxidants and stabilising agents, were incorporated into camel milk to overcome the problem of coagulation power during yoghurt manufacture. According to the results, MTGase effectively cross-linked milk proteins, as indicated by gel-electrophoresis and scanning electron microscopy. Adding BPP to yoghurt improves its physical, nutritional, and storage stability. Also, the addition improved protein, ash, total solids, and bioactive properties, as well as improved sensory characteristics, compared to MTGase treatment. BPP enhanced the storage stability of yoghurt by preserving its physicochemical quality attributes over 21 days at 4 °C. This study emphasised the potential of using BPP in yoghurt as a functional additive and an alternative to synthetic additives.

REFERENCES

- Abou-Soliman N.H.I., Sakr S.S., Awad S. (2017): Physico-chemical, microstructural and rheological properties of camel-milk yoghurt as enhanced by microbial transglutaminase. *Journal of Food Science and Technology*, 54: 1616–1627.
- Abou-Soliman N.H.I., Awad S., El-Sayed M.I. (2020): The impact of microbial transglutaminase on the quality and antioxidant activity of camel-milk soft cheese. *Food and Nutrition Sciences*, 11: 153–171.
- Ahmad I., Hao M., Li Y., Zhang J., Ding Y., Lyu F. (2022): Fortification of yogurt with bioactive functional foods and ingredients and associated challenges – A review. *Trends in Food Science and Technology*, 129: 558–580.
- Ait El Alia O., Zine-Eddine Y., Kzaiber F., Oussama A., Boutoial K. (2023): Towards the improvement of camel milk consumption in Morocco. *Small Ruminant Research*, 219: 106888.
- Ait El Alia O., Zine-Eddine Y., Chaji S., Boukrouh S., Boutoial K., Faye B. (2025): Global camel milk industry: A comprehensive overview of production, consumption trends, market evolution, and value chain efficiency. *Small Ruminant Research*, 243: 107441.
- Akbari M., Razavi S.H., Kieliszek M. (2021): Recent advances in microbial transglutaminase biosynthesis and its application in the food industry. *Trends in Food Science & Technology*, 110: 458–469.
- Alam M.J., Akter S., Afroze S., Islam M.T., Sayeem E.H. (2020): Development of fiber and mineral enriched cookies by utilization of banana and banana peel flour. *Journal of Microbiology, Biotechnology and Food Sciences*, 10: 329–334.
- Alenisan M.A., Alqattan H.H., Tolbah L.S., Shori A.B. (2017): Antioxidant properties of dairy products fortified with natural additives: A review. *Journal of the Association of Arab Universities for Basic and Applied Sciences*, 24: 101–106.
- Alia O.A.E., Zine-Eddine Y., Chaji S., Souhassou S., Kzaiber F., Oussama A., Boutoial K. (2023): Physico-chemical and sensory characterization of camel milk yoghurt enriched with persimmon (*Diospyros kaki*) fruit. *Acta Scientiarum Polonorum Technologia Alimentaria*, 22: 267–278.
- Almusallam I.A., Mohamed Ahmed I.A., Saleh A., Al-Juhaimi F.Y., Ghafoor K., Al Maiman S., Babiker E.E. (2021a): Potential of date palm spikelet extract as an antioxidative agent in set-type yoghurt during cold storage. *CyTA – Journal of Food*, 19: 190–197.
- Almusallam I.A., Ahmed I.A.M., Babiker E.E., Al-Juhaimi F.Y., Saleh A., Qasem A.A., Al Maiman S., Osman M.A., Ghafoor K., Hajji H.A., Al-Shawaker A.S. (2021b): Effect of date palm (*Phoenix dactylifera* L.) spikelets extract on the physicochemical and microbial properties of set-type yoghurt during cold storage. *LWT – Food Science & Technology*, 148: 111762.
- Al-Zoreky N.S., Al-Otaibi M.M. (2015): Suitability of camel milk for making yogurt. *Food Science Biotechnology*, 24: 601–606.
- Badertscher R., Berger T., Kuhn R. (2007): Densitometric determination of the fat content of milk and milk products. *International Dairy Journal*, 17: 20–23.
- Barros R.F., Cutrim C.S., da Costa M.P., Conte Junior C.A., Cortez M.A.S. (2019): Lactose hydrolysis and organic acids production in yoghurt prepared with different onset temperatures of enzymatic action and fermentation. *Ciência Animal Brasileira*, 20: e43549.
- Benmeziiane-Derradji F. (2021): Evaluation of camel milk: Gross composition – A scientific overview. *Tropical Animal Health and Production* 53: 308.

- Bulca S., Umut F., Koç A. (2022): The influence of microbial transglutaminase on camel milk yogurt. *LWT – Food Science and Technology*, 160: 113339.
- Bulca S., Büyükgümüş E. (2024): Production of yogurt analogs from peanut milk (extract) using microbial transglutaminase and two different starter cultures. *LWT – Food Science and Technology*, 205: 116546.
- Caipo L., Sandoval A., Sepúlveda B., Fuentes E., Valenzuela R., Metherel A.H., Romero N. (2021): Effect of storage conditions on the quality of arbequina extra virgin olive oil and the impact on the composition of flavor-related compounds (phenols and volatiles). *Foods*, 10: 2161.
- Dantas A.B., Jesus V.F., Silva R., Almada C.N., Esmerino E.A., Cappato L.P., Silva M.C., Raices R.S.L., Cavalcanti R.N., Carvalho C.C., Sant'Ana A.S., Bolini H.M.A., Freitas M.Q., Cruz A.G. (2016): Manufacture of probiotic Minas Frescal cheese with *Lactobacillus casei* Zhang. *Journal of Dairy Science*, 99: 18–30.
- Fazilah N.F., Ariff A.B., Khayat M.E., Rios-Solis L., Halim M. (2018): Influence of probiotics, prebiotics, synbiotics and bioactive phytochemicals on the formulation of functional yogurt. *Journal of Functional Foods*, 48: 387–399.
- Feng C., Wang B., Zhao A., Wei L., Shao Y., Wang Y., Cao B., Zhang F. (2019): Quality characteristics and antioxidant activities of goat milk yogurt with added jujube pulp. *Food Chemistry*, 277: 238–245.
- Gharibzahedi S.M.T., Chronakis I.S. (2018): Crosslinking of milk proteins by microbial transglutaminase: Utilization in functional yogurt products. *Food Chemistry*, 245: 620–632.
- Gomes S., Vieira B., Barbosa C., Pinheiro R. (2022): Evaluation of mature banana peel flour on physical, chemical and texture properties of a gluten-free Rissol. *Journal of Food Processing and Preservation*, 46: e14441.
- Hernández-Carranza P., Ávila-Sosa R., Guerrero-Beltrán J.A., Navarro-Cruz A.R., Corona-Jiménez E., Ochoa-Velasco C.E. (2016): Optimization of antioxidant compounds extraction from fruit by-products: Apple pomace, orange and banana peel. *Journal of Food Processing and Preservation*, 40: 103–115.
- Ho T.M., Zhao J., Bansal N. (2022a): Acid gelation properties of camel milk – Effect of gelatin and processing conditions. *Food Bioprocessing Technology*, 15: 2363–2373.
- Ho T.M., Zou Z., Bansal N. (2022b): Camel milk: A review of its nutritional value, heat stability, and potential food products. *Food Research International*, 153: 110870.
- Kamal-Eldin A., Alhamadi A., Gharsallaoui A., Hamed F., Ghnimi S. (2020): Physicochemical, rheological, and microstructural properties of yoghurts produced from mixtures of camel and bovine milks. *NFS Journal*, 19: 26–33.
- Khalifa M.I., Zakaria A.M. (2019): Physicochemical, sensory characteristics and acceptability of a new set yogurt developed from camel and goat milk mixed with buffalo milk. *Advances in Animal and Veterinary Sciences*, 7: 172–177.
- Khan M.Z., Xiao J., Ma Y., Ma J., Liu S., Khan A., Khan J.M., Cao Z. (2021): Research development on anti-microbial and antioxidant properties of camel milk and its role as an anti-cancer and anti-hepatitis agent. *Antioxidants*, 10: 788.
- Kim D.H., Cho W.Y., Yeon S.J., Choi S.H., Lee C.H. (2019): Effects of lotus (*Nelumbo nucifera*) leaf on quality and antioxidant activity of yogurt during refrigerated storage. *Food Science of Animal Resources*, 39: 792–803.
- Laemmli U.K. (1970): Cleavage of structural proteins during the assembly of the head of bacteriophage T4. *Nature*, 227: 680–685.
- Mohamed Ahmed I.A., Alqah H.A.S., Saleh A., Al-Juhaimi F.Y., Babiker E.E., Ghafoor K., Hassan A.B., Osman M.A., Fickak A. (2021): Physicochemical quality attributes and antioxidant properties of set-type yogurt fortified with Argel (*Solenostemma argel* Hayne) leaf extract. *LWT – Food Science and Technology*, 137: 110389.
- Mohamed H., Ayyash M., Kamal-Eldin A. (2022): Effect of heat treatments on camel milk proteins – A review. *International Dairy Journal*, 133: 105404.
- Mostafa H.S. (2020): Microbial transglutaminase: An overview of recent applications in food and packaging. *Biocatalysis and Biotransformation*, 38: 161–177.
- Mudgil P., Jumah B., Ahmad M., Hamed F., Maqsood S. (2018): Rheological, micro-structural and sensorial properties of camel milk yogurt as influenced by gelatin. *LWT – Food Science and Technology*, 98: 646–653.
- Pan L.-H., Liu F., Luo S.-Z., Luo J.-P. (2019): Pomegranate juice powder as sugar replacer enhanced quality and function of set yogurts: Structure, rheological property, antioxidant activity and *in vitro* bioaccessibility. *LWT – Food Science and Technology*, 115: 108479.
- Pascariu O.E., Estevinho L.M., Seixas N.L., Dopcea I., Boiu-Sicuia O.A., Geicu-Cristea M., Israel-Roming F. (2025): Antioxidant properties and microbiological stability of yogurt enriched with elderberry extract. *Foods*, 14: 1251.
- Rasidek N.A.M., Nordin M.F.M., Tokuyama H., Nagatsu Y., Mili N., Zaini A.S., Idham Z., Yunus M.A.C. (2021): Subcritical water-based pectin from banana peels (*Musa Paradisiaca* Cv. *Tanduk*) as a natural gelation agent. *Materials Today: Proceedings*, 47: 1329–1335.
- Rosmini M.R., Perlo F., Pérez-Alvarez J.A., Pagán-Moreno M.J., Gago-Gago A., López-Santoveña F., Aranda-Catalá V. (1996): TBA test by an extractive method applied to 'paté'. *Meat Science*, 42: 103–110.

<https://doi.org/10.17221/100/2024-CJFS>

- Safdari Y., Vazifedoost M., Didar Z., Hajirostamloo B. (2021): The effect of banana fiber and banana peel fiber on the chemical and rheological properties of symbiotic yogurt made from camel milk. *International Journal of Food Science*, 2021: 5230882.
- Sidhu J.S., Zafar T.A. (2018): Bioactive compounds in banana fruits and their health benefits. *Food Quality and Safety*, 2: 183–188.
- Swelum A.A., El-Saadony M.T., Abdo M., Ombarak R.A., Hussein E.O.S., Suliman G., Alhimaidei A.R., Ammari A.A., Ba-Awadh H., Taha A.E., El-Tarabily K.A., Abd El-Hack M.E. (2021): Nutritional, anti-microbial and medicinal properties of camel's milk: A review. *Saudi Journal of Biological Sciences*, 28: 3126–3136.
- Velazquez-Dominguez A., Hiolle M., Abdallah M., Delaplace G., Peixoto P.P.S. (2023): Transglutaminase cross-linking on dairy proteins: Functionalities, patents, and commercial uses. *International Dairy Journal*, 143: 105688.
- Zaini H.M., Roslan J., Saallah S., Munsu E., Sulaiman N.S., Pindi W. (2022): Banana peels as a bioactive ingredient and its potential application in the food industry. *Journal of Functional Foods*, 92: 105054.
- Zhang Y., Xia Y., Liu X., Xiong Z., Wang S., Zhang N., Ai L. (2019): High-level expression and substrate-binding region modification of a novel BL312 milk-clotting enzyme to enhance the ratio of milk-clotting activity to proteolytic activity. *Journal of Agricultural and Food Chemistry*, 67: 13684–13693.

Received: June 24, 2025

Accepted: September 5, 2025