Enhancing the fatty acid profile of camel milk dairy products through the incorporation of different carob forms

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Abstract

This study investigated the effect of incorporating different carob forms on the fatty acid profile of camel milk dairy products. Camel milk yogurts were fortified with carob syrup or carob powder, while camel milk cheese was coagulated using unripe (green) carob extract. Fatty acid profiles of the fortified products were compared with their respective controls. Lipids were extracted, converted to fatty acid methyl esters, and analyzed by GC–MS. In all products, saturated fatty acids (SFA) were predominant, followed by monounsaturated (MUFA) and polyunsaturated fatty acids (PUFA). Carob incorporation induced a significant reduction in total SFA, mainly palmitic (C16:0) and stearic (C18:0) acids, accompanied by a significant increase in MUFA, particularly oleic acid (C18:1 cis-9), in both yogurts and cheese. PUFA levels remained stable across treatments. The magnitude of these changes depended on the form of carob and the processing technology, with carob syrup exerting the strongest effect in yogurts and unripe carob extract influencing cheese lipid composition through coagulation. Overall, carob-derived ingredients improved the nutritional lipid quality of camel milk dairy products by favorably modulating the SFA–MUFA balance without altering essential fatty acids.

Keywords: Camel milk, Carob, Yogurt, Cheese, Fatty acid profile, Nutritional quality

INTRODUCTION

Camel milk is increasingly recognized as a valuable raw material for dairy production, particularly in arid and semi-arid regions where camels play a central socio-economic role. Beyond its technological particularities, camel milk is distinguished by a specific lipid composition that differs from that of bovine milk, including a relatively high proportion of long-chain fatty acids and a distinctive distribution between saturated and unsaturated fatty acid fractions (Bakry *et al.*, 2021). As the nutritional quality of dairy fat is strongly influenced by fatty acid composition, improving the lipid profile of camel milk products represents an important objective for both public health and product valorization.

From a nutritional standpoint, the balance between saturated fatty acids (SFA) and unsaturated fatty acids, particularly monounsaturated fatty acids (MUFA), is a key determinant of dairy fat quality. High intakes of certain SFA, notably palmitic acid (C16:0), have been associated with unfavorable cardiometabolic outcomes, whereas oleic acid (C18:1 cis) is widely regarded as beneficial due to its positive effects on lipid metabolism and cardiovascular health (Piccinin *et al.*, 2019; Shramko *et al.*, 2020). Consequently, strategies that reduce major SFA while increasing MUFA content in dairy products are generally considered nutritionally advantageous.

One promising approach to modulate dairy lipid composition involves the incorporation of plant-derived ingredients rich in bioactive compounds. Such ingredients may influence fat organization, fermentation dynamics, or coagulation processes, ultimately affecting the distribution of individual fatty acids in the final product (Kokić *et al.*, 2024; Paszczyk and Tońska, 2025). In recent years, increasing attention has been directed toward the use of natural plant materials as functional ingredients in dairy systems, driven by consumer demand for clean-label and nutritionally enhanced foods.

Carob (*Ceratonia siliqua* L.) is a leguminous tree native to the Mediterranean basin, whose pods and derived products have a long history of use in traditional foods. Carob is characterized by a high content of polyphenols, dietary fiber, and naturally occurring sugars, as well as antioxidant and functional properties that support its application in dairy matrices (Ikram *et al.*, 2023; Laaraj *et al.*, 2025). Previous studies have reported that carob powder, syrup, and aqueous extracts can influence the physicochemical, sensory, and functional properties of fermented dairy products (Omrani *et al.*, 2024 ; Omrani *et al.*, 2025). However, their potential impact on milk fat composition, particularly in camel milk dairy products, remains insufficiently explored.

In camel milk systems, the interaction between carob components and milk fat may be particularly relevant during fermentation or coagulation, where enzymatic activity, matrix structure, and fat–protein interactions can affect the relative abundance of individual fatty acids. Moreover, different technological applications of carob—such as fortification with powder or syrup, or the use of aqueous extracts as coagulating agents—may lead to distinct effects on fatty acid distribution. To date, comparative data addressing these aspects in camel milk yogurt and cheese are scarce.

Therefore, the objective of the present study was to evaluate the effect of incorporating different forms of carob on the fatty acid composition of camel milk yogurt, as well as the use of unripe carob extract as a coagulating agent in camel milk cheese. Particular attention was

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given to changes in major saturated fatty acids, especially palmitic and stearic acids, the modulation of oleic acid content, and the stability of polyunsaturated and trans fatty acids. This approach aims to assess the potential of carob as a natural ingredient for improving the lipid quality of camel milk dairy products.

MATERIAL AND METHODS

Raw materials

Raw camel milk was obtained from a herd of dromedaries (*Camelus dromedarius*) at the Livestock and Wildlife Laboratory, Arid Regions Institute (IRA), Medenine, Tunisia. Ripe and unripe (green) carob pods were collected from trees in the Medenine region. Carob powder and syrup were prepared from dried pods, while unripe carob extract was prepared from fresh pods and used as a cheese coagulant.

Dairy product preparation

Camel milk yogurts and soft cheeses were prepared following Omrani *et al.* (Omrani *et al.*, 2024; Omrani *et al.*, 2025). Yogurts were heat-treated at 95 °C for 6 min, cooled to 43 °C, inoculated with 10% (w/v) starter culture, and incubated at 42 °C until pH 4.6. Three formulations were produced: control (YC), fortified with 2% carob powder (YP), and fortified with 5% carob syrup (YS). Soft cheeses were pasteurized at 65 °C for 30 min and coagulated with 12% (v/v) green carob extract (CE) or camel chymosin (CC), incubated at 53.6 °C for 9 h 53 min, drained, and stored at 4 °C until analysis.

Fatty acid analysis

Lipid extraction procedure

Total lipids were extracted from yogurt and cheese samples using a cold chloroform/methanol (2:1, v/v) mixture (Saini *et al.*, 2021). Briefly, 10 g of sample was homogenized with the solvent, followed by addition of a saline solution to facilitate phase separation. The mixture was vortexed, centrifuged at 4000 × g for 15 min at 4 °C, and the lower lipid-containing phase was collected. The solvent was then evaporated to obtain purified lipids.

Fatty acid methyl esters (FAME) preparation

Approximately 100 mg of extracted lipids was dissolved in hexane and transesterified using methanolic KOH. The reaction mixture was vigorously shaken and allowed to separate, and the upper organic phase containing fatty acid methyl esters (FAMEs) was recovered for analysis.

GC-MS conditions

FAMEs were analyzed using a GC–MS system (Shimadzu GCMS-QP2010 Ultra) equipped with a T2560 capillary column (100 m × 0.25 mm × 0.20 µm). Samples were injected in split mode, and the oven temperature was programmed from 100 °C to 240 °C. Fatty acids were identified by comparing retention times and mass spectra with authentic standards and library spectra.

Statistical Analysis

All experiments were performed in triplicate. Data were analyzed using XLSTAT 2019 (Addinsoft, Paris, France). One-way analysis of variance (ANOVA) followed by Tukey test was applied to assess significant differences among treatments, with significance set at $p < 0.05$.

RESULTS AND DISCUSSION

Fatty acid profile of camel milk yogurts fortified with carob syrup or powder

The fatty acid composition of YC and YS and YP is presented in Table 1. In all yogurt samples, saturated fatty acids (SFA) constituted the predominant lipid fraction, followed by monounsaturated fatty acids (MUFA), while polyunsaturated fatty acids (PUFA) were present in lower proportions, which is consistent with the typical fatty acid profile of camel milk–based fermented products (Bakry *et al.*, 2021).

Palmitic acid (C16:0) was the major SFA in all yogurts. However, its proportion was significantly reduced in YS (29.6%) and YP (30.6%) compared with the control YC (33.2%). A similar trend was observed for stearic acid (C18:0), which decreased significantly in YS (13.6%) relative to YC (16.5%), whereas YP showed intermediate values. Consequently, the total SFA content was significantly lower in YS (52.60%) than in YC (58.6%), while YP did not differ significantly from the control. This reduction in SFA suggests that carob syrup, in particular, exerted a stronger modulatory effect on lipid composition during yogurt fermentation, possibly through enhanced interactions between soluble polyphenols, carbohydrates, and milk fat globules (Priyashantha *et al.*, 2025).

In contrast, MUFA levels increased significantly in both carob-fortified yogurts. Oleic acid (C18:1 cis) was the dominant MUFA and showed a significant increase in YS (34.6%) and YP (34.0%) compared with YC (31.0%). This increase was reflected in higher total MUFA contents in YS and YP (43.4% and 43.7%, respectively) relative to YC (40.5%). Similar increases in MUFA have been reported in fermented dairy products enriched with plant-derived ingredients rich in bioactive compounds, which may influence lipid distribution and fat globule stability during fermentation (Kokić *et al.*, 2024).

PUFA levels remained low and did not differ significantly among treatments, ranging from 3.13% to 3.20%. Linoleic acid (C18:2 cis) was the predominant PUFA, while arachidonic acid (C20:4 n-6) was detected in trace amounts. The stability of PUFA across treatments indicates that carob fortification did not adversely affect nutritionally valuable polyunsaturated fatty acids, in agreement with previous studies on functional dairy fortification (Paszczyk and Tońska, 2025).

Overall, yogurt fortification with carob, especially in syrup form, led to a favorable shift in fatty acid composition characterized by reduced SFA and increased MUFA, without compromising PUFA content.

Fatty acid profile of camel milk cheese coagulated with unripe carob extract

The fatty acid composition of CC and CE is shown in Table 2. As observed for yogurts, SFA were the dominant lipid fraction in both cheeses, followed by MUFA and PUFA, reflecting the intrinsic fatty acid profile of camel milk cheese (Alhassani, 2024).

Palmitic acid (C16:0) and stearic acid (C18:0) were the principal SFAs in both treatments. Their proportions were significantly lower in CE compared with CC, leading to a significant reduction in total SFA from 59.7% in CC to 55.7% in CE. These findings indicate that coagulation with unripe carob extract modifies fat retention or distribution during cheese manufacture, likely through differences in curd structure and whey expulsion compared with camel chymosin (Omrani *et al.*, 2024).

Table 1: Fatty acid composition (% of total fatty acids) of camel milk yogurts: control yogurt (YC) and yogurts fortified with carob syrup (YS) or carob powder (YP)

Fatty acid	YC (%)	YS (%)	YP (%)
C4:0	0,595 ± 0,497	1,485 ± 0,502	1,374 ± 0,346
C6:0	0,642 ± 0,442	1,154 ± 0,678	1,061 ± 0,413
C8:0	0,299 ± 0,229	0,463 ± 0,354	0,491 ± 0,287
10:0	0,262 ± 0,186	0,422 ± 0,311	0,487 ± 0,272
C12:0	0,408 ± 0,069	0,488 ± 0,321	0,594 ± 0,261
C14:0	5,681 ± 1,555	4,105 ± 2,812	5,181 ± 1,830
C14:1	0,246 ± 0,047	0,138 ± 0,025	0,262 ± 0,103
C15:0	0,277 ± 0,134	0,263 ± 0,035	0,440 ± 0,159
C16:0	**33,20 ± 1,542[a]**	**29,64 ± 1,140[b]**	**30,60 ± 1,716[b]**
C16:1	5,983 ± 1,412	4,894 ± 0,598	5,617 ± 0,729
C17:0	0,214 ± 0,098	0,454 ± 0,159	0,483 ± 0,157
C17:1	0,254 ± -	0,263 ± 0,026	0,244 ± 0,030
C18:0	**16,53 ± 0,740[a]**	**13,63 ± 0,520[b]**	**15,89 ± 0,579[a]**
C18:1 trans	3,084 ± 0,345	3,564 ± 0,271	3,360 ± 0,589
C18:1 cis	**30,97 ± 3,306[a]**	**34,56 ± 5,456[b]**	**34,04 ± 5,848[b]**
C18:2 trans	0,458 ± 0,507	0,154 ± 0,085	0,154 ± 0,047
C18:2 cis	2,627 ± 0,209	2,975 ± 0,114	2,861 ± 0,325
C20:0	0,418 ± 0,076	0,438 ± 0,025	0,409 ± 0,082
C20:1	-	-	0,138 ± 0,028
C22:0	0,031 ± -0,035	0,047 ± 0,026	0,040 ± 0,002
C20:4 n-6	0,108 ± 0,019	0,074 ± 0,064	0,112 ± 0,020
SFA (%)	**58.56 ± 2.43[a]**	**52.60 ± 3.25[b]**	**57.04 ± 2.68[a]**
MUFA (%)	**40.53 ± 3.61[a]**	**43.42 ± 5.49[b]**	**43.66 ± 5.92[b]**
PUFA (%)	3.19 ± 0.55	3.20 ± 0.16	3.13 ± 0.33

Table 2: Fatty acid composition (% of total fatty acids) of camel milk cheese: control cheese (CC) and cheese coagulated using green carob extract (CE)

Fatty acid	CC (%)	CE (%)
C4:0	0,098 ± 0,013	0,145 ± 0,105
C6:0	0,298 ± 0,169	1,277 ± 1,739
C8:0	0,166 ± 0,119	0,590 ± 0,783
C10:0	0,109 ± 0,062	0,440 ± 0,599
C12:0	0,426 ± 0,183	0,547 ± 0,495
C14:0	5,374 ± 2,892	4,870 ± 2,929
C14:1 n-5	0,230 ± 0,000	0,238 ± 0,153
C15:0	-	0,304 ± 0,015
C16:0	**33,52 ± 3,367[a]**	**30,76 ± 0,427[b]**
C16:1 n-7	6,353 ± 0,985	6,386 ± 1,455
C17:0	0,436 ± 0,130	0,304 ± 0,109
C17:1 n-7	0,205 ± 0,062	0,265 ± 0,005
C18:0	**18,74 ± 0,386[a]**	**15,90 ± 0,829[b]**
C18:1 trans-9	3,478 ± 0,501	3,169 ± 0,904
C18:1 cis-9	**30,79 ± 3,176[a]**	**33,41 ± 5,228[b]**
C18:2 trans, trans	0,132 ± 0,059	0,093 ± 0,005
C18:2 cis, cis	2,693 ± 0,246	2,705 ± 0,324
C20:0	0,475 ± 0,122	0,481 ± 0,116
C22:0	0,062 ± 0,037	0,033 ± 0,000
C20:4 n-6	0,132 ± 0,029	0,121 ± 0,023
SFA (%)	**59.71 ± 4.47[a]**	**55.66 ± 3.71[b]**
MUFA (%)	**37.58 ± 3.33[a]**	**40.30 ± 5.43[b]**
PUFA (%)	2.83 ± 0.25	2.83 ± 0.33

Values are expressed as mean ± standard deviation. Different lowercase letters within the same row indicate significant differences across treatments ($p < 0.05$).

Oleic acid (C18:1 cis-9) was the most abundant MUFA in both cheeses and increased significantly in CE (33.4%) relative to CC (30.8%). This increase was accompanied by a higher total MUFA content in CE (40.3%) compared with CC (37.6%). Such an enhancement in MUFA content is nutritionally relevant, as oleic acid is associated with beneficial effects on cardiovascular health (Milena and Maurizio, 2025). Minor MUFA showed only limited variation between treatments. PUFA content was low and identical in both cheeses (2.83%), with linoleic acid as the main contributor and arachidonic acid present in trace amounts. The absence of significant changes in PUFA suggests that the carob extract coagulant selectively influenced SFA–MUFA balance rather than affecting long-chain PUFA. Short- and medium-chain fatty acids tended to be higher in CE, particularly caproic, caprylic, and capric acids. These fatty acids contribute to cheese aroma and rapid digestibility and may be linked to the distinctive technological and sensory properties of cheese coagulated with plant-derived extracts (Paszczyk and Tońska, 2025).

CONCLUSION

This study demonstrates that the incorporation of carob-derived ingredients is an effective strategy for improving the fatty acid profile of camel milk dairy products. Both yogurt fortification with carob syrup or powder and cheese coagulation using unripe carob extract induced a consistent shift toward lower SFA and higher MUFA, particularly oleic acid, while preserving PUFA. The magnitude of these effects depended on the form of carob and the processing technology, highlighting the importance of ingredient–process interactions in modulating milk fat composition. Overall, these findings support the use of carob as a natural, multifunctional ingredient for the development of nutritionally improved, value-added camel milk dairy products.

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