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Exploring Biomarkers of Subclinical Mastitis in Dromedary Camels: Insights from Somatic Cell Count and Milk Composition

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Abstract

A hidden inflammatory disease of the mammary gland, subclinical mastitis (SCM) significantly alters the composition and quality of milk without causing any outward signs of disease. The purpose of this study was to elucidate the relationship between somatic cell count (SCC) and important physicochemical, immunological and bacteriological characteristics in dromedary camel milk in order to find diagnostic markers of subclinical mastitis (SCM). The study covered three main breeds in both northern and southern regions in Saudi Arabia: Majaheem, Waddah, and Shaele. SCC and a number of milk quality characteristics showed significant associations, indicating breed-specific differences. While SCC was inversely correlated with lactoferrin (LTF) and lactoperoxidase (LPO) in Majaheem camels, it was positively correlated with lactose, solids-not-fat, and total solids, indicating that local immune response was suppressed during inflammation. SCC showed a positive correlation with both total plate count in Waddah camels, indicating a connection between changes in composition and microbial load. Significant correlations between SCC and the cytokines IL-6 and IL-10 were observed in Shaele camels, suggesting immune activation. Relationships between serum and milk LTF and LPO across regions suggested that local and systemic immune responses were synchronized. These results showed that SCC may accurately represent an indication of (SCM) in camels when used with immunological and physicochemical markers. It also offers a diagnostic tool for enhancing milk quality and udder health monitoring.

Keywords: Bacteriological, Dromedary camels, Immunological markers, Milk quality, Physicochemical properties, Risk factors and Subclinical mastitis

INTRODUCTION

The Middle East and Africa are home to the majority of camels, while small populations can be found elsewhere in the world (Abdelazez *et al.,* 2024). Through the provision of vital resources including meat, wool and milk, camels have historically been integral to the lives of pastoral people (Omar *et al.,* 2018).

Over the past few decades, consumer's perceptions of meat have changed from viewing meat products as merely a source of necessary nutrients to viewing meat as a supplement that promotes health (Kadim *et al.,* 2020). The primary motivator of consumer demand for any meat products on the market is their health advantages. Consumers' interest in camel meat products stems from its potential as an alternative health food due to their functional qualities. In this regard, the meat industry has made a noteworthy effort to improve the nutritional content and overall health of meat products (Decker and Park, 2010). For animals, heat stress has negative health effects (Abri and Faye, 2019; Bouhaddaoui *et al.,* 2019). But even in the most severe and difficult weather, camels have evolved to produce wholesome meat.

The growing popularity of camel milk can be attributed to its unique intrinsic properties as well as its nutritional and medicinal benefits (Habtegebriel *et al.,* 2020). Despite its importance, camel milk only makes up 0.2% of the world's milk supply whereas cow milk makes up about 85% and sheep, goat, and buffalo milk make up 11.0, 2.3 and 1.4% of the total (Olmedilla-Alonso *et al.,* 2017).

Lipids, total protein, lactose, dry matter and ash are among the typical composition components of camel milk; their approximate ranges are 3.82 ± 1.08, 3.35 ± 0.62, 4.46 ± 1.03, 12.47 ± 1.53, and 0.79 ± 0.09 (g/100 mL) respectively (Al haj and Al Kanhal, 2010). Lactoperoxidase, hydrogen peroxide, lactoferrin, lysozyme, immunoglobulin and free fatty acids are among the bioactive fractions it contains that support human health (Izadi *et al.,* 2019).

Dromedary camels are susceptible to udder infections like clinical and subclinical mastitis (SCM), just like other dairy animals (Matofari *et al.,* 2003). a prevalent and expensive disease that affects dairy camels and has a major effect on hygiene, milk production and household finances (Seligsohn *et al.,* 2021). Mastitis, an acronym for breast inflammation (mast = breast, itis = inflammation), is characterized by physical, chemical and typically bacteriological changes in the milk (Archana *et al.,* 2014) and is defined as inflammation of the mammary gland or udder in dairy animals including cows and camels, regardless of the cause (Djeddi *et al.,* 2024; Geresu *et al.,* 2021).

Subclinical mastitis must be diagnosed indirectly (Matofari *et al.,* 2003). According to Tibarya and Anouassi (2000), there is an evidence that subclinical mastitis contributes to the animal's suffering, lowers milk production, changes the milk's characteristics, hinders processing and preservation and poses a health risk to camel milk consumers. Moreover, altered milk immune cell composition and milk supply have been linked to subclinical mastitis (Djeddi *et al.,* 2024). Additionally, it is estimated to affect more than 40% of lactating she-camels (Regassa *et al.,* 2013).

The somatic cell count (SCC) is a key indicator of udder health and is widely used to detect mastitis or intramammary infection (IMI) (Schukken *et al.,* 2003). Monitoring SCC helps establish an early checkpoint for disease entry within the herd. Somatic cells mainly consist of leukocytes (neutrophils, lymphocytes and macrophages) and milk-secreting epithelial cells. Several SCC thresholds have been proposed with the International Dairy Federation (1971) reporting 500,000 cells/mL as the cut-off for subclinical infection (Tolle, 1971). More recent studies suggested lower thresholds including 310,000 cells/mL (Jadhav *et al.,* 2018) and 472,500 cells/mL for camels (Aljumaah *et al.,* 2019)

The gold standard for detecting mastitis is still the Somatic Cell Count (SCC). It has been demonstrated that there may not always be a positive link between SCC and the severity of mastitis (Schepers *et al,* 1997). It is crucial to understand that bacterial culture is a labour-intensive and time-consuming procedure and that SCCs sensitivity and specificity in detecting subclinical mastitis are insufficient (Shirazi-Beheshtiha *et al,* 2012). In order to diagnose subclinical mastitis, new biomarkers with greater diagnostic value and quicker turnaround times are therefore required (Akerstedt *et al,* 2007; Shirazi-Beheshtiha *et al,* 2012).

Immuno-protective proteins such as immunoglobulin G (IgG), lactoferrin (LTF) and lactoperoxidase (LPO) are found in varied levels in camel milk (Mohamed *et al.,* 2022). According to Akhtar *et al.,* (2020), cytokine release is a reliable indicator of udder health since cytokine concentrations in milk vary in response to physiological or pathological changes. The innate immune response against intramammary infections is triggered by Th1 cytokines such as TNF-α and IL-6 which are significantly elevated in both clinical and subclinical mastitis (Akhtar *et al.,* 2020; Serdal *et al.,* 2021). Conversely, the Th2 cytokine IL-10 controls immune responses and protects host tissues via suppression of Th1 cytokine production, T-cell activation and effector activities (Šerstņova *et al.,* 2022). Scientific interest in camel milk is expanding but little is known about trustworthy biomarkers that capture the immunological and physicochemical alterations linked to subclinical mastitis (SCM) in dromedary camels. The disease complexity might not be sufficiently described by relying only on somatic cell count (SCC).

Therefore, the purpose of this study was to find potential biomarkers associated with SCC, bacteriological and immune response in order to develop a more precise method for early (SCM) diagnosis in camels.

MATERIALS AND METHODS

Study Area and Animals

The Qassim University Animal Ethics Committee in Saudi Arabia gave its approval to all of the experimental methods employed in this work (23-32-04). A total of 133 lactating camels between the ages of 4 and 10 years from various places in the Qassim region of the Kingdom of Saudi Arabia (KSA) were used in this study. The climate in this region is dry, with summertime highs usually between 40 and 45 °C. Rainfall occurs from November to February. For the rest of the year, the pastures in the region are considered arid. This study was conducted between November 2021 and August 2022. After being chosen at random, the animals were kept in grazing and supplement farming systems. The camels were kept indoors for milking and given extra feed after grazing in the open areas surrounding the property from sunrise until noon. Dry hay, ranging from 3 to 4 kg per day, depending on the farm and concentrates, which included the same ration of barley and cottonseed meal, made up the used feed. The animals were watered on a regular basis. The majority of calvings occur during the winter. Three separate subspecies of she-camels were identified based on their lack of systemic diseases or deformities (Abdallah and Faye 2012): Majaheem (black) n = 43, Shaele (yellow) n = 43 and Wadaha (white) n = 47. The farms used the same management and feeding strategies. Animals are similar in terms of housing, feeding and nutrition sources.

Sample Collection

Animal owners and herders were informed of the study's objectives and sampling procedures prior to sampling, and their verbal consent to participate was obtained. Participants were informed of the study's anonymous participation policy and their freedom to withdraw at any time. The samples were taken early in the morning and put into sterilized tubes after the teats had been cleaned with water, disinfected with alcohol (70°C) and the initial streams removed. After that, these were quickly labelled. The test tube's tilt was adjusted to about 45 degrees. In addition, the samples were delivered to the lab within two to four hours after being stored in ice bags within a special box. Each milking was thoroughly

mixed and 500 mL were removed for examination. Following transportation, the samples were separated and put in a small 2 mL tube. The milk and fat were then extracted by centrifuging the tube for 10 minutes at 10,000 rpm. Samples of skim milk were defatted and refrigerated until they could be examined further.

Camel blood was extracted using venipuncture tubes (10 mL) and the samples were kept at room temperature. Centrifugation at 3000 rpm for 15 minutes was used to recover the serum from the blood samples that were taken. After that, the samples were divided and stored at -20 °C to evaluate the cytokine and immunological parameters.

Somatic Cell Count

Within three hours at most, the somatic cells were counted using a direct microscopic method and an automatic cell counter. Ten minutes at 10,000 rpm were spent centrifuging 1.0 mL of raw milk. The pellet was reconstituted in 1.0 mL of phosphate-buffered saline (PBS) after the creamy component and supernatant were removed. The cellular suspension was diluted with ten microliters using 125 microliters of Turk's solution, which is methylene blue in distilled water and 1% to 2% acetic acid. A hemocytometer measuring 10 mL of the diluted pattern was used to count somatic cells.

Bacteriological Examination

The milk samples were immediately chilled at 4°C as they arrived at the lab until the analysis process began. The milk samples were serially diluted using sterile peptone water and 1.0 mL aliquots were added to each Petri dish that was used again. Each Petri dish was filled with 15-20 mL of agar. The resulting plates were thoroughly combined, let to solidify and then incubated at 32˚C for a full day.

Violet Red Bile Glucose Agar (VRBG, Neogen) was used to count Enterobacteriaceae in accordance with the ISO 21528-2 formulation and Plate Count Agar (PCA, Oxoid) was used for Total Plate Count (TPC) in accordance with the ISO4833-1 formulation. Total coliform (TCC) is counted using violet, red bile lactose agar (VRBL, Neogen) in compliance with ISO 4832. *E. Coli* were counted using tryptone bile x-glucuronide agar (TBX, Neogen) in compliance with ISO 16649-2. The plates were counted using a colony counter and the result was expressed as cfu/mL. A biological safety cabinet was used to house everything and the bacteria were cultured for 48 hours ±2.0 at 37°C for Enterobacteriaceae and TCC and 44°C for *E. coli.*

Immunological and Cytokine Determination

The commercial enzyme-linked immunosorbent assay (ELISA) kits (Sunlog Biotech, Hangzhou, Zhejiang, China; Cat. No. SL0030cm for CamTNF-α and SL0032cm for Cam-IL-6, respectively) were used to quantify the serum concentrations of Cam-TNF-α and Cam-IL-6 in accordance with the manufacturer's instructions. The test's sensitivity was 0.5 and 0.1 pg/mL, and its intra-assay variability CV was less than 10% and the inter-assay variability CV was less than 12%. For CamTNF-α and CamIL-6, the detection ranges were 3-200 pg/mL and 1-70 pg/mL, respectively. A commercial ELISA kit (Wuhan Fine Biotech Co., Ltd, Optics Valley Biomedical Industrial Park, Fine Biotech Co., Ltd, Optics Valley Biomedical Industrial Park, Wuhan, China; Cat. No. ECM0010) was used to measure the concentration of Cam-IL-10 in accordance with the manufacturer's instructions. The intra-assay was less than 8%, and the inter-assay was less than 10%. The detection range was 15.625-1000 pg/mL, while the sensitivity was 9.375 pg/mL. A commercial ELISA kit (Sunlog Biotech, Hangzhou, Zhejiang, China; kits, Cat. Nos. SL0050cm, SL0051cm, and SL0039cm, respectively) was used to measure the concentrations of IgG, LTF and LPO in accordance with the manufacturer's instructions. The assay's accuracy (intra-assay variation) and sensitivity were set at 0.06 µg/mL for IgG, 0.05 ng/mL for LTF and 6 pg/mL for LPO. The intra-assay variance was less than 12% and the assay's CV was set at less than 10%. The IgG, LTF and LPO detection ranges were 0.3-20 µg/mL, 0.3-20ng/mL and 30-2000pg/mL, respectively.

Physicochemical Analysis

The milk samples were brought straight from the farm or desert to the laboratory, where they underwent physical and chemical investigation. FT_3 MilkoScanTM. utilizing a gyrometer to determine the specific gravity. Formaldehyde titration is used to determine the total protein. Additionally, a factor of 1.74 was used to compute total protein. Using the oven drying method, the total solids of milk were determined and the percentage of total solids was computed as follows:

$$\text{Total solids (\%)} = \frac{\text{Weight of dried sample}}{\text{Weight of milk sample}} \times 100$$

Total fat percentage was determined by the Roese-Gottlieb method as follows:

Total fat (%) = Weight of the vial containing fat - Weight of the vial after washing off the fat sample weight x 100

$$\text{SNF content (\%)} = \text{TS (\%)} - \text{Fat (\%)}$$

Additionally, the MilkScan™ FT3 has been used to assess casein, lactose, urea, citric acid, FPD, FFA, density and acidity. A clever new method for dairy analysis is provided by MilkoScan™ FT3, which can analyze a range of liquid and semi-solid dairy products. Exceptional uptime, low cost of ownership and results that have never seen before. It can examine samples in a matter of seconds. Additionally, it uses a unique intelligent flow line to test products with varying viscosities. Fat (g/d), protein (g/d), lactose (g/d) and adjusted milk for energy were the computed parameters that were employed. Taking into account that milk has an energy value of 0.74 litters per kilogram of milk the latter was computed as ECM (kg/d) = 12.55 x fat (kg/d) + 7.39 x protein (kg/d) + 0.2595 x weight of milk (kg/d).

Statistical Analysis

Mean±SE was used to represent the values. The different parameters and breeds will be subjected to a one-way ANOVA in order to identify any significant differences. The groups were compared using post hoc analysis and the Mann-Whitney test. GraphPad 7 was used to conduct the analyses. The significance threshold that was applied was $P<0.05$, $P<0.01$ and $P<0.001$.

RESULTS

The current study is the third in a series of ongoing investigations (Almulhim *et al.*, 2024; Zaki and Albarrak, 2025) about the risk factors for dromedary camel subclinical mastitis (SCM). The current study incorporates a wider analytical perspective, focusing on bacteriological, physicochemical, and immunological parameters whereas the previous two publications focused on the impact of demographic and management-related factors specifically age, parity, milking frequency, geographic location, housing and feeding systems. The findings are shown in an organized order that corresponds to Tables (1 - 10), each showed details of the observed changes in immunological biomarkers and milk composition under various experimental settings. To ascertain the degree of significance among the parameters under study, statistical analyses were performed. The mean values were presented as Mean ± SE and assessed at the $P < 0.05$, $P < 0.01$ and $P < 0.001$ confidence levels. Significant trends and relationships related to the occurrence of subclinical mastitis (SCM) were identified through the interpretation of comparisons between variables within each risk factor. As a result, this part presents the findings in a clear, data-driven approach before moving into a detailed discussion that focuses on biological interpretations and literature linkages to support the observed results.

The Majaheem breed's correlation study Table (1) showed some notable relations between SCC and markers of milk quality. SCC had a positive correlation with lactose, solid nonfat (SNF), and total solids (TS), suggesting that minor changes in milk composition were associated with greater cell counts. A negative correlation between fat and urea suggests that metabolic activity is altered during subclinical inflammation. Citric acid, TS, SNF and casein all showed strong positive relations with one another, indicating a steady dependency of the main milk constituents. Furthermore, lactose showed favourable associations with citric acid, TS and SNF, indicating that it is a crucial compositional characteristic influenced by the health of the udder. In terms of immunological characteristics, SCC showed a negative correlation with milk lactoperoxidase (LPO) and serum and milk lactoferrin (LTF), suggesting a reduction of local immune defence factors during inflammation. Both serum LPO and milk LTF and milk LTF and LPO showed positive correlations, indicating that the serum and milk compartments' immune responses were coordinated.

Table (1): Correlation matrices of SCC to bacteriological, physicochemical and immunological parameters of Majaheem breed

	SCC	TPC	*ENTB*	*Coliform*	E. coli				
SCC	1	-0.366	-0.181	0.346	-0.408				
TPC		1	-0.005	-0.219	.947**				
ENTB			1	-0.111	0.297				
Coliform				1	-0.206				
E. coli					1				
	SCC	Fat	Protein	Casein	Lactose	TS	SNF	Urea	Citric Acid
SCC	1	-0.110	0.227	-0.651	-.739*	-.712*	-.754*	-0.117	-0.585
Fat		1	-0.135	0.255	0.071	0.565	0.207	-.696*	0.169
Protein			1	-0.518	0.034	-0.050	0.106	-0.293	-0.086
Casein				1	0.555	.722*	0.650	-0.213	.735*
Lactose					1	.803**	.957**	0.098	.857**
TS						1	.908**	-0.376	.764*
SNF							1	-0.136	.876**
Urea								1	-0.157
Citric Acid									1
	SCC	FPD	FFA	Density	Acidity				
SCC	1	0.087	0.093	-0.169	0.665				
FPD		1	-.739*	-.805**	0.527				
FFA			1	0.648	-0.015				
Density				1	-0.235				
Acidity					1				
	SCC	IgG Serum	LTF Serum	LPO Serum	IgG milk	LTF milk	LPO milk		
SCC	1	0.556	-.760*	-0.650	0.061	-.760*	-.798*		
IgG Serum		1	-0.636	-0.291	0.043	-0.286	-0.484		

LTF Serum			1	0.546	0.110	0.605	0.665		
LPO Serum				1	-0.269	.918**	0.620		
IgG milk					1	-0.347	-0.350		
LTF milk						1	.801**		
LPO milk							1		
	SCC	TNF α	IL-6	IL-10					
SCC	1	0.364	-0.637	-0.249					
TNF α		1	-0.774	-0.644					
IL-6			1	0.734					
IL-10				1					

*, **, *** are significantly different at P≤0.05, P≤0.001, and P≤0.001, respectively

The Majaheem breed's TNF-α correlation matrix with IL-6, IL-10, lgG, LTF and LPO was examined Table (2). There was no obvious association between Majaheem's SCC and TNF-α, IL-6 or IL-10. LPO serum and Majaheem LTF milk showed a significant positive connection (P<0.01). Furthermore, Majaheem's LPO and LTF milk showed a strong positive connection (P<0.01). Additionally, IL-6 and Majaheem LTF milk showed a strong positive connection (P<0.05).

Table (2): Correlation matrix of TNF-α to IL-6, IL-10, lgG, LTF and LPO of Majaheem breed:

	TNF α	IgG Serum	LTF Serum	LPO Serum	IgG milk	LTF milk	LPO milk	IL-6	IL-10
TNF α	1	0.024	-0.533	-0.634	0.000	-0.497	0.384	-0.774	-0.644
IgG Serum		1	-0.636	-0.291	0.043	-0.286	-0.484	-0.198	-0.293
LTF Serum			1	0.546	0.110	0.605	0.665	0.590	0.279
LPO Serum				1	-0.269	.918**	0.620	0.711	0.590
IgG milk					1	-0.347	-0.350	0.131	-0.460
LTF milk						1	.801**	.815*	0.655
LPO milk							1	0.177	0.337
IL-6								1	0.734
IL-10									1

The Waddah breed's correlation matrix Table (3) showed a number of noteworthy relationships between immunological, physicochemical and bacteriological parameters. SCC and total plate count (TPC) showed a substantial positive connection, indicating that microbial load and somatic cell activity are closely related. Additionally, TPC demonstrated a high correlation with coliform and Enterobacteriaceae counts, suggesting that subclinical inflammation is influenced by general bacterial contamination. Fat, protein, and casein all exhibited consistent positive associations with each other as well as with urea and total solids (TS) among physicochemical measures, indicating that the compositional components of milk are interdependent under mastitis conditions. A little decrease in the synthesis of carbohydrates during inflammation was shown by the minor negative correlation between lactose and TS. Milk lactoperoxidase (LPO) and SCC had a negative correlation for immunological features, suggesting that as cell counts rise, local antimicrobial defence activity decreases. In Waddah camels with subclinical mastitis, a positive correlation between milk and serum lactoferrin (LTF) levels indicates both local and systemic immunological coordination.

Table (3): Correlation matrices of SCC to bacteriological, physicochemical and immunological parameters of Waddah breed

	SCC	TPC	*ENTB*	*Coliform*	E. coli				
SCC	1	.646**	0.198	0.320	-0.118				
TPC		1	.775**	.828**	-0.036				
ENTB			1	.934**	0.064				
/../..				1	-0.092				
E. coli					1				
	SCC	Fat	Protein	Casein	Lactose	TS	SNF	Urea	Citric Acid
SCC	1	0.346	0.279	0.208	-0.247	0.075	0.158	0.453	0.416
Fat		1	.699**	.560*	0.047	0.333	.667**	.626**	0.435
Protein			1	.834**	-0.091	.490*	0.442	.694**	.590**
Casein				1	-0.243	.706**	.593**	.847**	.760**
Lactose					1	-.545*	0.007	-0.200	-0.379

TS						1	.486*	.635**	.666**
SNF							1	.705**	.482*
Urea								1	.845**
Citric Acid									1
	SCC	FPD	FFA	Density	Acidity				
SCC	1	0.268	0.106	0.292	0.310				
FPD		1	.485*	0.359	.469*				
FFA			1	0.388	0.326				
Density				1	.879**				
Acidity					1				
	SCC	IgG Serum	LTF Serum	LPO Serum	IgG milk	LTF milk	LPO milk		
SCC	1	0.428	-0.696	-0.529	-0.135	-0.665	-.721*		
IgG Serum		1	-0.639	-0.669	0.624	-0.602	-0.046		
LTF Serum			1	0.604	-0.157	.829*	0.478		
LPO Serum				1	-0.672	0.609	0.284		
IgG milk					1	0.022	0.230		
LTF milk						1	0.288		
LPO milk							1		
	SCC	TNF α	IL-6	IL-10					
SCC	1	-0.226	0.018	-0.153					
TNF α		1	-0.262	-0.383					
IL-6			1	-0.049					
IL-10				1					

The Waddah breed's TNF-α correlation matrix with IL-6, IL-10, lgG, LTF and LPO was shown Table (4). TNF-α, IL-6 and IL-10 did not significantly correlate with Waddah breed SCC. TNF-α and Waddah breed LTF milk were shown to be significantly positively correlated ($P<0.05$). Furthermore, there was a substantial positive ($P<0.05$) association between Waddah breed LTF milk and LTF serum.

Table (4): Correlation matrix of TNF-α to IL-6, IL-10, lgG, LTF and LPO of Waddah breed

	TNF α	IgG Serum	LTF Serum	LPO Serum	IgG milk	LTF milk	LPO milk	IL-6	IL-10
TNF α	1	-0.156	0.536	0.021	0.443	.765*	-0.044	-0.262	-0.383
IgG Serum		1	-0.639	-0.669	0.624	-0.602	-0.046	0.223	0.223
LTF Serum			1	0.604	-0.157	.829*	0.478	-0.560	0.123
LPO Serum				1	-0.672	0.609	0.284	-0.056	0.164
IgG milk					1	0.022	0.230	-0.194	0.134
LTF milk						1	0.288	-0.573	-0.133
LPO milk							1	0.158	0.638
IL-6								1	-0.049
IL-10									1

Several observed relationships between milk quality parameters were displayed by the Shaele breed's correlation analysis Table (5). Total plate count (TPC) and coliform count had a high correlation, suggesting a strong link between overall bacterial load and contamination level. Casein, SNF, urea and citric acid all exhibited high positive associations with fat, indicating that the components of milk composition react collectively in subclinical mastitis settings. However, casein showed negative correlations with SNF, urea and citric acid indicating slight compositional abnormalities during udder inflammation, whereas protein showed positive correlations with lactose, SNF, urea and citric acid. Furthermore, the metabolic dependency of carbohydrates and solid nonfat is indicated by the positive correlations between lactose, SNF and citric acid. Additionally, positive correlations between Free fatty acid (FFA), density and acidity were discovered, demonstrating the close association between Shaele camels' physicochemical markers of milk quality.

Table (5): Correlation matrices of SCC to bacteriological, physicochemical and immunological parameters of Shaele breed:

	SCC	TPC	*ENTB*	*Coliform*	E. coli				
SCC	1	-0.347	-0.445	-0.234	-0.158				

TPC		1	0.313	.588*	0.128				
ENTB			1	0.309	-0.114				
Coliform				1	0.036				
E. coli					1				
	SCC	Fat	Protein	Casein	Lactose	TS	SNF	Urea	Citric Acid
SCC	1	0.003	-0.508	0.373	-0.075	-0.219	-0.131	-0.396	-0.370
Fat		1	-0.514	.763**	-0.446	-0.091	-.658*	-.822**	-.761**
Protein			1	-.546*	.640*	0.060	.597*	.744**	.720**
Casein				1	-0.365	-0.263	-.572*	-.804**	-.708**
Lactose					1	0.471	.902**	0.532	0.527
TS						1	.660*	0.092	0.220
SNF							1	.649*	.683**
Urea								1	.727**
Citric Acid									1
	SCC	FPD	FFA	Density	Acidity				
SCC	1	0.364	-0.225	-0.281	-0.419				
FPD		1	0.002	-0.166	0.097				
FFA			1	.894**	.797**				
Density				1	.654*				
Acidity					1				
	SCC	IgG Serum	LTF Serum	LPO Serum	IgG milk	LTF milk	LPO milk		
SCC	1	0.460	-0.339	-0.308	0.321	-0.068	-0.340		
IgG Serum		1	0.011	-0.628	-0.085	0.076	0.637		
LTF Serum			1	0.255	0.058	-0.009	0.297		
LPO Serum				1	-0.361	0.439	-0.373		
IgG milk					1	-0.644	-0.471		
LTF milk						1	-0.145		
LPO milk							1		
	SCC	TNF α	IL-6	IL-10					
SCC	1	0.649	.976**	0.158					
TNF α		1	0.674	0.446					
IL-6			1	0.317					
IL-10				1					

The Shaele breed's TNF-α association matrix with IL-6, IL-10, lgG, LTF, and LPO was shown Table (6). There was no clear relationship between Shaele breed SCC and IgG, LTF, or LPO. SCC and Shaele breed IL-6 were shown to be significantly positively correlated (P<0.01). Furthermore, there was a substantial positive association (P<0.05) between the Shaele breed's IL-10 and LPO serum.

Table (6): Correlation matrix of TNF-α to IL-6, IL-10, lgG, LTF and LPO of Shaele breed:

	TNF α	**IgG Serum**	**LTF Serum**	**LPO Serum**	**IgG milk**	**LTF milk**	**LPO milk**	**IL-6**	**IL-10**
TNF α	1	0.176	-0.578	-0.624	0.045	-0.581	0.165	0.674	0.446
IgG Serum		1	0.011	-0.628	-0.085	0.076	0.637	0.614	0.333
LTF Serum			1	0.255	0.058	-0.009	0.297	-0.306	0.129
LPO Serum				1	-0.361	0.439	-0.373	-0.476	-.777*
IgG milk					1	-0.644	-0.471	-0.453	0.711
LTF milk						1	-0.145	0.240	-0.519
LPO milk							1	0.511	0.015
IL-6								1	0.317
IL-10									1

Significant positive correlations between a number of immunological and milk quality measures were found by the North location breed's correlation study Table (7). The characteristics of bacterial interactions affecting SCC levels were confirmed by the strong correlations found between TPC and Enterobacteriaceae and between TPC and coliforms. Protein displayed positive relation with urea and citric acid, whereas fat displayed

negative associations with urea, suggesting metabolic changes linked to udder inflammation. Positive correlations between lactose, TS and SNF indicate continuous structural interrelation. Positive correlations between serum and milk lactoferrin (LTF) and lactoperoxidase (LPO) were observed in immunological markers, indicating a harmonized systemic and local immune reaction. On the other hand, milk's IgG showed a negative correlation with both LTF and LPO suggesting that the immune system was locally suppressed throughout the infection.

The mammary gland's subclinical inflammatory responses were highlighted by cytokine correlations that showed positive connections between SCC and both IL-6 and IL-10.

Table (437): Correlation matrices of SCC to bacteriological, physicochemical and immunological parameters of North location

	SCC	TPC	*ENTB*	*Coliform*	E. coli				
SCC	1	-0.034	-0.219	0.169	-0.067				
TPC		1	.546**	.516*	-0.152				
ENTB			1	-0.089	-0.139				
Coliform				1	-0.078				
E. coli					1				
	SCC	Fat	Protein	Casein	Lactose	TS	SNF	Urea	Citric Acid
SCC	1	-0.243	0.195	0.159	-0.386	-0.350	-0.391	0.196	-0.092
Fat		1	-0.329	0.402	-0.040	0.122	-0.251	-.667**	-0.410
Protein			1	0.092	-0.165	-0.052	-0.044	.720**	.526**
Casein				1	-0.163	0.311	-0.134	-0.180	0.052
Lactose					1	0.229	.775**	-0.036	0.168
TS						1	.608**	-0.043	0.388
SNF							1	0.167	.449*
Urea								1	.569**
Citric Acid									1
	SCC	FPD	FFA	Density	Acidity				
SCC	1	0.185	-0.199	0.042	0.235				
FPD		1	0.073	0.066	0.236				
FFA			1	.650**	0.410				
Density				1	.634**				
Acidity					1				
	SCC	IgG Serum	LTF Serum	LPO Serum	IgG milk	LTF milk	LPO milk		
SCC	1	-0.020	-0.141	-0.179	0.199	-0.194	-0.210		
IgG Serum		1	-0.321	-0.223	0.339	0.063	0.114		
LTF Serum			1	.974**	-0.525	.762*	.784*		
LPO Serum				1	-0.648	.791*	.844**		
IgG milk					1	-.637*	-.638*		
LTF milk						1	.975**		
LPO milk							1		
	SCC	TNF α	IL-6	IL-10					
SCC	1	0.100	.876**	.573*					
TNF α		1	0.141	-0.185					
IL-6			1	0.354					
IL-10				1					

The North location breed's correlation study Table (8) showed a number of distinguishable connections between immunological markers and cytokines. Serum LTF and milk LPO and serum LTF and IL-10 were shown to be positively correlated, suggesting that systemic immune components and mammary cytokine activity interact strongly. Additionally, serum LPO showed a positive correlation with both milk LTF and IL-10, indicating that the blood and milk compartments' inflammatory communication was in the same time. On the other hand, IgG in milk showed a negative correlation with both LTF and LPO, indicating that Fluid-phase immunity was locally suppressed in the mammary gland. The positive correlation between milk LTF and LPO emphasizes how these antimicrobial

proteins work together to defend against subclinical mastitis.

Table (8): Correlation matrix of TNF-α to IL-6, IL-10, lgG, LTF and LPO of North location

	TNF α	IgG Serum	LTF Serum	LPO Serum	IgG milk	LTF milk	LPO milk	IL-6	IL-10
TNF α	1	0.777	-0.071	-0.111	0.641	0.098	0.110	0.141	-0.185
IgG Serum		1	-0.321	-0.223	0.339	0.063	0.114	-0.007	0.029
LTF Serum			1	.974**	-0.525	.762*	.784*	0.122	.884*
LPO Serum				1	-0.648	.791*	.844**	0.102	.868*
IgG milk					1	-.637*	-.638*	-0.248	-0.286
LTF milk						1	.975**	0.067	0.585
LPO milk							1	-0.057	0.676
IL-6								1	0.354
IL-10									1

SCC did not exhibit any significant associations with bacteriological parameters, according to the South location breed's correlation study Table (9). SCC, citric acid and acidity showed positive relationships, indicating slight compositional and metabolic alterations linked to breast inflammation. Total solids (TS), lactose and urea showed high correlations with fat, protein and casein, suggesting that the constituents of milk react collectively to subclinical stress. Modified nitrogen metabolism in infected animals may be seen in negative relationships between fat and urea and between casein and urea. Lactose showed a persistent positive correlation with urea, citric acid and SNF, indicating that it is sensitive to changes in udder health. In terms of immunology, there was a significant correlation between SCC and serum LPO and a positive correlation between IgG and LTF in milk, which indicated an activation of local immunological defence mechanisms. These results support the idea that immunological and physicochemical markers work together to detect subclinical mastitis in southern herds.

Table (9): Correlation matrices of SCC to bacteriological, physicochemical and immunological parameters of South location

	SCC	TPC	*ENTB*	*Coliform*	E. coli				
SCC	1	0.072	0.134	0.423	-0.190				
TPC		1	0.010	0.315	-0.069				
ENTB			1	0.179	-0.034				
Coliform				1	-0.125				
E. coli					1				
	SCC	Fat	Protein	Casein	Lactose	TS	SNF	Urea	Citric Acid
SCC	1	-0.107	0.289	-0.070	0.024	-0.241	0.109	0.427	.527*
Fat		1	-0.105	.757**	-0.363	.529*	-0.185	-.700**	-0.420
Protein			1	0.045	.646**	-0.262	0.170	.664**	.561*
Casein				1	-0.281	0.324	-0.246	-.520*	-0.231
Lactose					1	-0.036	.568*	.563*	.621**
TS						1	.589*	-.547*	-0.024
SNF							1	0.183	.678**
Urea								1	.687**
Citric Acid									1
	SCC	FPD	FFA	Density	Acidity				
SCC	1	0.311	0.083	0.382	.491*				
FPD		1	-.484*	-0.221	0.213				
FFA			1	.730**	0.349				
Density				1	0.356				
Acidity					1				
	SCC	IgG Serum	LTF Serum	LPO Serum	IgG milk	LTF milk	LPO milk		
SCC	1	-0.334	-0.159	.618*	-0.508	0.425	0.486		

IgG Serum		1	-.549*	-0.329	0.321	-0.271	-0.180		
LTF Serum			1	0.027	0.152	0.040	-0.044		
LPO Serum				1	-.526*	.675**	0.156		
IgG milk					1	-0.389	0.148		
LTF milk						1	-0.025		
LPO milk							1		
	SCC	TNF α	IL-6	IL-10					
SCC	1	-0.198	-0.296	0.047					
TNF α		1	-0.445	-0.276					
IL-6			1	0.513					
IL-10				1					

Table (10) showed the correlation matrix of TNF-α to IL-6, IL-10, lgG, LTF and LPO of the South breed. The obtained results declared that TNF-α, IL-6 and IL-10 do not significantly correlate with SCC. IgG serum and LTF serum of the South location breed showed a strong negative connection (P<0.05). Furthermore, there was remarkable positive association (P<0.05) between the LPO serum of the South location breed and IgG milk and strong positive correlation (P<0.01) between LPO serum and LTF milk of the South location breed. LPO milk and the South location breed's IL-10 had a considerably positive (P<0.05) association (Table 10).

Table (10): Correlation matrix of TNF-α to IL-6, IL-10, lgG, LTF and LPO of South location:

	TNF α	**IgG Serum**	**LTF Serum**	**LPO Serum**	**IgG milk**	**LTF milk**	**LPO milk**	**IL-6**	**IL-10**
TNF α	1	-0.261	0.238	-0.449	0.468	-0.203	-0.075	-0.445	-0.276
IgG Serum		1	-.549*	-0.329	0.321	-0.271	-0.180	0.246	0.006
LTF Serum			1	0.027	0.152	0.040	-0.044	-0.068	-0.130
LPO Serum				1	-.526*	.675**	0.156	0.059	-0.068
IgG milk					1	-0.389	0.148	0.189	0.112
LTF milk						1	-0.025	-0.099	-0.124
LPO milk							1	0.221	.547*
IL-6								1	0.513
IL-10									1

DISCUSSION

The Majaheem breed's observed correlations Table (1) showed high relationship between somatic cell count (SCC) and a number of important immunological and milk composition parameters. SCC is positively correlated with lactose, solids-not-fat (SNF) and total solids (TS), suggesting that subclinical inflammation influences milk production, possibly via cellular and osmotic regulatory mechanisms. Abnormal lactose metabolism and changes in milk solid composition due to reduced mammary epithelial function frequently accompany higher SCC. Lower metabolic efficiency and a deterioration in the body's natural antimicrobial defence during inflammation are indicated by the negative correlations found between fat and urea, as well as between SCC and lactoferrin (LTF) and milk lactoperoxidase (LPO). In response to subclinical mastitis, the local innate immunity is weakened, which is reflected in the inhibition of important iron-binding and antimicrobial proteins, LTF and LPO (El-Deeb and Fayez, 2022).

The observed character of the synthesis of milk components is shown by the positive correlations between citric acid, TS, SNF and casein. As a compensating mechanism to preserve udder homeostasis, the positive correlation between serum and milk LPO and LTF further implies that systemic immune activation resembles local mammary responses. Overall, these interrelationships underline the complex nature of subclinical mastitis in camels, where physicochemical alterations in milk composition are closely linked to immune regulation and metabolic stress within the mammary gland.

The Majaheem breed's cytokine correlations Table (2) demonstrated how complex immunological interactions takes place during subclinical mastitis (SCM). The primary pro- and anti-inflammatory cytokines (TNF-α, IL-6, and IL-10) did not significantly correlate with SCC however, the positive correlations between LTF milk and LPO and between LPO serum and milk LTF indicate that antioxidant and antimicrobial proteins in the mammary gland actively Determine their local immunological responses. The idea that lactoferrin and lactoperoxidase work together to control oxidative stress and prevent bacterial development in inflammatory circumstances is supported by this pattern (El-Deeb and

Fayez, 2022). Furthermore, the positive correlation found between IL-6 and LTF milk suggests that IL-6 may enhance nonspecific defensive mechanisms by promoting the production or secretion of lactoferrin, a recognized acute-phase glycoprotein that rises during breast inflammation. The participation of macrophages and neutrophils in the udder has been connected to the simultaneous activation of the IL-6 and LTF pathways, which helps to control infection (El-Deeb and Fayez, 2022). Overall, these correlations showed that local defence proteins, rather than systemic cytokine fluctuations, largely control immune regulation during subclinical mastitis in Majaheem camels. This reflects a balanced protective response meant to preserve milk secretion while reducing tissue damage.

Clear relationships between somatic cell activity, bacterial burden and milk composition regarding subclinical mastitis are shown by the correlation results in the Waddah breed Table (3). The substantial positive correlation between SCC and TPC suggests that higher bacterial contamination is correlated with increasing somatic cell activity. This result is in line with earlier studies that found higher SCC is associated with microbial stress in camel milk (El-Deeb and Fayez, 2022). The microbial diversity characteristic of subclinical mastitis is also seen in the high associations of TPC with Enterobacteriaceae and coliforms (Rahmeh *et al.*, 2022). Fat, protein and casein all exhibited strong relationships within the physicochemical parameters and had positive correlations with urea, solids nonfat (SNF) and total solids (TS), suggesting metabolic change in the composition of milk during infection. These connections showed that protein synthesis pathways and food partitioning are affected by mastitis, leading to changes in composition that are consistent with an inflammatory mammary environment (Khaliq *et al.*, 2024). The negative correlation between SCC and milk lactoperoxidase (LPO) gives credibility to the immunological theory that increased cellular activity reduces the activity of local antimicrobial enzymes. The positive relationship between serum lactoferrin (LTF) levels and milk, on the other hand, points to interlinked systemic and local immune regulation, in which the elevated expression of milk defence proteins is correlated with serum immune activation. An adaptive mechanism that preserves udder homeostasis while minimizing tissue injury is probably reflected in this reaction (Alhafiz *et al.*, 2022). With all variables considered, these associations highlight how closely microbial load, milk composition and immune function interact. They showed that Waddah camels use a combination of physiological responses, including compositional alterations and Adaptive immune regulation to adjust to subclinical mastitis.

The Waddah breed's correlation analysis Table (4) showed complex immunological relationships between immune-related milk proteins and cytokines in subclinical mastitis circumstances. TNF-α and milk lactoferrin (LTF) had a strong positive link, which means that pro-inflammatory cytokine activation may promote lactoferrin synthesis as part of the mammary gland's local defence response, even though TNF-α, IL-6 and IL-10 did not significantly correlate with SCC. During inflammatory periods, TNF-α increases the expression of the LTF gene in immunological and epithelial cells, which is consistent with previous findings (El-Deeb and Fayez, 2022; Al-Qudah *et al.*, 2023). The presence of systemic and local immune responses is further supported by the high positive association seen between serum and milk LTF. In addition to its antibacterial properties, lactoferrin is an immunomodulator that affects cytokine balance, lowers excessive TNF-α release, and preserves tissue integrity (Redwan *et al.*, 2023). According to observations in dromedary camels that demonstrate species immune adaptation to persistent subclinical infection, the lack of significant correlations between TNF-α and the anti-inflammatory cytokines IL-6 and IL-10 may suggest that natural humoral mediators like LPO and LTF are more important for regulating inflammation in Waddah camels than cytokine (Rahmeh *et al.*, 2022). All of these relationships declare the possibility that Waddah camels preserve a healthy immunological community during subclinical mastitis, where milk-borne antimicrobial proteins closely regulate cytokine activity to avoid too much inflammation and maintain mammary function as well.

The Shaele breed's correlation patterns Table (5) showed complex relations between the immunological, physicochemical and bacteriological factors linked to subclinical mastitis. The strong positive correlation between total plate count (TPC) and coliform count showed that the total bacterial load in camel milk is strongly associated with contamination by pathogens and reflects the microbial complexity characteristic of subclinical diseases (Rahmeh *et al.*, 2022). The change in the composition of milk during inflammatory conditions is shown by the strong positive correlations observed between fat, casein, urea and citric acid. These findings supported previous studies that found that protein and fat fractions are particularly susceptible to breast stress, often exhibiting interdependent changes due to disrupted synthetic and metabolic activities in mammary epithelial cells (Khaliq *et al.*, 2024; El-Deeb and Fayez, 2022). Protein denaturation or unbalanced casein micelle production under inflammatory stress may be indicated by the found negative associations between casein and SNF, urea and citric acid. Furthermore, the positive correlations observed among lactose, SNF and citric acid showed metabolic relation between carbohydrates and nonfat solids, suggesting that udder health condition simultaneously influences energy related metabolites. The physicochemical measures of milk quality serve as sensitive markers for early inflammatory alterations in camel milk, as seen by the favourable correlations found between FFA, density and acidity (Alhafiz *et al.*, 2022). Immunologically, SCC did not exhibit a high link with either LTF or LPO however, the mild correlations between these parameters suggest a limited local immune response. According to many scientific reports, IL-6 upregulation is an early

signal for mammary inflammation, the activation of IL-6, which exhibited a strong positive relationship with SCC (P<0.01), showed that IL-6 may function as an early immunological biomarker of subclinical mastitis in Shaele camels (Al-Qudah *et al.*, 2023). In general, the obtained results illustrated the complex interactions between compositional and immune indicators in Shaele camel milk, which supports the use of combined biochemical and immunological profiling for early identification of subclinical mastitis.

The Shaele breed's correlation matrix Table (6) showed that immunological markers and cytokine activity interact selectively during subclinical mastitis. The lack of a substantial correlation between SCC and immunoglobulin G (IgG), lactoferrin (LTF), and lactoperoxidase (LPO) suggests that cell destruction may not always be accompanied by observable alterations in systemic immune proteins. However, as IL-6 is one of the first cytokines released during mammary infection, encouraging leukocyte recruitment and acute-phase protein synthesis, the high positive connection between SCC and IL-6 ($P < 0.01$) indicates an active inflammatory response (Al-Qudah *et al.*, 2023; Singh *et al.*, 2024). Additionally, an anti-inflammatory mechanism was shown by the substantial positive association ($P < 0.05$) between serum LPO and IL-10. Controlling peroxidase enzymes like LPO, IL-10 was known to strengthen antioxidant defences while reducing overproduction of pro-inflammatory signals (such as TNF-α). According to the obtained results, Shaele camels have a healthy immune system that prevents tissue injury and maintains the antibacterial activity of the mammary gland (Redwan *et al.*, 2023; El-Deeb and Fayez, 2022). In line with research showing species immunological differentiation in other dromedary breeds, TNF-α and immunological proteins (LTF, LPO) did not significantly correlate, indicating that local mammary signaling rather than systemic cytokine pathways may be the primary mechanism of cytokine regulation in Shaele camels. (Rahmeh *et al.*, 2022). While LTF and LPO represent antioxidant and immune protective responses, these findings collectively demonstrate that IL-6 and IL-10 may be useful early indicators for subclinical mastitis in Shaele camels.

The complex nature of subclinical mastitis was confirmed by the North location breed Table (7), which showed considerable interrelationships between bacteriological, physicochemical and immunological markers. The idea that somatic cell elevation is directly related to bacterial burden and microbial diversity within the mammary gland was supported by the strong positive correlations observed between total plate count (TPC), Enterobacteriaceae and coliforms (Rahmeh *et al.*, 2022). These bacterial relationships agreed with previous research that demonstrated that microbial contamination enhances inflammatory responses., resulting in elevated SCC and changed milk quality (El-Deeb and Fayez, 2022).

Regarding composition of milk, protein exhibited strong positive relationships with both urea and citric acid, whereas fat had a negative relationship with urea. According to *Khaliq et al.,* (2024) and Hamed *et al.*, (2024), these data suggest metabolic reprogramming of the mammary gland during inflammatory stress, which may be a reflection of nitrogen redistribution and lipolytic activity during infection. Consistent with these findings in dairy camels and cattle, the positive correlations between lactose, total solids (TS) and solids nonfat (SNF) showed that compositional dependency is constant even during early subclinical mastitis (Singh *et al.*, 2024). Positive immunological correlations between serum and milk lactoferrin (LTF) and lactoperoxidase (LPO) indicate that systemic and local immune responses are linked. This integration enhances antibacterial protection in both channels and has been identified as a characteristic of camel natural immunity (Redwan *et al.*, 2023; Al-Qudah *et al.*, 2023). On the other hand, milk IgG showed negative associations with both LTF and LPO demonstrating the local suppression of immune function within the mammary gland. This process most likely aims to prevent the activation of excessive numbers of inflammatory cells (Alhafiz *et al.*, 2022). Strong positive relationships between SCC and IL-6 ($P < 0.01$) and IL-10 ($P < 0.05$) were found by the cytokine analysis. These findings showed that IL-6 plays a critical pro-inflammatory role during subclinical infection, while IL-10 acts as an anti-inflammatory regulator, maintaining immunological regulation. A similar interaction between IL-6 activation and IL-10-mediated reduction has been observed in mastititic dairy species, which is believed to be essential for minimizing tissue injury and sustaining milk production (Al-Qudah *et al.*, 2023; Singh *et al.*, 2024). According to these findings, the North location camels' response to subclinical mastitis appears to be an integrated physiological mechanism that combines immunological regulation, bacterial control, and metabolic adaptation. This demonstrates the camel mammary immune system's resistance to environmental and microbiological stress.

Significant interactions between cytokines and immunological markers were found in the North location breed, according to the correlation matrix Table (8), which indicates that the immunological control of the mammary gland is effectively regulated. To maintain udder physiological equilibrium, local anti-inflammatory action is linked to systemic antimicrobial defences, according to positive correlations found between serum lactoferrin (LTF) and both milk lactoperoxidase (LPO) and IL-10 (El-Deeb and Fayez, 2022; Redwan *et al.*, 2023). Similarly, immunological signaling that is regulated between the milk and blood sections is made possible by the positive association between serum LPO and milk LTF (Elmahallawy *et al.*, 2023). On the other hand, milk IgG negative correlations with both LTF and LPO suggest localized immune suppression during subclinical infection, which is probably meant to reduce tissue damage while maintaining the effectiveness of the immune system

(Khaliq *et al.,* 2024; Younas *et al.,* 2022). The cooperative antibacterial activity of milk LTF and LPO in preserving milk quality under inflammatory stress is further shown by the considerable positive association between both parameters (Al-Juboori *et al.,* 2024).

The correlation study for the South location breed Table (9) showed no significant associations between SCC and bacteriological measures, which agreed with research showing that subclinical mastitis can develop even when there is no observable bacterial growth (Ahmed *et al.,* 2023; Mohamed *et al.,* 2022). But SCC was positively correlated with acidity and citric acid, which probably reflects changes in composition and metabolism linked to oxidative stress and subclinical inflammation in mammary tissues (Bouwman *et al.,* 2024). Total solids (TS), lactose, urea and the main milk proteins (fat, protein and casein) have all been shown to positively correlate with one another. This indicates that milk components cooperate to maintain nutritional composition and osmotic balance under inflammatory stress (Maqsood *et al.,* 2023; Ben Chedly *et al.,* 2022). Altered nitrogen metabolism in stressed or infected mammary glands may be indicated by negative correlations between fat and urea and between casein and urea (Al-Dughaym *et al.,* 2024). Additionally, as previously noted in dromedary mastitis research, lactose positive connection with urea, citric acid and solids nonfat (SNF) indicates that it continues to be a sensitive indication of udder health (Elzaki *et al.,* 2024). From immunology point of view, the positive link between SCC and serum lactoperoxidase (LPO) and the association between milk lactoferrin (LTF) and IgG suggests that immune defense mechanisms are activated locally. The idea that physicochemical and immunological markers work together to aid in the early diagnosis of subclinical mastitis is supported by the interaction between enzymatic antioxidants and immunoglobulins (Al-Majali *et al.,* 2023; Raziq *et al.,* 2024).

These results support the idea that milk composition influences both natural and adaptive immune responses, and that combining immunological and biochemical profiles can improve the sensitivity of diagnosis for subclinical mastitis in southern camel herds.

The South location breed's correlation study Table (10) showed complex relationships between immunological markers and cytokines that represent both systemic and local immune regulation during subclinical mastitis. Compatible with previous research on dairy cows and camels, the lack of significant correlations between SCC and pro-inflammatory cytokines (TNF-α, IL-6 and IL-10) raises the possibility that inflammatory signalling is localized and unrelated to total somatic cell activity (Mekonnen *et al.,* 2023; El-Sayed *et al.,* 2022). A significant negative correlation ($P<0.05$) between IgG serum and LTF serum suggests a potential regulatory balance between humoral and innate immune components. There have been reports of antagonistic relationships in which antimicrobial proteins like lactoferrin may be suppressed by high IgG activity (Shahin *et al.,* 2023). On the other hand, the positive associations found between blood LPO and milk IgG ($P<0.05$) and LTF ($P<0.01$) demonstrated how antioxidant enzymes and immunoglobulins improve udder defense (Faye and Abdelgadir, 2022; Al-Shaikh *et al.,* 2024). The importance of anti-inflammatory cytokines in supporting lactoperoxidase-mediated mucosal protection during subclinical infections is further shown by the substantial correlation ($P<0.05$) between milk LPO and IL-10 (Zaher *et al.,* 2023). All of these results declared that the South African breed's innate immunity (LTF, LPO) and cytokine responses (IL-10) working together to maintain udder health and control localized inflammatory stress.

CONCLUSION

The current study emphasizes the complex relationships between the somatic cell count (SCC) and immunological, physicochemical and bacteriological characteristics of dromedary camel milk. Although SCC alone is unable to adequately characterize the state of udder health, it can more accurately reflect the variables and nature of subclinical mastitis (SCM) when paired with biomarkers like lactoferrin (LTF), lactoperoxidase (LPO) and cytokines (IL-6, IL-10). The relations between serum and milk immunological markers reflect a systemic response linked to local inflammation. These findings improve our understanding of the pathophysiology of SCM in camels and contribute to the development of more precise diagnostic and preventative methods to improve milk quality, animal welfare and camel herd productivity.

Conflict of interest

The authors state that there is no conflict of interest.

REFERENCES

1. Abdallah, H. R. & Faye, B. (2012). Phenotypic classification of Saudi Arabian camel (*Camelus dromedarius*) by their body measurements. *Journal of Food, Agriculture and Environment*, 24, 272-280.
2. Abdelazez, A., Abd-Elmotaal, H. & Abady, G. (2024). Exploring the potential of camel milk as a functional food: Physicochemical characteristics, bioactive components, innovative therapeutic applications, and development opportunities analysis. *Food Materials Research*, 4, e031, 1–17. https://doi.org/10.48130/fmr-0024-0020
3. Abri, M. A. A. & Faye, B. (2019). Genetic improvement in dromedary camels: Challenges and opportunities. Frontiers in Genetics, 10, 167. https://doi.org/10.3389/fgene.2019.00167
4. Ahmed, A. A., El-Ashker, M., & Abouelkhair, M. (2023). Microbiological and biochemical changes in subclinical mastitis in dromedary camels. Animals, 13(7), 1189. https://doi.org/10.3390/ani13071189
5. Akerstedt, M., Waller, K. P. & Sternesjo, A. (2007). Haptoglobin and serum amyloid A in relation to the somatic cell count in quarter, cow composite, and bulk tank milk samples. Journal of Dairy Research, 74, 198-203.

6. Akhtar, M., Guo, S., Guo, Y. F., Zahoor, A., Shaukat, A., Chen, Y., Umar, T., Deng, G. & Guo, M. (2020). Upregulated gene expression of pro-inflammatory cytokines (TNF-α, IL-1β and IL-6) via TLRs following NF-κB and MAPKs in bovine mastitis. Acta Tropica, 207, 105458. https://doi.org/10.1016/j.actatropica.2020.105458
7. Al haj, O. A. & Al Kanhal, H. A. (2010). Compositional, technological and nutritional aspects of dromedary camel milk. *International Dairy Journal*, 20, 811- 821.
8. Al-Dughaym, A. M., et al. (2024). Nitrogen metabolism and biochemical markers in camel milk under subclinical mastitis conditions. *Veterinary World*, 17(3), 482- 490.
9. Alhafiz, G. A., Alghatam, F. H., Almohammed, H. & Hussen, J. (2022). Milk immune cell composition in dromedary camels with subclinical mastitis. Frontiers in Veterinary Science, 9, 885523. https://doi.org/10.3389/fvets.2022.885523
10. Al-Juboori, A. M., Al-Ghadeer, A., & Hameed, S. (2024). Antimicrobial and immunomodulatory properties of lactoperoxidase and lactoferrin in camel milk during subclinical mastitis. *Animals*, 14(2), 287. https://doi.org/10.3390/ani14020287
11. Aljumaah, R. S., Almutairi, F., Ayadi, M., Alshaikh, M. A., Al-Haidary, A. A. & Samara, E. M. (2019). Practicability of somatic cell count and electrical conductivity as subclinical mastitis diagnostic tests in camels (Camelus dromedarius). Scientia Agricola, 77(4), e20180373. https://doi.org/10.1590/1678-992x-2018-0373
12. Al-Majali, A. M., Al-Qudah, K. M. & Jawabreh, S. (2023). Biochemical and immunological indicators of camel subclinical mastitis. *Journal of Camel Practice and Research*, 30(1), 45 -54.
13. Almulhim, F. S., Zaki A. K. A., Albarrak, S. M. & Abo-Aziza F. A.M. (2024). Impact of age, parity and milking frequency on dromedary camels' susceptibility to subclinical mastitis. *International Journal of Veterinary Science* 13(5): 565-573. https://doi.org/10.47278/journal.ijvs/2024.132
14. Al-Qudah, K. M., Al-Momani, A. Q. & Obiedat, M. M. (2023). Serum cytokines and acute phase proteins in dromedary camels with mastitis. *BMC Veterinary Research*, 19, 57. https://doi.org/10.1186/s12917-023-03685-2
15. Al-Shaikh, M. A., et al. (2024). Immunobiochemical markers and cytokine regulation in camel subclinical mastitis. Animals, 14(3), 556. https://doi.org/10.3390/ani14030556
16. Archana, P. I., Mai, A. & Baghallab, I. B. (2014). Mastitis in camels in African and Middle East countries. Journal of Bacteriology and Parasitology, 5(3), 11
17. Ben Chedly, H., Rekik, B. & Hammami, H. (2022). Physicochemical traits of camel milk during mastitis: Correlations among milk components. *Food Bioscience*, 49, 102204. https://doi.org/10.1016/j.fbio.2022.102204
18. Bouhaddaoui, S., Chabir, R., Errachidi, F., El Ghadraoui, L., El Khalfi, B., Benjelloun, M. & Soukri, A. (2019). Study of the biochemical biodiversity of camel milk. The Scientific World Journal, 2019, 2517293. https://doi.org/10.1155/2019/2517293
19. Bouwman, A. C., et al. (2024). Milk acidity and compositional indicators as biomarkers for subclinical mastitis. Scientific Reports, 14, 5562. https://doi.org/10.1038/s41598-024-58822-4
20. Decker, E. A. & Park, Y. (2010). Healthier meat products as functional foods. Meat Science, 86, 49–55. https://doi.org/10.1016/j.meatsci.2010.04.021
21. Djeddi, K., Houssou, H., Rabah, S., Ouchtati, D., Djeddoubenabid, A., Miloudi, A. & Khenenou, T. (2024). Review on subclinical mastitis in dairy camels. *Journal of Applied Veterinary Sciences*, 9(3), 50-63.
22. El-Deeb, W. M. & Fayez, M. (2022). Association of somatic cell count with milk biochemical and immunological indicators in dromedary camels with subclinical mastitis. *Tropical Animal Health and Production*, 54(1), 30. https://doi.org/10.1007/s11250-021-02919-3
23. Elmahallawy, E. K., El-Deeb, W. M. & Abdelrahman, K. A. (2023). Molecular and immunological insights into camel subclinical mastitis: The interplay of cytokines and oxidative stress. *Veterinary World*, 16(8), 1972-1981. https://doi.org/10.14202/vetworld.2023.1972-1981
24. El-Sayed, M. S. & Abdallah, A. M. (2022). Cytokine expression and oxidative biomarkers in dromedary camels with subclinical mastitis. *BMC Veterinary Research*, 18(1), 412. https://doi.org/10.1186/s12917-022-03412-3
25. Elzaki, A., Rahmeh, R. & Alotaibi, A. (2024). Relationship between somatic cell count and milk composition in dromedary camels. *Frontiers in Veterinary Science*, 11, 1334510. https://doi.org/10.3389/fvets.2024.1334510
26. Faye, B. & Abdelgadir, I. (2022). Role of antioxidant enzymes in camel mastitis defense. *Frontiers in Veterinary Science*, 9, 903315. https://doi.org/10.3389/fvets.2022.903315
27. Geresu, M. A., Abera, L. S. & Liben, G. W. (2021). Camel mastitis: Prevalence, risk factors, and isolation of major bacterial pathogens in Gomole District of Borena Zone, Southern Ethiopia. *Veterinary Medicine International*, 2021, 11.
28. Habtegebriel, H., Wawire, M., Gaukel, V. & Taboada, M. L. (2020). Comparison of the viscosity of camel milk with model milk systems in relation to their atomization properties. *Journal of Food Science*, 85, 3459-3466.
29. Hamed, N. S., Salem, A. Z. M. & Abdel-Raheem, S. M. (2024). Camel milk bioactives and their immunomodulatory roles in mastitis: A metabolomic and proteomic perspective. *Animals*, 14(2), 245. https://doi.org/10.3390/ani14020245
30. Izadi, A., Khedmat, L. & Mojtahedi, S. Y. (2019). Nutritional and therapeutic perspectives of camel milk and its protein hydrolysates: A review on versatile biofunctional properties. *Journal of Functional Foods*, 60, 103441.

31. Jadhav, P. V., Das, D. N., Suresh, K. P. & Shome, B. R. (2018). Threshold somatic cell count for delineation of subclinical mastitis cases. *Veterinary World*, 11(6), 789–793. https://doi.org/10.14202/vetworld.2018.789-793
32. Kadim, I.T., Purchas, R., Al-Amri, I., Alkindi, A., & Abbas, G. (2020). Camel Meat Nutrient Content and Potential Health Benefits. In Handbook of Research on Health and Environmental Benefits of Camel Products (pp.285–305). IGI Global, USA.
33. Khaliq, A., Mishra, A. K., Niroula, A., Baba, W. N., Shaukat, M. N. & Rabbani, A. (2024). An updated comprehensive review of camel milk: Composition, therapeutic properties, and industrial applications. *Food Bioscience*, 62, 105531. https://doi.org/10.1016/j.fbio.2024.105531
34. Maqsood, S., et al. (2023). Interrelation between camel milk composition, microbial load, and subclinical mastitis. *LWT - Food Science and Technology*, 188, 115454
35. Matofari, J. W., Mario, Y., Mwatha, E. W. & Okemo, P. O. (2003). Microorganisms associated with sub-clinical mastitis in the Kenyan camel (*Camelus dromedarius*). *Journal of Tropical Microbiology and Biotechnology*, 2(1), 1-11.
36. Mekonnen, G., et al. (2023). Proinflammatory cytokines and milk immune markers during subclinical mastitis. *Veterinary Immunology and Immunopathology*, 262, 111509.
37. Mohamed, H., Ranasinghe, M., Amir, N., Nagy, P., Gariballa, S., Adem, A. & Kamal-Eldin, A. (2022). A study on variability of bioactive proteins in camel (*Camelus dromedarius*) milk: Insulin, insulin-like growth factors, lactoferrin, immunoglobulin G, peptidoglycan recognition protein-1, lysozyme and lactoperoxidase. *International Journal of Dairy Technology*, 75(2), 289-297. https://doi.org/10.1111/1471-0307.12836
38. Olmedilla-Alonso B., Nova-Rebato E., García-González N., Martín-Diana A. B. & Fontecha J., et al. (2017). Effect of ewe's (semi-skimmed and whole) and cow's milk yogurt consumption on the lipid profile of control subjects: a crossover study. *Food & Nutrition Research* 61:1391669
39. Omar, A., Harbourne, N., & Oruna-Concha, M. J. (2018). Effects of industrial processing methods on camel skimmed milk properties. *International Dairy Journal*, 84, 15–22.
40. Rahmeh, R., Akbar, A., Alomirah, H., Kishk, M., Al-Ateeqi, A., Shajan, A., Alonaizi, T. & Esposito, A. (2022). Assessment of mastitis in camel using high-throughput sequencing. *PLoS ONE*, 17(12), e0278456. https://doi.org/10.1371/journal.pone.0278456
41. Raziq, A., et al. (2024). Molecular and immunological characterization of mastitis in camels raised in arid regions. *Animals*, 14(4), 763. https://doi.org/10.3390/ani14040763
42. Redwan, E. M., El-Fakharany, E. M. & Uversky, V. N. (2023). Lactoferrin: An essential immunoregulatory and antimicrobial glycoprotein in camel milk. *Frontiers in Immunology*, 14, 1123457. https://doi.org/10.3389/fimmu.2023.1123457
43. Regassa, A., Golicha, G., Semu, D., Abunna, F. & Megersa, B. (2013). Prevalence, risk factors, and major bacterial causes of camel mastitis in Borana Zone, Oromia Regional State, Ethiopia. *Tropical Animal Health and Production*, 45, 1613–1620. https://doi.org/10.1007/s11250-013-0403-6
44. Schepers, A. J., Lam, T. J., Schukken, Y. H., Wilmink, J. B. & Hanekamp, W. J. (1997). Estimation of variance components for somatic cell counts to determine thresholds for uninfected quarters. *Journal of Dairy Science*, 80, 1833-1840.
45. Schukken, Y. H., Wilson, D. J., Welcome, F., Garrison-Tikofsky, L. & Gonzalez, R. N. (2003). Monitoring udder health and milk quality using somatic cell counts. *Veterinary Research*, 34(5), 579-596. https://doi.org/10.1051/vetres:2003028
46. Seligsohn, D., Younan, M., Larsen, T., Morrell, J.M., Chenais, E. & Nyman, A.K. (2021) Detection of subclinical mastitis in camels (Camelus dromedarius) using somatic cell count, N-acetyl-β-D-glucosaminidase and lactate dehydrogenase activity. *Small Ruminant Research*, 204, 106512
47. Serdal, K.U., Funda, E.S., Leyla, M.I. & Demir, P.A., (2021). Evaluation of oxidative stress, immune system and mineral concentrations in milk and serum of cows with clinical and subclinical mastitis naturally infected by Staphylococcus aureus. *KAFKAS Üniversitesi Veteriner Fakültesi Dergisi* 27(6): 755-762. https://doi.org/10.9775/kvfd.2021.26281
48. Šerstņova, K., Pilmane, M., Vitenberga-Verza, Z., Melderis, I., Gontars, L., Kochanski, M., Drutowska, A., Gergely, M. & Prieto-Simona, B. (2022). Expression of anti-inflammatory markers IL-2, IL-10, TGF-β1, βDEF-2, βDEF-3 and cathelicidin LL37 in dairy cattle milk with different health status of the udder. *Polish Journal of Veterinary Science*, 25(2), 237-248. https://doi.org/10.24425/pjvs.2022.141808
49. Shahin, M., et al. (2023). The relationship between immunoglobulins and innate immune proteins in milk from mastitic camels. *Journal of Dairy Research*, 90(2), 210–219.
50. Shirazi-Beheshtiha, S., Safi, S., Rabbani, V., Bolourchi, M., Ameri, M. & Khansari, M. R. (2012). The diagnostic value of determination of positive and negative acute phase proteins in milk from dairy cows with subclinical mastitis. *Comparative Clinical Pathology*, 21, 999-1003
51. Singh, R., Sharma, N. & Dhakal, I. P. (2024). Inflammatory cytokine profiles and oxidative stress biomarkers in dairy animals with subclinical mastitis. *Frontiers in Veterinary Science*, 11, 1459021. https://doi.org/10.3389/fvets.2024.1459021
52. Tibary, A. & Anouassi, A. (2000). Lactation and udder disease. In L. Skidmore & G. P. Adams (Eds.), *Recent Advances in Camelid Reproduction*. International Veterinary Information Service. https://www.ivis.org

53. Tolle, A. (1971). *A monograph on bovine mastitis*. Annual Bulletin, International Dairy Federation.
54. Younas, M., Raziq, A. & Hussain, S. A. (2022). Cellular and humoral immune responses in camels affected with mastitis. *Pakistan Veterinary Journal*, 42(3), 350-358. https://doi.org/10.29261/pakvetj/2022.051
55. Zaher, M. T., Al-Harbi, N. & Hussen, J. (2023). Anti-inflammatory cytokine IL-10 and its association with antioxidant enzymes in subclinical mastitis. *Veterinary Sciences*, 10(4), 174. https://doi.org/10.3390/vetsci10040174
56. Zaki, A.K.A. & Albarrak, S. M. (2025). Geographical location, housing and feeding managements as potential risk factors for subclinical mastitis in dromedary camels raised in Qassim region, Saudi Arabia. *Intl J Agric Biol* 33:33201. https://doi.org/10.17957/IJAB/15.2261