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Calcium, Phosphorus and Magnesium Status: A Correlation between Camelids and Their Newborns in Semi-arid District

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ABSTRACT

Background: Camel products are attracting great interest worldwide due to their high functional properties and nutritional value, but concerns have also been raised about their high content of unhealthy ingredients.

Methods: ICP-OES was used to investigate the variation of macrominerals (Ca, Mg and P) in the blood and milk of camelids and their newborns collected over three seasons in five areas in Saudi Arabia.

Result: Seasons ($p \leq 0.05$) altered macrominerals in the serum of she-camels and their newborns, in contrast to mother's milk. The district had an effect $p \leq 0.05$ on the macrominerals of she-camels and their newborns. Interactions between seasons and districts were observed, except for Mg and P in the serum of she-camels. With the exception of Mg of neonatal serum, which is positively associated with Ca and Mg serum and positively linked with P serum.

Key words: Calcium, Magnesium, Newborns, Phosphorus, Semi-arid districts, She-camels.

INTRODUCTION

The Middle East and Africa predominantly feature arid or semi-arid ecosystems, with over 70% of the land receiving minimal rainfall (≤100 mm annually) (Awadh, 2023; Gintzburger, 2003). In Saudi Arabia, the demand for livestock products is rapidly increasing, yet supply remains below the required level, partly due to the low productivity of livestock (Al-Ghaswyneh, 2023). Dromedary camels (*Camelus dromedarius*) are indispensable pack animals adapted to arid and semi-arid regions across extensive pastoral tracts in arid and semi-arid regions (Demlie *et al.,* 2023). These animals possess exceptional physiological, anatomical and behavioral adaptations that enable them to thrive in harsh, dry and extreme climatic conditions with minimal food and water, where other species struggle to survive (Adah *et al.,* 2023).

Minerals are essential for camels' growth and physiological functions. Their metabolic profile is strongly influenced by season, mineral intake and health status (Qureshi, 2020). Macrominerals are essential for various physiological processes and bodily functions, including enzyme regulation and chemical reactions (Damarany, 2017). A deficiency in these minerals can lead to clinical disorders and metabolic abnormalities (Deen, 2004). Scientific studies have shown that camels, like other ruminants, are susceptible to macromineral imbalances resulting from deficiencies or toxicities (Faye and Bengoumi, 2018). However, clinical cases of mineral deficiencies in camels are often underreported, as subclinical signs may go unnoticed for extended periods (Ali *et al.,* 2010; Faye and Bengoumi, 2018), while mineral toxicity remains rare.

Most studies have not adequately considered the major factors influencing the mineral and nutritional status of camels, such as season, age, breed, sex, physiological status and management practices, particularly those related to feeding systems (Osman and Al-Busadah, 2003). Yousif *et al.* (2017) reported that season, pregnancy and management systems significantly affect serum mineral levels and thyroid hormone concentrations in camels.

During pregnancy and lactation, she-camels have an increased calcium requirement to support fetal skeletal development and milk production. Similarly, newborn camels require calcium for bone formation and muscle function (Faye and Bengoumi, 2018). Magnesium (Mg) plays a crucial role in calcium metabolism, muscle function, enzyme activation and nerve transmission (Rosol and Capen, 1997). Phosphorus is essential for energy metabolism, cell membrane integrity and bone health, working in close association with calcium to maintain skeletal integrity (Rosol and Capen, 1997).

For camel breeders and veterinarians in semi-arid regions, monitoring the mineral status of she-camels and

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their newborns is vital. Proper supplementation and a well-balanced diet are necessary to maintain herd health and productivity. This can be achieved through regular blood testing and dietary adjustments tailored to the reproductive and developmental stages of the animals.

Serum and milk macromineral levels (calcium, phosphorus and magnesium) in camelids and their newborns vary based on multiple factors, including geographic location, seasonal variations and their interactions in semi-arid environments. Districts within the same region may have differences in soil composition, forage availability and water quality, which directly impact the mineral content of feed and water sources (Ahmed *et al*., 2011; Hassen *et al*., 2022). Consequently, the serum mineral composition of camels and their offspring may vary across districts (Faye *et al*., 2018).

In semi-arid regions, the nutritional needs of animals fluctuate by season. During the rainy season, forage and water availability increase, leading to higher mineral intake in camelids. Conversely, the dry season often results in scarce feed, reduced mineral intake and lower mineral concentrations in serum and milk (Abdelrahman *et al*., 2021; Hassen *et al*., 2022). Seasonal variations in temperature, particularly extreme heat or cold, also influence metabolic processes, subsequently affecting mineral utilization and requirements (Ahmed *et al*., 2013). Ahmed *et al*. (2013) observed that serum phosphorus and calcium levels fluctuate with seasonal changes, being higher during hotter periods. Establishing reference ranges for serum mineral levels can aid in the early detection of nutritional and metabolic disorders in dromedary camels.

This study hypothesizes that the mineral content in healthy she-camels and their newborns varies across districts and seasons. Therefore, the objective of this study is to investigate the macromineral status in the serum and milk of camelids and their newborns from five districts (eastern, western, central, southern and northern) in Saudi Arabia during three distinct seasons (summer, winter and spring).

MATERIALS AND METHODS

Experimental site

This study was conducted across five semi-arid agricultural zones of Saudi Arabia, located in the central, eastern, western, southern and northern districts. These districts experience a semi-arid climate, characterized by hot summers and freezing winters, with varying severity depending on the region. The central and eastern districts tend to have more extreme summer temperatures, while the northern and western districts experience harsher winter conditions. The southern region, influenced by elevation, shows a more moderate temperature range compared to the other areas. Winter extends from mid-September to the end of January, with December being the coldest month. The experiment commenced in early winter 2022 and concluded in late summer 2023 (November 2022 to July 2023).

Districts and temperatures

The five selected districts of Saudi Arabia are shown in Supplementary Fig S1A. The mean temperature across Saudi Arabia was 41.6±3.4°C, with minimal variation between districts (Supplementary Fig S1B) and seasons. Feed samples were collected from five locations within each region, along with water and soil samples. Homogenized samples were prepared by thoroughly mixing collected feed, water and soil samples to ensure uniformity. After homogenization, representative subsamples were taken, properly labeled and analyzed in the laboratory for mineral composition.

Samples collection

A total of fifty milk and blood samples were collected from multiparous she-camels across different districts and seasons. The samples were not taken from the same animals but from camels within the same locale and management system. Additionally, blood samples were obtained from newborn camels under three months old in the same locations. Blood samples were collected using sterilized vacutainer tubes from the jugular vein of she-camels and their newborns reared in the five semi-arid districts (central, eastern, western, southern and northern) during three seasons (summer, winter and spring). Milk samples were collected from she-camels, along with fodder, water and soil from the same regions at the time of biological sampling. All samples were analyzed for mineral concentrations using ICP-MS.

To obtain serum, blood samples were centrifuged at 2000 rpm for 10 minutes. The serum was immediately treated with 10% trichloroacetic acid (TCA) (1 part serum to 4 parts TCA) and centrifuged at 1500×g for 10 minutes. The supernatant was collected and stored at -20°C until macromineral analysis. Simultaneously, milk samples were processed for macromineral analysis.

Mineral analysis

Blood and milk samples were analyzed for calcium, phosphorus and magnesium levels using an inductively coupled plasma optical emission spectrometer (ICP-OES) equipped with a Meinhard atomizer type A2. High-purity argon (99.9%), supplied by AH Group (Dammam, Saudi Arabia), was used as the plasma support and carrier gas, following the methodology described by Abdelrahman *et al*. (2022b). The ICP-OES operating conditions included: 1300 W RF power, 15 L min^{-1} plasma flow, 0.2 L min^{-1} auxiliary flow, 0.8 L min^{-1} nebulizer flow and 1.5 mL min^{-1} sample acquisition rate. All laboratory diagnoses were conducted at animal production laboratories, King Saud University. Both axial and radial views were utilized for metal determination, with a two-point background correction and three replicates for each measurement. The analytical signal was processed using the peak area method.

Emission intensities were measured at the most sensitive wavelengths free of spectral interferences. Calibration standards were prepared by diluting a multi-element standard solution (1000 mg L^{-1}) in 0.5% (v/v) nitric acid. The calibration curves for all elements ranged from 1.0 ng mL^{-1} to 1.0 µg mL^{-1} (1-1000 ppm). All laboratory analyses were conducted at the Animal Production Laboratories, King Saud University.

Statistical analysis

Application of statistical methods such as analysis of variance or Pearson correlation tests to evaluate the influence of districts, seasons and their interactions on blood serum and milk mineral values was performed. Data were analyzed using a completely randomized experimental design using a two-way ANOVA table and the general linear model procedure (Proc GLM) from SAS (v. 9.4, SAS Institute Inc., Cary, NC, USA). The dependent variable was macromineral concentration and the independent variables were the main effects of seasons (summer, winter and spring) and districts (five semi-arid districts: central, eastern, western, southern and northern) and their interactions. The statistical model was as follows:

$$\Upsilon_{ij} = \mu + D_i + S_j + DS_{ij} + e_{ijk}$$

Where,

Υ_{ij} = Macrominerals (Ca, Mg and P) content in the serum of she-camels and their newborns and in the milk of the she-camels.

μ = Experimental mean.

D_i = The i^{th} district effect.

S_j = The j^{th} season effect.

DS_{ij} = The ij^{th} district effect by season effect interaction.

e_{ijk} = Random error.

To determine the models' validity, the variation coefficients (R^2 and VC) were used. To understand the relationship between the minerals in the serum and milk of she-camels and their newborn serum macromineral status, a correlation coefficient was done using the Pearson correlation test. Least statistical differences (LSD) were used to compare mean differences when $p \leq 0.05$ was used.

RESULTS AND DISCUSSION

The minimum and maximum temperatures (°C) in each region selected for this study during sampling, which may influence macromineral status, are shown in SFig S1B. Ahmed *et al.* (2013) observed that serum phosphorus and calcium levels were season dependent (high in the hot season).

Environmental influence on macromineral status

Environmental influence on macromineral status are shown in Table 1. Seasonal variations affected feed Mg levels, with significantly higher values in summer and spring than in winter. Soil P content was highest in spring, lowest in summer and moderate in winter. The Ca content in soil and water was highest in the central region (Riyadh), leading to significant differences between districts. The Mg content in feed and soil was significantly higher in Riyadh, while P content in feed and soil was lower in the central region and higher in the southern region (Najran).

Serum macrominerals in she-camels

As shown in Table 2, serum Ca, Mg and P levels of she-camels were significantly influenced by season ($p \leq 0.05$), with higher concentrations in spring, lowest in winter and intermediate in summer. In regional differences, serum Ca and Mg were significantly higher in the eastern, western and northern districts than in the central district. Serum P levels were not significantly affected by district. Highest Ca levels were observed in the eastern district in spring and lowest in the central district in summer, indicating an interaction effect. Mg levels were also highest in the eastern district in spring and lowest in the central district in summer.

Serum macrominerals in newborn camels

As shown in Table 3, season, district and their interactions had significant effects on neonatal serum Ca, Mg and P levels ($p<0.05$), except for seasonal P levels, which showed

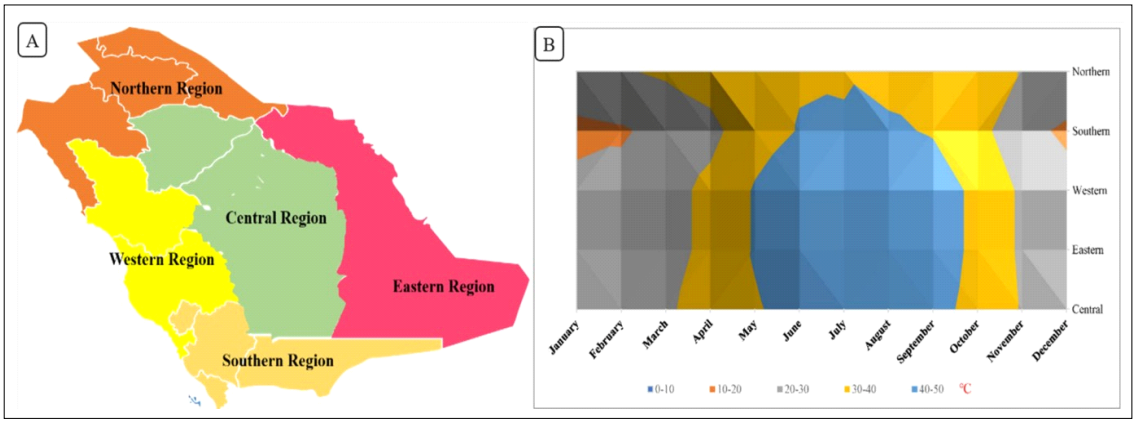


Fig S1: A. The map shows the five Saudi Arabia districts of this study. B. Minimum and maximum temperatures (°C) in the five districts selected for this investigation: Northern Region [AlJouf]; Southern Region [Najran]; Western Region [Mekka]; Eastern Region [Dammam]; and Central Region [Riyadh] (GAS, 2010).

a non-significant trend (p = 0.08). In term of seasonal trends, highest Ca and Mg levels were in spring, lowest in winter and intermediate in summer. In respect regional differences, serum Ca levels were highest in the eastern district, lowest in the northern district and intermediate in the central, western and southern districts. Also, Mg levels peaked in the eastern district in spring and were lowest in the southern district in winter. P levels were highest in the eastern and central districts and lowest in the Southern and western districts.

Macrominerals in she-camel milk

As shown in Table 4, milk Ca, Mg and P concentrations in she-camels were significantly affected by district and season*district interaction (p≤0.05), while season alone had no significant effect (p>0.05). Seasonal trends of Mg concentrations were significantly higher in winter and spring compared to summer (p≤0.05). Regional differences, milk macrominerals were significantly higher in the eastern and western districts and lowest in the northern district. Highest Ca levels in milk were observed in the eastern district in spring, while lowest values were in the northern and southern districts in winter and spring, respectively. P content in milk was highest in the eastern district in spring and lowest in the northern district in winter and southern district in spring. Mg content was highest in the western district in spring and lowest in the southern district in winter.

Correlations between serum, milk and newborn mineral levels

She-camel serum vs. newborn serum

As illustrated in Table 5, Mg in newborn serum showed significant (p≤0.05) positive correlations with Ca (R^2= 0.595) and Mg (R^2 = 0.548) in she-camel serum. While, P in newborn serum showed a non-significant (p>0.05) correlation with P in she-camel serum. In she-camel serum, strong positive correlation (p≤0.05) between Ca and Mg (R^2 = 0.805). In addition, weak positive correlations between P and Ca (R^2 = 0.526) and P and Mg (R^2 = 0.532). In newborn serum, slight positive correlations (p≤0.05) between Ca and Mg (R^2 = 0.590) and P and Mg (R^2 = 0.628).

She-camel milk vs. newborn serum

As presented in Table 6, newborn Ca and Mg levels showed significant (p≤0.05) positive correlations with P in she-camel milk (Ca: R^2 = 0.531, Mg: R^2 = 0.546). P in milk showed significant (p>0.05) positive correlations with Ca and Mg in newborn serum. In milk, strong positive correlations were observed between Ca and Mg (R^2 = 0.934) and between Mg and P (R^2 = 0.630). In newborn serum, positive correlations were observed between Ca and Mg (R^2 = 0.590) and between P and Mg (R^2 = 0.628).

She-camel serum vs. milk

As summarized in Table 7, no significant correlations were observed between macromineral levels in the serum and milk of she-camels. Serum P showed no significant negative correlations (p>0.05) with Ca, Mg and P in milk. Milk macrominerals showed strong correlations: Ca and Mg (R^2 = 0.933), Ca and P (R^2 = 0.734) and Mg and P (R^2 = 0.630).

Physiology, environmental conditions, nutrition and genetics influence the various biochemical parameters. Regarding camels, in previous literature there are very few references about mineral elements in relation to various physiological conditions (Faye and Bengoumi, 2018;

Table 1: Mineral concentration in representative feed, soil and drinking water samples from the five districts during three seasons.

Effects	Average of minerals (µg/g) in feed			Average of minerals (µg/g) in soil			Average of minerals (µg/mL) in drinking water		
	Ca	Mg	P	Ca	Mg	P	Ca	Mg	P
Season effects									
Summer	436.6	2283.4^{a}	2109.2	902.3	2211.2	215.7^{c}	413.7	275.4	0.57
Spring	388.4	2535.7^{a}	2698.4	1088	1876.3	1086.4^{a}	561.7	368.9	0.73
Winter	291.3	1452.8^{b}	2413	1396.2	2075.9	433.7^{b}	833.9	326.5	0.72
District effects 1									
1	300	2485.7^{a}	1282.7^{c}	2486^{a}	2620.3^{a}	113.2^{d}	1138.1^{a}	411.4	0.72
2	342.5	1852.3^{bc}	1583.2^{bc}	725.7^{b}	1926.2^{ab}	683^{b}	579.8^{b}	131.7	0.67
3	388.1	2441^{ab}	2837.6^{ab}	476.9^{b}	2065.1^{ab}	320.8^{c}	205.7^{b}	498.6	0.69
4	509.4	2101.1^{ab}	3975.1^{a}	465.2^{b}	1464.2^{b}	1995.6^{a}	317.4^{b}	71.3	0.67
5	357.2	1298.1^{c}	2939.8^{ab}	301.7^{b}	1606.2^{b}	174.9^{cd}	552.9^{b}	485	0.57
SEM^{2}	38.07	134.5	261.0	209.3	182.5	0.035	101.5	72.76	207.7
P-value									
Season	0.125	0.0002	0.605	0.826	0.105	<.0001	0.072	0.613	0.285
District	0.360	0.018	0.006	0.001	0.015	<.0001	0.003	0.178	0.796
Season*District	0.665	0.077	0.422	0.949	0.027	<.0001	0.099	0.150	0.399

1Districts: 1= Central [Riyadh]; 2=Eastern [Dammam]; 3=Western [Mekka]; 4= Southern [Najran]; 5= Northern [AlJouf]. 2SEM: Standard error of means.

Vyas *et al.,* 2011). Despite the claims made in many reviewpublications about the benefits of camel milk, its mineral content is not fundamentally different from that of cow's milk. The mineral composition of camel milk is characterized by its relative richness in K, Na and Cl as well as iron and zinc (Konuspayeva *et al.,* 2022). However, due to the lack of studies on the effects of many elements, it is difficult to determine a specific reference value or typical values. In addition, the diversity of analytical procedures and the lack of precision of the methodology used by numerous authors, leading to highly contradictory results, call into question some of the published data. Therefore, this study was conducted to determine the status of macro minerals in camelids and their neonates, which could be useful as baseline information for dromedary camels (*Camelus dromedarius*). There is limited information on the bioavailability of macrominerals in camelids and their neonates in Saudi Arabia, so studying their macromineral status in semiarid environments is an interesting topic. Most of the scientific work dealt with ruminant nutrition, mineral deficiency and animal welfare research. Due to the scarcity of feed and the low mineral content, minerals are extremely important in the diet of animals and humans in arid districts. These in turn affect animal health and production performance in ruminant production systems, regardless of whether they are kept indoors or outdoors. In addition to nutrition, several other factors need to be considered, including geographical region (east, west, central, south and north), air temperature (high, medium and low), animal species (monogastric, pseudo-ruminants and ruminants) and sex (male or female). The present study aimed to deduce the role of seasonal ambient temperature and districts on the concentrations of macrominerals in the studied samples of indigenous camels in Saudi Arabia under arid and semi-arid conditions. The total calcium, phosphorus and magnesium content in camel milk ranged from 0.3 to 2.57 g/L, 0.34 to 1.00 g/L and 45 and 200 mg/L, respectively (Faye and Bengoumi, 2018; Konuspayeva *et al.,* 2022).

Calcium and phosphorus influence the ability of animals to utilize other trace elements. Their influence on certain enzyme systems can impair reproductive performance (Vyas *et al.,* 2011). Calcium excess or deficiency can cause various types of non-specific or specific diseases, particularly affecting the bones. Therefore, the dosage of calcium is recommended for bone, neuromuscular, cardiovascular and renal diseases. Increased mineral content in milk is caused by bacterial infection in the udder, which destroys the epithelial cells of the secretory alveolar ducts and causes increased vascular permeability in this area (Hamadani *et al.,* 2013).

Kuria *et al.* (2006) found that trends in minerals were inconsistent, resulting in interactions and that plasma concentration of minerals was not a reliable predictor of dietary mineral content. These results showed that serum calcium levels fluctuate within narrow limits but are not a reliable predictor of the balance between intake and removal. However, calcium intake is not only regulated by the seasons and nutritional phases, but also by physiological phases, such as the late phase of pregnancy, where a decrease in calcium concentration indicates a

Table 2: Seasons and districts effects on mean values of macro-minerals in she-camel's serum.

Effects	She-camels serum macrominerals (µg/ml or PPM)		
	Ca	Mg	P
Season effects			
Summer	286^{ab}	43.5^{ab}	288^{ab}
Winter	271^{b}	37.7^{b}	272^{b}
Spring	334^{a}	46.4^{a}	302^{a}
SEM	0.101	0.827	16.8
District effects			
Central	234^{b}	33.5^{b}	208
Eastern	337^{a}	50.2^{a}	288
Western	313^{a}	44.5^{a}	304
Southern	271^{ab}	39.1^{ab}	311
Northern	329^{a}	45.0a	325
SEM	2.74	2.79	25.6
P-value			
Season	<0.0001	0.001	0.023
District	0.013	0.054	0.676
Season*District	0.019	0.061	0.983

a-c Means were significantly different within column ($p \leq 0.05$), SEM: Standard error of means.

Table 3: Seasons and districts effects on mean values of macrominerals in she-camel's new born serum macro-minerals.

Effects	New born she-camels' serum macro-minerals (µg/ml or PPM)		
	Ca	Mg	P
Season effects			
Summer	304^{ab}	38.06^{ab}	311
Winter	275^{b}	35.27^{b}	276
Spring	352^{a}	44.15^{a}	314
SEM	0.122	1.23	11.3
District effects			
Central	293^{bc}	38.3^{b}	326^{a}
Eastern	366^{a}	51.6^{a}	347^{a}
Western	292^{b}	39.0^{b}	286^{b}
Southern	331^{ab}	32.0^{c}	247^{b}
Northern	269^{c}	34.9^{b}	296^{ab}
SEM	0.148	1.53	16.4
P-value			
Season	0.002	0.001	0.081
District	0.001	<0.0001	0.001
Season*District	0.054	<0.0001	0.001

$^{a-c}$ Means were significantly different within column ($p \leq 0.05$), SEM: Standard error of means.

dangerous scenario. This decrease could be due to insufficient calcium absorption from the intestine, which is thought to be important in milk fever (Abraham, 1983). According to Thilsing *et al.* (2007), lactating dairy animals consume significant amounts of calcium to synthesize milk. Neves *et al.* (2017) reported that multiparous cows with low Ca concentrations in the prepartum phase are more likely to be classified as subclinically hypocalcemic at calving. He established this as a cut-off point for prepartum animals that are more likely to be hypocalcemic after calving. Moore *et al.* (2000), showed that Ca levels are slightly lower when a cow is close to calving.

The Ca, P and Mg status of camelids and their newborns were found to vary by region and season. In agreement with Abdelrahman *et al.* (2022b), the differences in Ca, P and Mg status of growing camels were influenced by districts, which could be due to variations in their concentration in soil, feed and water, which are largely controlled by environmental factors. In addition, the concentration of minerals in milk varies by country and region, mainly due to factors such as the growing conditions of the feed (soil, irrigation water and type of fertilizer), processing methods that alter pH and the use of metal containers (AW, 2008). Mineral analysis of feeds by Gupta *et al.* (2016) revealed a lack of calcium and phosphorus in wheat straw and cereal grains. Also, the cereal grains, maize and sorghum fodders had lower Mn concentration than the indicated critical limit. Macromineral variability of camel milk has been associated with the types of production systems, while slight variations may occur according to the age of camels, lactation stages and parity orders (Elhassa *et al.,* 2023).

The macromineral serum of she-camels and their newborns had the highest values in spring, especially in the western district and the lowest in winter, with values varying by district. Assessment of macromineral serum levels in dromedary camels may influence the macromineral status of neonates, in addition to numerous other factors that act synergistically. Camel milk is recommended as a valuable source of nutrition for humans (Abduku and Eshetu, 2024).

Serum levels of the macrominerals Ca, P, Mg, Na and K did not differ statistically between the different lactation phases of dairy cows; however, calcium levels were not statistically significantly high in the early and mid-lactation phases, while they were lowest in the prepartum and postpartum phases (Fadlalla *et al.,* 2020). They found that calcium was positively associated with daily milk yield but negatively associated with serum potassium levels.

Table 4: Seasons and districts effects on mean values of macro-minerals she-camels' milk.

Effects	She-camels' milk macro-minerals (µg/ml or PPM)		
	Ca	Mg	P
Season effects			
Summer	181	171[b]	1041
Winter	194	205[a]	1035
Spring	170	186[a]	1120
SEM	10.8	8.63	67.2
District effects			
Central	184[b]	184[b]	1091[a]
Eastern	242[a]	206[a]	1347[a]
Western	228[a]	261[a]	1133[a]
Southern	161[b]	192[b]	946[a]
Northern	94.0[c]	93.1[c]	810[b]
SEM	15.168	11.823	81.304
P-value			
Season	0.384	0.051	0.652
District	<.0001	<.0001	0.004
Season*District	<.0001	<.0001	0.002

[a-c] The mean was significantly different within column ($p \leq 0.05$), SEM: Standard error of means.

Table 5: Correlation coefficients matrix between macrominerals, µg/ml concentrations in serum of she- camels and of their newborn.

Variables	Macrominerals					
	^{DS}Ca	^{DS}Mg	^{DS}P	^{NS}Ca	^{NS}Mg	^{NS}P
^{DS}Ca	1					
^{DS}Mg	0.805	1				
	0.0003					
^{DS}P	0.526	0.5316	1			
	0.044	0.0414				
^{NS}Ca	0.3812	0.4213	0.04872	1		
	0.161	0.1178	0.8631			
^{NS}Mg	0.595	0.54791	-0.18808	0.5898	1	
	0.0193	0.0345	0.5021	0.0207		
^{NS}P	0.2032	0.29164	-0.33746	0.2848	0.62761	1
	0.468	0.2916	0.2187	0.3036	0.0123	

DS = Dam serum; NS = Newborn serum. *p*-value: less or equal to 0.05 and 0.01 is considered to be significantly different.

Mg, Ca, Cu, Zn, Fe and Mn concentrations of hair mineral status differed significantly between calf groups in intensive, semi-intensive and extensive management systems (Faraz, 2021).

The most mineral contents in the milk of the studied animals in the different districts were similar to those in the previously reported (AW, 2008).

Human milk has the lowest levels of calcium, phosphorus, iron, magnesium, zinc, sodium and potassium. Human milk contains a better Ca:P ratio than other animals (Soliman, 2005). Human milk contains about 6.5 times more manganese than camel, cow and goat milk. Buffalo milk has the highest content of calcium, phosphorus and magnesium. Camel milk contains the highest concentrations of Fe, Zn, Na and Cu. The chemical and mineral composition of the five animal species studied (human, cow, buffalo, camel and goat) varied considerably (Soliman, 2005). Soliman (2005) found that camel, goat, buffalo and cow milk cannot replace human milk, but can supplement it.

Almost all plants, especially desert plants, cause minimal changes such as discolored milk in livestock, wildlife and humans (Stegelmeier and Davis, 2023).

The interrelationship between the calcium, phosphorus and magnesium status of camelids and their newborns in semi-arid districts is a complex and important aspect of camel health and reproduction. These three major minerals play a crucial role in various physiological processes and their balance is essential for the overall well-being of both the mother and her offspring (Faye and Bengoumi, 2018). An imbalance in one mineral can affect the absorption and utilization of others. For example, calcium and phosphorus are often considered in a calcium-phosphorus ratio and an imbalanced ratio can lead to problems such as secondary hyperparathyroidism, which results in weak bones. Normal fetal development depends on an adequate supply of trace elements such as magnesium (Mg), iron (Fe), manganese, zinc (Zn), copper (Cu) and selenium (Se) (Nandakumaran *et al.,* 2016).

Table 6: Correlation coefficients matrix between macrominerals, µg/ml concentrations in milk of she-camels and in serum of their newborns.

Variables	Macrominerals					
	^{DM}Ca	^{DM}Mg	^{DM}P	^{NS}Ca	^{NS}Mg	^{NS}P
^{DM}Ca	1					
^{DM}Mg	0.93377	1				
	<.0001					
^{DM}P	0.73411	0.62965	1			
	0.0018	0.0119				
^{NS}Ca	0.37185	0.25984	0.5311	1		
	0.1723	0.3496	0.0416			
^{NS}Mg	0.44756	0.27227	0.54599	0.5898	1	
	0.0944	0.3262	0.0352	0.0207		
^{NS}P	0.58858	0.43658	0.33357	0.2848	0.62761	1
	0.021	0.1037	0.2244	0.3036	0.0123	

DM = Dam milk; NS = Newborn serum. *p*-value: less or equal to 0.05 and 0.01 is considered to be significantly different.

Table 7: Correlation coefficients matrix between macrominerals, µg/ml concentrations in serum and milk of she-camels.

Variables	Macrominerals					
	^{DS}Ca	^{DS}Mg	^{DS}P	^{DM}Ca	^{DM}Mg	^{DM}P
^{DS}Ca	1					
^{DS}Mg	0.80479	1				
	0.0003					
^{DS}P	0.52635	0.53164	1			
	0.0438	0.0414				
^{DM}Ca	0.07431	0.22662	-0.30461	1		
	0.7924	0.4167	0.2696			
^{DM}Mg	0.01291	0.12346	-0.22173	0.93377	1	
	0.9636	0.6611	0.4271	<.0001		
^{DM}P	0.1178	0.40891	-0.28328	0.73411	0.62965	1
	0.6759	0.1302	0.3063	0.0018	0.0119	

DS = Dam serum; DM = Dam milk. *p*-value: less or equal to 0.05 and 0.01 is considered to be significantly different.

Calcium deficiency in cows can lead to problems such as weak bones, muscle tremors, difficulties in calving and delayed fetal growth. Calcium is also involved in the pathogenesis of metabolic diseases that can disrupt the normal regulation of calcium balance and lead to hypercalcemia or hypocalcemia (Payne, 2013). Hypocalcemia was found in a camel with musculoskeletal disorders (Faye and Bengoumi, 2018). Magnesium deficiency can lead to muscle tremors, nervousness and problems with calcium utilization. Phosphorus deficiency can lead to weakened bones and poor growth in both camelids and their newborns. Shamat *et al.* (2009) showed that the interaction between districts and seasons can have an increased effect on serum and milk mineral values. For example, in a district with an already low mineral content in the feed, there may be greater fluctuations in serum or milk mineral values during the dry season when feed quality is even more impaired. On the other hand, districts with more stable environmental conditions and better forage quality may have less fluctuation in milk mineral values throughout the year. The interaction of districts and seasons on mineral concentrations in green forage and forages led to different results (Shamat *et al.,* 2009).

The macromineral serums of she-camels and their neonates were lowest in winter, although values varied between districts. Winter is a very stressful season for camels, especially for lactating camels, which affects milk yield and composition and thus the health and growth rate of newborn camels (Abdelrahman *et al.,* 2022b; Ahmed *et al.,* 2019).

As far as we know, there are no or few previous studies that have investigated the relationship between serum or milk concentrations of camelids and their newborns in Saudi Arabia and little information is available on the bioavailability of macrominerals, so the practice of mineral supplementation is scarce or non-existent. To investigate mineral imbalances and their interrelationships, elements were determined in the serum and milk of camels with their newborns in winter, spring and summer.

In the current study, Mg in the serum of newborn camels showed significant, negligible positive correlations with Ca and Mg in the serum of she-camels. In agreement with Essawi and Gouda (2020a) and Essawi and Gouda (2020b), active transfer of Mg, Fe, Zn, Cu, Se and Mn between pregnant camelids and fetuses was found. On the other hand, the P content in the serum of the newborns showed an insignificant, negligible negative correlation with the P content in the serum of the she-camels. Essawi and Gouda (2020b) and Essawi and Gouda (2020a) found that there was no correlation between neonatal birth weight and serum levels of trace elements in camelids. They showed a favorable correlation between neonatal weight and Fe, Se and Zn levels in umbilical cord venous serum. In addition, no correlation was found between maternal and fetal trace elements in pregnant camels (Essawi and Gouda, 2020b).

Mineral content in blood serum or milk could be considered an indicator of mineral status in animals, including camels (Faye and Bengoumi, 2018).

In agreement with Abdelrahman *et al.* (2022a), a regional effect occurred, with the samples from the four districts of the she-camels serum, especially from the eastern region (Dammam), having more major elements (especially Ca and Mg) than the samples from the central region (Riyadh). This regional difference helps to explain this pattern: one in Ca and Mg of the she-camels serum, but there was no significant difference in P.

Although there is a higher Ca content in water and soil and a higher Mg content in forage and soil in the Riyadh. The P content in grass and soil was also different, with lower P levels in the central region and higher P levels in the southern parts [Najran] of Saudi Arabia. This could have an impact on the regional mineral status of the animals grazing in these different areas. Soil, water and grass are the main sources of minerals in the diet of camels kept in semi-arid and arid areas. The Mg content in the forage was significantly higher in summer and spring than in winter. The P content in the soil was significantly higher in the spring, lower in the summer and in between in the winter.

In the serum of a she-camel in Saudi Arabia, the calcium content was 9.0 mg/dl, the Mg content was 2.16 ug/ml and the P content was 3.8 ug/ ml (Osman and Al-Busadah, 2003).

This study contributes to the understanding of the nutritional dynamics of camelids in semi-arid districts and sheds light on the factors that influence the mineral content of their milk. It helps in developing appropriate feeding and management strategies to optimize milk quality and quantity in camel herds in these districts. It also contributes to the development of region-specific guidelines for camel breeding and the formulation of balanced feeds that meet the mineral requirements of nursing camels, especially during critical periods such as lactation. Overall, the interaction between districts and seasons in semi-arid districts can have a significant impact on the macromineral content of camel milk, which is important for both animal health and the nutritional value of milk for human consumption.

CONCLUSION

Collecting samples from several districts in Saudi Arabia provides a visual record of the macromineral condition of camels and their neonates in the selected districts, but cannot be supported by theories of diet quality. The regional differences in our study have a complicated basis. The discrepancies in Ca, P and Mg status of the affected camels in different districts could be due to different concentrations in soil, water and feed in different seasons, which are primarily influenced by many environmental factors. Indeed, the main minerals in milk and blood reflect the mineral metabolism. Consequently, macro minerals in the body can vary greatly depending on the physiologicalstate of the animals, their health status, nutritional status,

feed quality and the mineral status of the feed in relation to the soil components. Further studies could be conducted by collecting more information on the breeding conditions, diet, seasons, districts and mineral composition status of camel milk to explain some of the attributed health effects. In different districts and depending on the season, the potential for developing a supplementation program needs to be explored.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

All animal procedures for experiments were approved by the Committee of Experimental Animal care and handling techniques were approved by the King Saud University of Animal Care Committee (protocol code KSU-SE-22-21 and date of approval: 24 March 2022).

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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