



Physiological and Biochemical Traits of Omani and Sudani Camel Breeds and their Hybrid under Extensive Management System in Saudi Arabia

A.A. Mohammed¹, H. Darrag², S. Al-Suwaiegh¹, I. AlGherair¹, H. Almari¹

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ABSTRACT

Background: Productive, reproductive, hematological and plasma biochemical traits have been shown to be affected by an extensive management system.

Methods: Omani and Sudani (Anafi) camel breeds and their Hybrid bred in Riyadh region under an extensive management system for monitoring the number of services per pregnancy, gestation period, lactation period and daily milk production in addition to analysis of hematological and plasma biochemical traits.

Result: The study explored the lactation period, daily milk production (kg), services per pregnancy and gestation period in addition to the hematological and plasma biochemical traits of Omani, Sudani camel breeds and their Hybrid animals. The results revealed significant differences in several key blood cell indices, suggesting variations in the physiological characteristics of these groups. The number of services per pregnancy was significantly higher in Omani and Sudani camel breeds if compared to their Hybrid camel group. The Omani and Sudani groups generally showed higher values for RBC-related parameters (RBC, PCV, Hb), while the Hybrid group exhibited higher granulocyte counts. The results revealed significant differences in several key metabolic indicators, suggesting variations in their physiological and metabolic states. The findings indicate distinct biochemical profiles across the Omani, Sudani and their Hybrid camel groups. The Hybrid group consistently showed a higher total protein and GGT, while the Sudanese group had higher glucose and LDH. The Omani group, in contrast, had the highest urea levels but lower values for several other parameters, including glucose and liver enzymes. It could be concluded that physiological, hematological and plasma biochemical traits might differ due to physiological traits and camel breeds.

Key words: Biochemical, Hematological, Hybrid, Milk, Omani, Reproductive, Sudani.

INTRODUCTION

Given that the world's population is expected to reach 10.4 billion by 2100 due to longer life span and declining death rates but food security is a major challenge for this century. Meeting this demand requires more intensive and sustainable agricultural and livestock productions (Gilbert *et al.*, 2021). Out of the estimated 35 million camels worldwide, the majority are found in Africa, particularly in countries like Somalia, Ethiopia and Sudan, which have the largest dairy herds (Sikkema *et al.*, 2019). Around 90% of these camels are the one-humped species, *Camelus dromedarius*. The number of milk-producing dromedary camels and their annual milk output are consistently on the rise. Camels are an essential source of protein, especially for nomadic groups in dry regions who have limited access to other food sources. The increasing demand for camel milk and its products shows that it's becoming more recognized as a healthy and medicinal food (El-Hanafy *et al.*, 2023).

Camels are especially important in Saudi Arabia's efforts to achieve food security. They are the most significant domesticated animals in the country because they can uniquely handle harsh environments. Camels provide meat, milk, urine, wool and fertilizer, which are essential resources for both nomadic and settled communities

¹Department of Animal and Fish Production, College of Agriculture and Food Sciences, King Faisal University, P.O. Box 402, Al-Ahsa 31982, Kingdom of Saudi Arabia.

²Research and Training Station, King Faisal University, P.O. Box 402, Al-Ahsa 31982, Kingdom of Saudi Arabia.

Corresponding Author: A.A. Mohammed, Department of Animal and Fish Production, College of Agriculture and Food Sciences, King Faisal University, P.O. Box 402, Al-Ahsa 31982, Kingdom of Saudi Arabia. Email: aamohammed@kfu.edu.sa
ORCID: <https://orcid.org/0000-0002-1825-7248>

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(Mohammed and Alshaibani, 2024; Mohammed and Alshaibani 2025a,b; Mohammed *et al.*, 2025a,b). The Arabian Peninsula's diverse environment is home to the dromedary camel, a species that has adapted to a wide range of habitats, from deserts to mountains to coastlines. Saudi Arabia is an ideal place to study the genetics and adaptability of these camels due to its varied landscape

(Al-Swailem *et al.*, 2007; Burger *et al.*, 2019; Mahmoud *et al.*, 2020). Camels have played a vital role in the social and economic development of human societies in the Arabian Peninsula and elsewhere. Camels from Sudan (Hashim *et al.*, 2015), which are also found in Saudi Arabia, particularly in the yellow Maghateer category. They are often used for racing. In addition, Omani camel breed is also found and prized in Saudi Arabia, especially in the context of racing (Almathen *et al.*, 2022). Therefore, the purposes of the study were to investigate physical traits including coat color, hematological traits and productive performance traits as well of Sudani and Omani camel breeds and their traits.

MATERIALS AND METHODS

The experimental procedures were conducted on a camel farm and in lab settings to analyze their productive, physiological, hematological and biochemical traits for understanding their health, nutritional status and remarkable adaptability to harsh, arid environments. These studies provide baseline reference values and help to identify how extensive management systems affect a camel's well-being.

Site of study and animal management

The current experiment was carried out from August 2024 to August 2025. Eight Sudani and eight Omani camel breeds and eight of their hybrids, of 6-10 years old under an extensive management system, were selected for the study in the Eastern Province of the Kingdom of Saudi Arabia (Fig 1).

Animals were fed on a grazing system in addition to berseem hay. The averages of relative humidity (%) and

temperature (°C) values during the study were $35.5 \pm 3.30^\circ\text{C}$ and $42 \pm 8.0\%$, respectively. The duration of the study was thirteen months.

Morphological traits of Sudani and Omani camel breeds and their hybrid

The Sudani (Anafi) camel breed is a single-hump breed with coats that range in color from a light, creamy white to a sandy-colored (Fig 2A). The Omani camel breed (Fig 2B) is a single-hump breed with a light brown or tan coat, a dark brown mane on its neck and hump. The Hybrid camel breed (Fig 2C and 2D) is a single-hump breed with sandy-brown color. The Sudani and Omani breeds and their Hybrid have slim, muscular bodies and long legs for a more slender and athletic build.

Monitoring milk production and the lactation period

The milk production of Sudani and Omani breeds and their Hybrid was recorded monthly through hand milking after parturition during the lactation season. The udders of she-camels were cleaned prior to hand milking and the milk yield per head (kg/head) was recorded. The first three milk squirts were discarded and the udder was completely emptied into a plastic sterilized container. The collected milk samples were determined (kg/head).

Monitoring the numbers of services per pregnancy and gestation period

The numbers of services per pregnancy after calving of the she-camel were counted per she-camel until confirmation of pregnancy. The gestation period is calculated from the difference between the date of service until the parturition date.

Blood sample collection and analyses

Blood samples of Sudani and Omani camel breeds and their Hybrid were collected from the jugular veins. The obtained blood samples were analyzed using an automatic hematology analyzer (Mythic 5Vet PRO) and biochemistry analyzer (Skyla VB1 Analyzer). The resulting blood parameters include red and white blood cell profiles. The resulting biochemistry parameters include total proteins, urea, creatinine, liver and kidney enzymes and mineral values.

Statistical analysis

Milk production (kg), lactation period, number of services, gestation period, blood and plasma profile values of Sudani and Omani camel breeds and their Hybrid were statistically analyzed using general linear model procedure of one way ANOVA (SAS, 2008) according to the model:

$$Y_{ij} = \mu + T_i + e_{ij}$$

Where,

μ = Mean.

T_i = Effects of Sudani and Omani camel breeds and their Hybrid.

e_{ij} = Standard error.

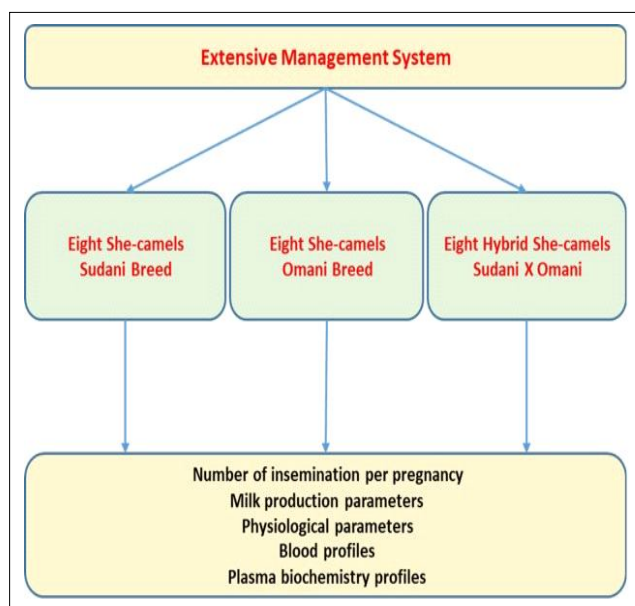


Fig 1: Experimental design of study for Sudani and Omani camel breeds and their hybrid.

Duncan's multiple range test (1955) was used to compare the means of Sudani and Omani camel breeds and their Hybrid groups.

RESULTS AND DISCUSSION

The results of milk production (kg), lactation period, number of services, gestation period, blood and plasma profile values of Omani, Sudani camel breeds and their Hybrid are presented in (Table 1-3).

Milk production, lactation period, number of services, gestation period

Milk production, lactation period, number of services and gestation period are presented in (Table 1). The Omani camels exhibited the longest lactation period, averaging 360 days, which was significantly longer than both the Sudani (330 days) and Hybrid (340 days) camels ($P < 0.05$). This was also reflected in their daily milk production, where Omani camels produced the highest average yield at 3.50 kg, which was significantly greater than that of Sudani (1.50 kg) and Hybrid (2.0 kg) camels ($P < 0.0001$).

The reproductive efficiency, as measured by the number of services per pregnancy, showed the opposite trend. Omani camels required a significantly higher number of services (4.0) to achieve a pregnancy compared to Sudani

(2.0) and Hybrid (3.0) camels ($P < 0.0001$). This suggests that Sudani and Hybrid camels possess superior fertility or reproductive efficiency under the conditions of this study. The gestational period did not show a significant difference among the Omani, Sudani camel breeds and their Hybrid ($P < 0.09$). The Omani camels had a slightly longer average gestational period (386.5 days) compared to the Sudani (375 days) and Hybrid (380.0 days) camels, but this variation was not statistically significant. This finding is consistent with the established knowledge that gestation length is a species-specific trait that is largely consistent across different dromedary camel breeds.

Blood and plasma profiles

Values of blood profiles of Omani, Sudani camel breed and their Hybrid are presented in (Table 2). Concerning red blood cells (RBCs) and related parameters, the Omani and Sudani camel groups had significantly higher RBC counts (8.72 and $8.70 \times 10^6/\mu\text{l}$, respectively) compared to the Hybrid group ($8.03 \times 10^6/\mu\text{l}$). The Sudani camel group showed the highest PCV (31.40%), followed by the Omani camel group (30.10%), while the Hybrid camel group had a comparable PCV to the Omani group (29.26%). Similar to the PCV results, the Omani and Sudani camel groups had significantly higher Hb levels (12.23 and 12.20, g/dl)



Fig 2: Camel breeds under an extensive management system; (A) Sudani (Anafi) camel breed (A), Omani camel breed (B) and their Hybrid (C and D).

Table 1: Lactation period (days) and milk production (kg), number of services per pregnancy and gestational period (days) of Omani, Sudani and their hybrid she-camels.

Parameters	Omani	Sudani	Hybrid	SEM	P value
Lactation period, days	360 ^a	330 ^b	340 ^b	10.0	0.05
Daily milk production, kg	3.50 ^a	1.50 ^c	2.0 ^b	0.4	<0.0001
No. services/pregnancy	4.0 ^a	2.0 ^b	3.0 ^b	0.3	<0.0001
Gestational period, days	386.5	375	380.0	5.4	0.09

^{a,b,c} Values between groups with different superscripts significantly differ at $P < 0.05$.

SEM: Standard error.

than the Hybrid group (11.53, g/dl). The Sudani and Hybrid camel groups had significantly higher MCV values (36.0 and 36.30, fl) compared to the Omani group (34.30, fl). The Hybrid camel group had the highest MCH (14.30, pg), which was significantly different from both the Omani and Sudani camel groups (14.0 and 14.0, pg). There were no statistically significant differences in MCHC among the three groups ($P < 0.07$). The Hybrid camel group had the highest red cell distribution width (RDW) (12.70%), followed by the Sudani (12.10%) and Omani (11.63%) camel groups.

Concerning white blood cells (WBCs) and subtypes, the Omani and Hybrid camel groups had significantly higher WBC values (9.20 and 9.30, $10^3/\mu\text{l}$) compared to the Sudani camel group (8.60, $10^3/\mu\text{l}$). The Hybrid camel group had a significantly higher granulocyte count (7.20, $10^3/\mu\text{l}$) than the Omani and Sudani camel groups (6.50 and 6.38, $10^3/\mu\text{l}$). The Omani camel group had a significantly higher non-granulocyte count (2.70, $10^3/\mu\text{l}$) compared to the Sudani and Hybrid camel groups (2.22 and 2.10, $10^3/\mu\text{l}$).

Concerning to platelets (PLT) and related parameters, No significant differences were observed in platelet counts among the camel groups ($P < 0.07$). The Omani camel group had the highest ($P < 0.001$) MPV (6.66, μm^3), followed by the Sudani (6.10, μm^3) and Hybrid (5.13, μm^3) camel groups. The differences were highly significant.

The values of plasma biochemical profiles of the Omani, Sudani camel breed and their Hybrid are presented in (Table 3). The Hybrid camel group had the highest total protein concentration (6.93 g/dl), which was significantly different from both the Sudanese (6.06 g/dl) and Omani (5.96 g/dl) groups. The Sudanese camel group also had a significantly higher concentration than the Omani camel group. The Omani camel group had the highest urea concentration (18.60 mg/dl) followed by the Hybrid (17.60 mg/dl) and Sudanese (15.30 mg/dl) camel groups. The Sudanese camel group had a significantly higher creatinine concentration (1.33 mg/dl) compared to both the Omani (1.23 mg/dl) and Hybrid (1.20 mg/dl) camel groups. The

Table 2: Changes in blood profiles of Omani, Sudani and their hybrid she-camels.

Parameters	Omani	Sudani	Hybrid	SEM	P value
RBCs, $10^6/\mu\text{l}$	8.72 ^a	8.7 ^a	8.03 ^b	0.08	0.001
PCV, %	30.1 ^b	31.4 ^a	29.26 ^b	0.31	0.05
Hb, g/dl	12.23 ^a	12.2 ^a	11.53 ^b	0.09	0.05
MCV, fl	34.3 ^b	36.0 ^a	36.3 ^a	0.33	0.01
MCH, pg	14.0 ^b	14.0 ^b	14.3 ^a	0.05	0.05
MCHC, g/dl	40.63	38.96	39.3	0.30	0.07
RDW, %	11.63 ^c	12.1 ^b	12.7 ^a	0.16	<0.04
WBCs, $10^3/\text{ml}$	9.2 ^a	8.6 ^b	9.3 ^a	0.31	<0.0001
Granulocytes, $10^3/\mu\text{l}$	6.5 ^b	6.38 ^b	7.20 ^a	0.21	<0.01
Non-granulocytes, $10^3/\mu\text{l}$	2.7 ^a	2.22 ^b	2.10 ^b	0.15	<0.0001
PLT, $10^3/\mu\text{l}$	327.3	302.6	332	9.47	0.07
MPV, μm^3	6.66 ^a	6.10 ^b	5.13 ^c	0.18	<0.001

^{a,b}. Values between groups with different superscripts significantly differ at $P < 0.05$.

SEM: Standard error; RBCs: Red blood cells; PCV: Packed cell volume; Hb: Hemoglobin; MCV: Mean corpuscular volume; MCH: Mean corpuscular hemoglobin; MCHC: Mean corpuscular hemoglobin concentration; RDW: Red cell distribution width; WBCs: White blood cells; PLT: Platelet, MPV: Mean platelet volume.

Table 3: Changes in blood biochemical profiles of Omani, Sudani and their hybrid she-camels.

Parameters	Omani	Sudanese	Hybrid	SEM	P value
Total protein, g/dl	5.96 ^c	6.06 ^b	6.93 ^a	0.10	<0.0001
Urea, mg/dl	18.6 ^a	15.3 ^c	17.6 ^b	0.34	<0.0001
Creatinine, mg/dl	1.23 ^b	1.33 ^a	1.20 ^b	0.02	0.01
Glucose, mg/dl	100.60 ^b	120.6 ^a	116.3 ^a	2.52	0.01
Aspartate Aminotransferase, U/l	50.30 ^b	64.30 ^a	66.0 ^a	2.52	0.05
Alanine Aminotransferase, U/l	11.6 ^c	15.0 ^a	13.3 ^b	0.42	0.001
γ -glutamyl transferase, U/l	23.6 ^b	24.0 ^b	33.3 ^a	1.14	<0.0001
Creatine kinase, U/l	75.3	76.6	77.3	2.29	0.09
Lactate dehydrogenase, U/l	464.3	640.3	555.3	18.91	<0.0001
Iron, $\mu\text{g}/\text{dl}$	116.6	118.6	104	2.96	0.001
Copper, $\mu\text{g}/\text{dl}$	77.0	76.6	80.3	0.90	<0.07

^{a,b}. Values between groups with different superscripts significantly differ at $P < 0.05$.

SEM: Standard error.

Sudanese (1.20 mg/dl) and Hybrid (116.3 mg/dl) camel groups showed significantly higher glucose levels than the Omani camel group (100.60 mg/dl). The Sudanese (64.30 U/l) and Hybrid (66.0 U/l) camel groups had significantly higher AST levels compared to the Omani camel group (50.30 U/l) ($P < 0.05$). The Sudanese camel group had the highest ALT level (15.0 U/l) followed by the Hybrid (13.30 U/l) and Omani (11.60 U/l) camel groups. The Hybrid camel group had a significantly higher GGT concentration (33.30 U/l) than the Sudanese (33.30 U/l) and Omani (23.60 U/l) camel groups ($P < 0.0001$). There were no significant differences in CK levels among the three groups ($P < 0.09$). Significant differences were found in LDH levels, with the Sudanese camel group having the highest values (640.3 U/l), followed by the Hybrid (555.3 U/l) and Omani (464.3 U/l) camel groups ($P < 0.0001$). Significant differences were observed in iron levels, with the Sudanese camel group (118.60 $\mu\text{g/dl}$) having the highest concentration, followed by the Omani (116.6, $\mu\text{g/dl}$) and Hybrid (104.0, $\mu\text{g/dl}$) camel groups ($P < 0.001$). No significant differences were found in copper levels among the three groups ($P < 0.07$).

Results of the present study are presented in (Table 1-3) indicating physiological, hematological and plasma biochemistry profiles of Omani, Sudani and their Hybrid camel groups.

Milk production, lactation period, number of services, gestation period

Milk production, lactation period, number of services and gestation period are presented in (Table 1). The results of this study provide valuable insights into the productive and reproductive differences among Omani and Sudani breeds and their Hybrid. The findings highlight key trade-offs between production traits (lactation period and milk yield) and reproductive efficiency (services per pregnancy) (Amm et al., 2024), while also confirming the species-specific consistency of gestation length.

The finding that Omani camels have a significantly longer lactation period and higher daily milk production compared to the Sudani and Hybrid camel breeds is particularly noteworthy. This result aligns with the general understanding that camels from the Arabian Peninsula, such as the Omani, have been selectively bred over generations for their dual-purpose utility, which includes milk production for human consumption. This long lactation and high yield make them a superior choice for dairy-oriented farming systems. The lower values observed in Sudani camels are likely a reflection of their traditional role as riding animals, where milk is primarily for the calf and the herder's immediate sustenance rather than for commercial production. The Hybrid camels, being a cross of these two types, show intermediate values, suggesting a combination of traits from both parental lines.

The most striking and unexpected result is the significantly lower number of services per pregnancy in Sudani and Hybrid camels compared to Omani camels.

This indicates that Sudani and Hybrid camels are more reproductively efficient, requiring fewer mating attempts to achieve conception. This finding is crucial for breeding management and herd profitability. The high reproductive efficiency of Sudani camels is likely a result of natural selection pressures in their native, challenging environments. In a traditional nomadic system, a camel's ability to conceive quickly is vital for the herd's survival and growth, as it ensures a consistent supply of new calves. Traits that favor hardiness and fertility are paramount. The lower reproductive efficiency of the Omani camels (higher number of services/pregnancy) could be attributed to several factors. High milk yield might have come at the cost of reproductive traits (Santos et al., 2025). The Hybrid camels, once again, demonstrate their intermediate status, having better reproductive efficiency than the Omani but not quite reaching the level of the pure Sudani breed. This suggests that the desirable fertility traits from the Sudani parent were successfully passed on to the offspring. The lack of a significant difference in the gestational period among the three breeds ($P < 0.09$) is an expected and important result. It reaffirms that gestation length in dromedary camels is a highly conserved species-specific trait that is not significantly influenced by breed. This provides a reliable baseline for management, as the timing of calving can be predicted with a high degree of consistency regardless of the breed.

Blood and plasma profiles

Values of blood profiles of Omani, Sudani and their Hybrid camel groups are shown in (Table 2). Such differences might be related to breed, age and productive differences. It seems that the hematological parameters were ranged within normal levels of values of *Camelus dromedaries* (Martín-Barrasa et al., 2023). These differences likely reflect physiological adaptations to their respective harsh environments and extensive management systems.

The hematological data reveal significant differences among the Omani, Sudani and their Hybrid camel groups, which likely reflect a combination of genetic, environmental and physiological factors. These findings are consistent with previous research demonstrating that hematological parameters can vary considerably between different breeds of the same animal species, as well as being influenced by factors such as climate, diet, age and health status (Karaşahin et al., 2022; Benashour et al., 2024; Mohammed et al., 2025b). The significantly lower RBCs, PCV and Hb values in the Hybrid group compared to the pure Omani and Sudani groups are notable. These parameters are crucial for oxygen transport and lower values might suggest a reduced physiological capacity for this function (Xu et al., 2025). This finding contrasts with the concept of "Hybrid vigor" or heterosis, where crossbred offspring often exhibit improved performance over their parent breeds. In this case, the crossbreeding appears to have had a negative impact on these specific red cell parameters. This could be due to a disruption of the genetic combinations that favor high oxygen-carrying capacity in the parent breeds or

it could be a physiological response to different environmental adaptations.

The Omani and Sudani camel breeds are indigenous to different arid and semi-arid regions and their hematological profiles may be a result of centuries of adaptation to their respective environments. For example, higher RBC counts, PCV and Hb levels could be an adaptation to the heat and limited water availability of these regions, allowing for more efficient oxygen transport (D'Alessandro *et al.*, 2016; Kuhn *et al.*, 2017).

Conversely, the MCV and MCH, which measure the size and hemoglobin content of individual red blood cells (Zhang *et al.*, 2022), tell a different story. The Hybrid and Sudani groups had larger red blood cells (higher MCV) and the Hybrid group had a higher hemoglobin content per cell (higher MCH). This suggests a compensatory mechanism in the Hybrid group: While having fewer red blood cells overall, each cell is larger and carries more hemoglobin. This could be an attempt to maintain a sufficient overall oxygen-carrying capacity despite the lower cell count. The higher RDW in the Hybrid group, which indicates a greater variation in red cell size, further supports this idea of a dynamic and possibly less stable red blood cell population, which is often seen in conditions of anemic response.

The WBC count and its differentials provide insight into the immune status of the animals (Farschtschi *et al.*, 2022; Ribeiro *et al.*, 2024). The higher WBC and granulocyte counts in the Hybrid group suggest a more active immune response. This could be a result of the animals' physiological state, such as an ongoing subclinical infection or a more general stress response. The Omani camel group, while having a high total WBC count similar to the Hybrid group, had a significantly higher non-granulocyte (lymphocyte) count compared to both Sudani and Hybrid camel groups. This difference in leukocyte composition may point to different types of immune responses or general health status (Wu *et al.*, 2025). Lymphocytes are central to the adaptive immune system and their higher count in the Omani camel breed could indicate a well-established and robust long-term immunity, possibly inherited from their genetic background.

The lack of significant difference in PLT counts among the camel groups indicates that the different breeds and the crossbreeding process did not have a major effect on the number of platelets, which are essential for blood clotting. However, the highly significant differences in MPV are notable. MPV reflects the size of platelets and larger platelets are generally more reactive and are associated with a higher risk of clotting. The Omani group had the largest platelets, while the Hybrid group had the smallest. This suggests a physiological difference in platelet function among the groups, which could have implications for their hemostatic response and susceptibility to conditions involving inflammation or thrombosis. The smaller size of platelets in the Hybrid group could be a response to the other observed hematological changes.

The results demonstrate that crossbreeding between the Omani and Sudani breeds did not lead to a straightforward improvement in all hematological parameters. While some parameters like MCV and MCH showed what could be a compensatory mechanism in the Hybrid camel group, the lower values for key indicators like RBCs count, PCV and Hb suggest a potential disadvantage. These differences highlight the importance of understanding breed-specific hematological reference values when assessing the health of animals. Furthermore, the findings underscore the complex interplay of genetics and environment in shaping an animal's physiological profile. Future research could explore the specific genetic markers responsible for these differences and how the unique environmental conditions of the native Omani and Sudani habitats influence the observed hematological values.

Biochemical profiles

The values of plasma biochemical profiles of Omani, Sudani camel breed and their Hybrid are presented in (Table 3). This suggests potential differences in protein metabolism and liver or kidney functions in Omani and Sudani camel breeds and their Hybrid. It has been indicated that biochemical profiles might differ due to age, productive and reproductive performances (Senosy *et al.*, 2017, 2018; Martín-Barrasa *et al.*, 2023). The results of this study might give references values for the Omani and Sudani camel breeds and their Hybrid breeds and might contribute to the understanding of differences in hematological and biochemical profiles in dromedary camel with potential impacts in body health and welfare for those breeds.

The analysis of biochemical blood parameters reveals significant differences among the Omani, Sudanese and Hybrid camel groups, providing insights into their metabolic and physiological status. These variations likely stem from genetic backgrounds, nutritional factors and adaptation to different environments (Manee *et al.*, 2024; Guo *et al.*, 2025; Ibrahim *et al.*, 2025; Bahbahani *et al.*, 2025). The significantly higher total protein levels in the Hybrid group (6.93 g/dl) could be an indicator of superior nutritional status or an active immune response, as immunoglobulins contribute to total protein. This finding might reflect a form of "Hybrid vigor," where the crossbred animals demonstrate improved protein synthesis or retention compared to their parent breeds. Conversely, the significant difference between the Omani and Sudanese camel groups, with the Sudanese having slightly higher levels, suggests that even between the parent breeds, there are subtle but important physiological distinctions. These parameters are key indicators of kidney function and protein metabolism (Krstic *et al.*, 2016). The Omani camel group's highest urea level (18.6 mg/dl) could indicate a higher rate of protein catabolism, a high-protein diet, or a slightly reduced glomerular filtration rate compared to the other groups (Ko *et al.*, 2020). The Sudanese camel group, with the lowest urea concentration, may have a more efficient nitrogen recycling system or a different dietary protein intake. The

Sudanese camel group having the highest creatinine concentration (1.33 mg/dl) could be related to a greater muscle mass compared to the other groups, as creatinine is a byproduct of muscle metabolism (Yim *et al.*, 2023). The similar creatinine levels in the Omani and Hybrid camel groups suggest similar muscle mass or metabolic rates for this parameter. The combined results for urea and creatinine suggest that each group has a distinct metabolic profile related to protein and nitrogen metabolism.

The significantly higher glucose levels in the Sudanese (120.6 mg/dl) and Hybrid (116.3 mg/dl) camel groups compared to the Omani (100.60 mg/dl) group are noteworthy. These differences could be a reflection of metabolic variations related to diet, stress, or differences in energy utilization (Kleinridders *et al.*, 2018). The higher glucose levels in the Sudanese and Hybrid animals might suggest a greater reliance on carbohydrate metabolism or a state of metabolic activity that requires higher circulating glucose (Dilworth *et al.*, 2021). Elevated levels of the enzymes (AST, ALT, GGT) are often indicative of liver cell damage or stress (van Beek *et al.*, 2013). The significantly higher levels of AST and ALT in the Sudanese and Hybrid camel groups compared to the Omani camel group suggest a higher level of liver activity or stress in these animals. This could be a normal physiological variation, or it could point to environmental stressors or subclinical conditions. The Hybrid camel group having the highest GGT levels further supports the idea of greater liver activity or a potential for bile duct stress (Lin *et al.*, 2022). The liver plays a central role in metabolism and detoxification and these differences likely reflect adaptation to different diets or environmental conditions. Creatine kinase (CK) and lactate dehydrogenase (LDH) are enzymes primarily found in muscle tissue and are released into the bloodstream upon muscle damage (Holmes and Goldberg 2009; Kristjansson *et al.*, 2016). While CK levels were not significantly different, the highly significant differences in LDH levels, with the Sudanese camel group having the highest concentration, could indicate a higher degree of physical activity, muscle turnover, or possibly subclinical muscle injury in that group (Callegari *et al.*, 2017).

The significant differences in iron levels, with the Sudanese and Omani camel groups having higher concentrations than the Hybrid camel group, could be related to differences in diet, iron absorption or genetic predispositions (Jallow *et al.*, 2020; Bösch *et al.*, 2024). This finding is particularly interesting when considered with the lower RBCs parameters observed in the Hybrid camel group in a previous analysis, as iron is crucial for hemoglobin synthesis (Abbaspour *et al.*, 2014). The lack of significant difference in copper levels suggests that this mineral is more consistently regulated across the three camel groups. In conclusion, the biochemical analysis highlights that the Omani, Sudanese and Hybrid camel groups possess distinct physiological profiles. The Hybrid camel group shows a unique blend of traits, demonstrating

higher total protein and some liver enzymes, which may indicate a robust metabolic status. However, this group also exhibits lower levels of certain key parameters like urea and iron, which could reflect different metabolic pathways or nutritional requirements. The Sudanese camel group consistently shows a trend towards higher levels of key metabolic indicators like glucose, AST, ALT and LDH, suggesting a more active metabolic state. These results underscore the importance of establishing breed-specific reference ranges for accurate clinical assessment and understanding the complex interplay of genetics and environment in shaping an animal's health and performance.

CONCLUSION

It could be concluded that the Omani, Sudanese and Hybrid camel groups have notable differences in several productive, physiological, hematological and biochemical profiles. These differences could be attributed to variations in metabolic processes, physiological adaptations, or potential health variations between the Omani, Sudanese and Hybrid camel groups. Further investigation and analysis are still needed to determine the underlying causes and clinical significance of these differences.

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Disclaimers

This paper presents the independent views of the authors and does not constitute a statement on behalf of their associated organizations.

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Conflict of interest

The authors have declared no conflict of interest.

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