



Hematological, Biochemical, and Antioxidant Parameters of Three Breeds and Two Ages of Dromedary Camels During Extraordinary Hot Waves

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ABSTRACT

Background: Environmental stressors, such as heat stress, can significantly impact camel blood profiles. Variations in hematology and biochemistry of dromedary camel blood are closely linked to their ability to tolerate heat stress. This study investigates the hematological, biochemical and antioxidant parameters of three camel breeds (black, yellow and white) at two age groups (young: 3-5 years and adults: >5 years) during intense summer heat in central Saudi Arabia.

Methods: Blood samples were collected from three hundred camels belonging to three distinct phenotypic groups: black, yellow and white and stratified by age into two equal categories: young camels: 3-5 years and adults: >5 years. Blood samples were collected from government-regulated slaughterhouses located in Riyadh, Buraydah, Unaizah and Al-Rass, major cities in central Saudi Arabia. Complete blood count (CBC) and serum biochemistry were analyzed during the summer months.

Result: The results revealed significant differences in red blood cells (RBCs) counts, hemoglobin (HGB) levels and hematocrit (HCT) values between young and adult camels, particularly in the yellow breed, indicating age-related changes in oxygen transport capacity. White camels showed higher HCT values, suggesting better adaptation to arid conditions. Leukocyte analysis showed higher white blood cell (WBC) counts in young white camels, indicating a robust immune response, while adult yellow camels had reduced WBC counts. Significant variations were also observed in lymphocyte and neutrophil counts across breeds and ages ($P < 0.05$), reflecting breed-specific immune responses and the influence of heat stress. Serum protein analysis revealed differences in total protein, albumin and globulin levels, with adult camels generally having higher protein concentrations. Liver enzyme activities (ALT, AST, ALP) showed variations, with ALP activities being significantly different across groups ($P < 0.05$). Overall, the study highlights the complex interplay of breed and age on hematological and biochemical parameters in camels under heat stress, providing valuable insights into their physiological adaptations to harsh environmental conditions.

Key words: Antioxidants, Biochemical profile, Dromedary camel, Heat stress, Physiology.

INTRODUCTION

The camel blood profiles can be influenced by various factors, including environmental stressors (Faraz *et al.* 2020a; Islam *et al.* 2019). Several studies have investigated the impact of stress on camel blood profiles, shedding light on the factors that can influence these changes and their significance in camel health (Elitok and Cirak, 2018; Faye and Bengoumi, 2018). Key markers indicative of stress, immune and metabolic status, as well as potential risks of anemia can be identified by interpreting the variations among the different groups. CBC analysis in camels plays a crucial role in assessing their health and diagnosing various conditions. Several studies have provided valuable insights into the factors that can impact camel health and hematological parameters. Evaluating serum biochemistry analyte concentrations has been reported as a useful diagnostic approach, providing valuable information for clinical investigations (Cockcroft *et al.*, 2016). Furthermore, the impact of parasitic infection on the hemato-biochemistry of camels is widely investigated (Abo-Aziza *et al.*, 2017; Shehzad *et al.*, 2022).

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Heat stress significantly impacts camel blood profiles, with dromedary camels exhibiting specific adaptations to withstand high temperatures. These adaptations include

changes in serum metabolites and enzyme activities, allowing them to maintain homeostasis (Idoko *et al.*, 2024). Dromedary camels show higher levels of urea, glucose, total protein, albumin, phosphorus and calcium, indicating efficient protein and energy metabolism under heat stress (Badakhshan and Mirmahmoudi, 2016).

The impact of heat stress on immune status in cows revealed the upregulation of immune-related pathways in response to acute heat stress, indicating the influence of environmental stressors on blood profiles (Dahl *et al.*, 2020). Additionally, a study on changes in cell vitality, phenotype and function of dromedary camel leukocytes after whole blood exposure to heat stress *in vitro* reported a significant increase in apoptotic cells within granulocytes, lymphocytes and monocytes after exposure to heat stress, highlighting the impact of heat stress on camel blood profiles (Hussen, 2022).

Breed-specific differences in erythrocyte indices are documented. For instance, Bactrian camels at high altitudes show distinct morphometric and biochemical variations compared to lowland breeds, which may include differences in erythrocyte size and distribution (Lamo *et al.*, 2020). Similarly, studies on dromedary camels in different regions and management systems reveal variations in hematological parameters, suggesting that breed and environmental factors could influence erythrocyte characteristics (Faraz *et al.*, 2020a; Islam *et al.*, 2019). The detailed analysis assessment of camel hematological and biochemical parameters provides valuable insights into the physiological, health pathological and metabolic status of camels categorized by their ages and coat colors. The current study provides insights into the hematological, biochemical and antioxidant parameters of camels across breeds and ages during the summer intense heat. The data of the current study highlights the physiological adaptations of camels to their environments, particularly in terms of oxygen transport, immune response and hemostasis.

MATERIALS AND METHODS

Study area and sampling periods

Blood samples were collected from government-regulated slaughterhouses located in Riyadh, Buraydah, Unaizah and Al-Rass, major cities in central Saudi Arabia, during the summer months from June to September 2023. These areas lie between latitudes 24°N and 27°N, a geographic zone characterized by an arid desert climate, intense solar radiation and prolonged exposure to hot, dry winds. Average daytime temperatures during the collection period exceeded 42°C, with recorded peaks above 44°C and relative humidity remained low throughout. Such conditions induce thermal stress in livestock, affecting physiological parameters, including hematological indices such as red blood cell count and hemoglobin concentrations.

Animal selection and sample classification

Three hundred animals belonging to three distinct phenotypic groups: black, yellow and white, were stratified

by age into two equal categories: young male camels: 3–5 years and adults males: >5 years. All animals were apparently healthy based on pre-slaughter inspection. Blood collection was performed shortly post-slaughter to ensure the quality of hematological and biochemical parameters. Blood samples were divided into two portions. One portion was collected in lavender-top tubes containing EDTA as an anticoagulant to be used for CBC analysis. The second portion was collected in plain tubes without anticoagulants, allowed to clot at room temperature (20 minutes) and centrifuged at 3,000 rpm for 20 minutes to separate serum. The serum was used for biochemical antioxidant profiling assays.

Complete blood count

CBC analysis was performed using the VetScan HM5 v2.31 (Abaxis, Zoetis, USA), a veterinary hematology analyzer that operates using laser-based flow cytometry and colorimetric impedance. It provides 22 hematological parameters, including RBCs count, hemoglobin (Hb), hematocrit (HCT), WBC differentials (lymphocytes (LYM), monocytes (MON), neutrophils (NEU), eosinophils (EOS) and basophils (BAS)) and platelet (PLT) counts. The analyzer does not require daily calibration and is known for its rapid analysis and histogram-based output formats.

Biochemical parameters analysis

Serum biochemistry was assessed using the VetScan VS2 analyzer (Abaxis, Zoetis, USA). This system uses single-use rotors to evaluate up to 14 biochemical markers from a 100 µL serum sample. Total protein, albumin, globulin and liver enzymes (ALT, AST, ALP) as well as kidney function markers (BUN, creatinine) were determined. The device operates with minimal user input, providing accurate results in approximately 12 minutes and is commonly used in field and clinical settings due to its reliability.

Antioxidant activities analysis

Antioxidant enzymes activity was determined in serum of camels using colorimetric kits according to the manufacture instructions. The specific kits used were: Glutathione peroxidase assay (Biodiagnostic, Cat. no. 2518), superoxide dismutase assay (Biodiagnostic, Cat. no. 2523), catalase assay (Biodiagnostic, Cat. no. 2529) and malondialdehyde (MDA, Elabscience, Cat. no. E-BC-K028-M). Total antioxidant capacity (TAC, Elabscience, Cat. no. E-BC-K136-S). Iron assay colorimetric kit (Novus Biologicals, part of Bio-Techne Cat. no. # NBP3-25844) and iron binding capacity (IBC) colorimetric assay kit (Elabscience, Cat. no. E-BC-K071-S).

Ethical considerations

The study adhered to ethical animal research and biomedical sample collection guidelines, using blood samples from camels slaughtered in licensed abattoirs. No live animal experimentation or invasive procedures were performed.

Statistical analysis

Statistical analysis was performed using GraphPad Prism version 9.0 (Franklin Street, Fl. 26, Boston, MA, USA) and IBM SPSS Statistics version 26 (Chicago, IL, USA). Descriptive statistics, including means, standard errors (SE), were calculated for all hematological and biochemical parameters. The Shapiro–Wilk test was used to assess the normality of the data distribution. One-way ANOVA followed by Tukey's post hoc test for comparisons among three phenotypic groups (black, yellow, white) when normality was assumed. Significance was set at $p < 0.05$.

RESULTS AND DISCUSSION

Hemogram

As shown in Table 1, the impact of heat stress on the hemogram parameters of the examined camel groups was assessed. Although no significant differences were observed among the adult groups, a significant decrease ($P < 0.05$) in RBCs counts was noted in young yellow camels compared to their White counterparts. The RBCs counts were generally lower for young camels compared to adult camels which was significant only in camels with the yellow coat ($P < 0.05$). This observation is attributed to the developmental stage, where the hematopoietic system is still maturing. Studies have shown that young camels exhibit gradual increase in RBCs production as they approach adulthood (Monaco *et al.*, 2024). This increase is associated with the maturation of the hematopoietic system and the adaptation to environmental stressors such as aridity and physical activity (Faraz *et al.*, 2020b). White camels, often found in arid regions, the RBCs counts are slightly higher than those of other breeds, possibly due to their adaptation to harsh climatic conditions (Sahraoui *et al.*, 2016). Black camels typically exhibit RBCs counts comparable to that of white camels but may vary slightly based on geographic and dietary factors (Sahraoui *et al.*, 2016; Roba *et al.*, 2023). The observation that yellow camels have RBCs counts slightly lower than those of white and black camels, is potentially due to differences in genetic and environmental factors (Roba *et al.*, 2023). Physiological states can significantly influence RBCs counts, for instance, lactating camels often exhibit a decrease in RBCs count due to increased metabolic demands (Mohamed *et al.*, 2021). Studies in Algeria showed no significant differences in hematological parameters between different camel breeds, suggesting a level of consistency across breeds within the region (Aichouni *et al.*, 2010). Similarly, in Nigeria, the hematological values showed broad ranges but were not significantly influenced by sex or age (Waziri *et al.*, 2019). Camels in Bangladesh showed significant variations in hematological parameters based on body condition scores and age (Islam *et al.*, 2019). Heat stress leads to increased RBCs and HTC levels, which enhance oxygen transport capacity and support metabolic demands during high temperatures (El Khasmi *et al.*, 2013).

Table 1: Effects of heat stress on hemogram of three camel breeds with two age categories.

Breed Items	Yellow			Black			White		
	Young	Adults	P value	Young	Adults	P value	Young	Adults	P value
RBCs ($10^6/\text{mm}^3$)	5.593±1.872ab??	10.83±1.478a		9.311±1.798	11.61±0.155		11.64±0.185b	11.5±0.201	< 0.0001
HGB(g/dl)	9.187±1.738a	13.02±1.453		11.84±1.644	14.19±0.3898		14.48±0.4146a	14.19±0.3804	< 0.0001
HCT (%)	23.8±2.890	29.49±2.585		27.75±2.786a	31.32±0.8599a		31.87±0.9429	31.12±0.9318	0.0035
MCV (μm^3)	46.8±5.364ab	29.73±4.396a		33.25±5.276	27.16±0.50		27.55±0.4931b	27.3±0.4642	< 0.0001
MCH (pg)	11.26±0.4817	11.62±0.4509		11.56±0.4281	12.36±0.1910		12.5±0.2247	12.44±0.1999	0.0785
MCHC (g/dl)	30.87±3.864ab	42.26±2.938a		39.37±3.655	45.58±0.1228		45.6±0.1192b	45.68±0.1384	< 0.0001
RDW (%)	31.07±0.4318b	30.72±0.3705b		30.66±0.3925a	28.8±0.3054ab		28.42±0.3685b	28.78±0.2849b	0.0317
PLT ($10^6/\text{mm}^3$)	77.61±17.58ab	22.98±13.05a		36.07±16.89	10±0.02437		10.04±0.04904b	9.961±0.03839	< 0.0001
Iron (mg/dl)	438.15±4.31	436.36±3.89		435.19±3.44	433.52±2.22		434.87±5.46	433.19±4.11	< 0.3794
IBC (mg/L)	352.31±1.61	318.33±4.02		329.47±3.77	352.44±2.64		364.21±1.88	362.16±8.41	< 0.0627

Mean± standard error, RBCs: (Red blood cells), HGB (hemoglobin), MCV: (Mean corpuscular volume), MCH: (Mean corpuscular hemoglobin), MCHC: (Mean corpuscular hemoglobin concentration), RDW: (Red cell distribution width), PLT: (Platelet count), IBC: (Iron binding capacity). Within the same breed, values have the letter (a) are significant at $P < 0.05$. In the same age, values have the letter (b) are significant at $P < 0.05$. (P-values). Denotes the p-value for all camels regardless of age or color phenotype.

The normal ranges of hemoglobin levels (HGB) in camels vary based on breed and age, with black camels having the highest values. Young yellow camels have significantly reduced HGB levels compared to white breeds ($P<0.05$). Age plays a significant role, with adult camels showing higher HGB levels. The direct correlation between HGB levels and specific breed characteristics remains complex.

This study confirms previous research on Algerian camels showing no significant breed differences in blood constituents, including HGB concentrations (Aichouni *et al.*, 2010). However, a study in Iraq found significant effects of sex on HGB parameters but did not attribute these differences to breed characteristics (Alzubaidi *et al.*, 2019). Environmental and nutritional factors, such as trace element supplementation, also affect HGB levels. Young camels have lower levels (Faraz *et al.*, 2020b and Mohammed and Alshaibani, 2025).

HCT values, represent the volume percentage of red blood cells in blood. The Yellow breed shows a notable increase from young to adults. The Black and White breeds also show increases, though the differences are less marked. Young camels exhibited lower hematocrit values compared to adults, which correlates with their lower RBCs and HGB values. White camels, particularly adults have the highest HCT values, suggesting a superior ability to cope with dehydration and temperature extremes typical of their desert habitat. Our findings correspond to a previous study (Lamo *et al.*, 2020) which reported that the HCT values for Bactrian camels were found to be higher in younger age groups compared to adults. Limited data is available on HCT values for old camels. However, studies suggest that HCT values tend to decline with age, possibly due to reduced erythropoietic activity and increased oxidative stress (Lamo *et al.*, 2020). While breed-specific differences in HCT values are not as pronounced as age-related differences, some studies have reported variations. Bactrian camels generally have higher HCT values compared to dromedary camels (Lamo *et al.*, 2020; Islam *et al.*, 2019; Waziri *et al.*, 2019).

MCV, a hematological parameter, shows higher values in younger camels than adult ones, particularly in the yellow breed ($P<0.05$). This indicates age-related increases in red blood cells, likely to support higher metabolic demands (Hussein *et al.*, 2012). MCH values are consistent across different breeds and MCHC values generally increase with age ($P<0.05$), indicating enhanced oxygen-carrying capacity (Sajjad, 2011).

Leukogram

The effects of heat stress on leukogram were assessed (Table 2). WBC counts are critical indicators of immune status in camels, varying across breeds and physiological stages. The total WBC counts were significantly higher ($P<0.05$) in young white camels compared to black and yellow camels, suggesting a robust immune system. WBC counts in adult yellow camels were significantly reduced compared to their black and white counterparts ($P<0.05$).

Table 2: Effects of heat stress on leukogram of three camel breeds with two age categories.

Breed Items	Yellow		Black		White		P value
	Young	Adults	Young	Adults	Young	Adults	
WBC ($10^3/\text{mm}^3$)	10.29±1.226a	9.439±1.337b	10.49±1.301a	26.26±2.536b	24.66±2.289a	24.32±2.344b	0.0287
LYM ($10^3/\text{mm}^3$)	13.35±2.356b	11.51±2.68	12.85±2.442a	7.856±0.7297	7.699±0.76b	7.327±0.8205	0.0015
MON ($10^3/\text{mm}^3$)	0.8386±0.336	0.4886±0.1587	0.6714±0.278	0.8914±0.1778	0.6386±0.1525	0.9771±0.1743	0.2529
NEU ($10^3/\text{mm}^3$)	57.42±10.56	49.51±11.41b	56.38±10.31	85.31±1.013ab	86.18±0.9689	86.36±0.9081b	< 0.0001
EOS ($10^3/\text{mm}^3$)	8.24±3.03	8.39±4.08	9.96±2.65a	5.746±0.517a	5.421±0.5141	5.196±0.4274	< 0.001
BAS ($10^3/\text{mm}^3$)	0.1586±0.05405	0.1014±0.05886	0.1471±0.08646	0.1929±0.1056	0.0571±0.0309	0.1371±0.0812	<0.1147

Mean± standard error, WBC: (White blood cells), Lym: (Lymphocytes), Mon: (Monocytes), Neu: (Neutrophils), Eos: (Eosinophils), basophils: (Bas). Within the same breed, values have the letter (a) are significant at $P<0.05$. In the same age, values have the letter (b) are significant at $P<0.05$. (P-values). Denotes the p-value for all camels regardless of age or color phenotype.

Young camels often show higher WBC counts due to developing immune systems. This is crucial for withstanding infections, reflecting an age-related adaptation. However, adult camels maintain stable WBC levels, essential for balanced immune responses (Faye and Bengoumi, 2018). In the adult groups, LYM were significantly elevated ($P < 0.05$) in the yellow breed compared to the black and white breeds. The young white camels exhibited significantly reduced ($P < 0.05$) LYM counts compared to their black and white counterparts. This suggests breed-specific immune responses, potentially linked to environmental or genetic factors (Hussen *et al.*, 2022). The normal range of lymphocytes in camels is influenced by various factors (Mohamed *et al.*, 2021). In adult camels, LYM are the most abundant leukocytes (Waziri *et al.*, 2019), with variations observed across different breeds and environmental conditions (Sajjad, 2011). The data of the present study provided a comprehensive analysis of the normal ranges of LYM in different camel breeds, with a focus on comparisons between adult and young camels.

The study found no significant differences in MON prevalence among examined groups, similar to previous studies (Hussen *et al.*, 2022). Adult yellow camels had a significantly reduced NEU prevalence ($P < 0.05$), possibly due to a more stable immune system and reduced exposure to novel pathogens. Arid environments also showed lower NEU counts (Roba *et al.*, 2023).

Adult camels have higher EOS counts in the yellow breed, while young camels show reduced EOS in the white breed as reported previously (Hussen *et al.*, 2022). Factors like breed, age and physiological status influence EOS

levels. BAS prevalence is not significant but increases in response to allergic reactions (Jalali *et al.*, 2018). BAS counts stabilize as camels mature.

Protein parameters

As shown in Table 3, heat stress affects total protein (TP), albumin (ALB), globulin (GLOB) and albumin/globulin ratio in adult camels. Adult camels have higher TP levels and lower ALB levels compared to young camels ($P < 0.05$). Low ALB impairs hemoglobin synthesis, increasing anemia risks. This variation could be due to liver function, nutritional status, or hydration levels. The study found similar results in adult male dromedary camels in Libya and Sudan (Abudabos *et al.*, 2024), Bangladeshi Camels (Islam *et al.*, 2019) and Algerian Camels (Hamad *et al.*, 2018).

GLOB levels in adult camels varied significantly, with reduced levels in the yellow group and significantly lower in the white group ($P < 0.05$). GLOB levels are influenced by factors like breeds, age and environmental conditions (Abudabos *et al.*, 2024). Young camels have lower GLOB levels due to developing immune systems and nutritional differences (Faraz *et al.*, 2020b; Waziri *et al.*, 2019). The ALB/GLOB ratio was significantly reduced in young black camels, indicating poor liver function and nutritional status.

Liver/kidney function indicators

As shown in Table 4, heat stress affects the liver and kidney functions in camels. Enzymes like ALT, AST and ALP are crucial indicators of liver health. No significant variations were found in enzyme activities among groups. However, ALP levels were significantly lower in young camels

Table 3: Effects of heat stress on protein parameters of three camel breeds with two age categories.

Breed Items	Yellow		Black		White		P value
	Young	Adults	Young	Adults	Young	Adults	
ALB (g/L)	26.97±0.20a	26.84±3.80a	9.79±0.16ab	32.80±0.37a	21.04±0.24ab	32.79±0.44a	< 0.001
TP (g/L)	60.29±0.84b	64.30±5.93b	48.66±1.89ab	75.84±0.96ab	58.80±1.58a	77.87±0.68ab	< 0.001
GLOB (g/L)	33.31±0.99	37.46±2.17b	38.87±1.79	43.04±1.13	37.76±1.50ab	45.09±0.58a	< 0.001
ALB/GLOB	0.81±0.23ab	0.69±0.07a	0.25±0.01ab	0.76±0.03a	0.56±0.01b	0.73±0.01	< 0.001

Mean± standard error, ALB: (Albumin), TP: (Total protein), GLOB: (Globulin), ALB/GLOB: (Albumin/globulin ratio), Within the same breed, values have the letter (a) are significant at $P < 0.05$. In the same age, values have the letter (b) are significant at $P < 0.05$. (P-values) Denotes the p-value for all camels regardless of age or color phenotype.

Table 4: Effects of heat stress on liver/kidney function indicators in three different camel breeds with two age categories.

Breed Items	Yellow		Black		White		P value
	Young	Adults	Young	Adults	Young	Adults	
ALT(U/L)	14.14±1.24	17.71±1.55	15.92±1.72	13.91±1.81	10.21±1.22	13.93±2.40	0.5482
AST(U/L)	71.71±6.87	89.43±9.39	82.86±10.04	86.30±7.35	101.10±7.15	84.43±7.58	0.2550
ALP(U/L)	80.86±3.56	82.71±3.31	79.86±5.32	86.29±4.45	69.26±6.95	77.43±6.40	0.0604
AST/ALT	5.10±0.48	5.05±0.91	5.21±0.53	6.21±0.72	4.42±0.42	6.06±0.49	0.8737
BUN (mmol/L)	8.41±0.46	9.48±0.39	11.28±1.71	14.87±0.52	9.33±0.77	9.48±0.48	0.8689
BUN/CREA	4.97±0.87	4.64±0.71	4.05±0.48	3.42±0.57	3.94±0.31	3.38±0.27	0.3051

Mean± standard error, ALT: (Alanine transaminase), AST: (Aspartate aminotransferase), ALP: (Alkaline phosphatase), AST/ALT: (Aspartate aminotransferase/alanine transaminase ratio), BUN: (Blood urea nitrogen), BUN/CREA: (Blood urea nitrogen/creatinine ratio). (P-values). Denotes the p-value for all camels regardless of age or color phenotype.

Table 5: Effects of heat stress on oxidative stress biomarkers in three different camel breeds with two age categories.

Breed Items	Yellow		Black		White		P value
	Young	Adults	Young	Adults	Young	Adults	
SOD U/ml	217.16±11.34a	108.5±10.55	286.45±11.34ab	222.65±11.64	244.45±11.54	296.26±9.63ab	<0.0321
CAT U/L	232.17±10.22ab	211.12±5.87b	222.6±10.95a	174.0±10.53	185.35±9.06	193.87±10.55	<0.0121
TAC mM/l	1.922±0.2023ab	1.382±0.234	0.9682±0.1795	1.743±0.654ab	1.355±0.101a	1.0987±0.254	<0.0031
GSH-Px mU/L	33.34± 2.09	42.87±1.63ab	39.43±2.74	38.85±3.77	42.86±1.73ab	35.11±2.60	<0.0081
MDA(nmol/L)	24.12±3.86	24.74±4.54	27.41±5.11	26.34±3.81	22.34±1.32	29.43±1.02ab	<0.0241

Mean± standard error, SOD: (Superoxide dismutase), CAT: (Catalase), (TAC): Total Antioxidant Capacity, GSH-Px: (Glutathione peroxidase), MAD: (Malondialdehyde), Within the same breed, values have the letter (a) are significant at P<0.05. In the same age, values have the letter (b) are significant at P<0.05. (P-values). Denotes the p-value for all camels regardless of age or color phenotype.

compared to adult ones, regardless of coat color (P<0.05). Age-related liver function changes may slightly elevate ALT levels in older camels. Seasonal changes can also influence ALT levels. However, studies suggest that age-related changes in liver function may slightly elevate ALT levels in older camels, though these changes are not typically significant (Roba *et al.*, 2023). BUN levels and BUN/CREA ratio showed no significant differences among groups.

Oxidative stress biomarkers

The impact of heat stress on the oxidative status was examined (Table 5) through the measurements of oxidative stress biomarkers such as SOD, CAT, TAC, GSH-Px and MDA as previously recorded by Jain and Shakkarpude (2024). SOD activities were generally reduced in young yellow camels with differences being of statistical significance (P<0.05) when compared to young black camels. In the yellow breed, SOD activities were significantly lower (P<0.05) in adult camels compared to the young camels. In adult camels, SOD activities were generally reduced in the yellow breed, this observation was of statistical significance (P<0.05) when compared to the white breed. Mousa *et al.* (2006) reported no significant age-related change in SOD in camels, which disagrees with our finding of significant differences between young and adult groups within and between breeds. Our observations agree with the findings by Giergiel and Kankofer, (2015) on bovines, which reported higher SOD in younger animals, suggesting age-related decline may apply across species.

CAT activities were significantly lower (P<0.05) in young white camels compared to their yellow and black peers. Our data showed that CAT activities were significantly reduced (P<0.05) in adult black camels compared to their yellow and white counterparts. High CAT activities have been observed in camel organs (kidney, liver) reported by Chafik *et al.* (2023) and Al-Bar, (2012), which aligns with the idea that camels from arid environments (like yellow breed) may possess superior oxidative defenses. In young camels, TAC activity was significantly lower (P<0.05) in the black breed compared to other two breeds. No significant variations were observed among the adult camel groups regarding TAC activity. Studies in rats and horses Sugimoto

et al. (2023); Žak *et al.* (2020) have observed a decline in TAC with age. Breed-related differences are also supported by (Górecka *et al.*, 2002), who reported antioxidant variation among horse breeds-suggesting a similar trend may exist in camels.

GSH-Px activity was generally lower in young yellow camels compared their black and white peers with the differences being significant against the white breed (P<0.05). In the yellow breed, the GSH-Px activity was significantly higher (P<0.05) in the adult camels compared the young ones. This observation was reversed in the white breed. Séboussi *et al.* (2008, 2009, 2010) established a clear correlation between selenium status and GSH-Px activity. The age-based trend (adults > young) also aligns with (Mousa *et al.*, 2006) and Corbera *et al.* (2001), confirming that GSH-Px increases with age due to maturing antioxidant systems. In the white breed, MDA activity was significantly higher (P<0.05) in the adult camel compared to the young camels. Adult white camels had also significantly higher (P<0.05) MAD activity as compared to their yellow counterparts. This agrees with Salar-Amoli and Baghbanzadeh, (2010) and Kabakçi, (2022) who found that MDA increases with age, due to accumulated oxidative damage. Breed-related variation in MDA is also supported by Kirbas *et al.* (2014) in sheep, indicating that genetic and environmental differences among breeds can alter lipid peroxidation profiles.

CONCLUSION

Overall, the study highlights the complex interplay of breed and age on hematological and biochemical parameters in camels under heat stress, providing valuable insights into their physiological adaptations to harsh environmental conditions.. However, addressing the limitations and expanding research into genetic, molecular behind these variations and environmental interactions will be crucial for improving camel welfare and productivity in extreme climates. Further research could explore these mechanisms to enhance camel resilience in extreme climates.

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Disclaimers

The authors' views and conclusions in this study are solely their own and do not necessarily reflect the views of their affiliated institutions. They are responsible for the accuracy and completeness of the information provided, but they accept no liability for any direct or indirect harm resulting from the use of this content.

Conflict of interest

The authors of this work state that they have no conflicts of interest related to its publication. There was no impact from funding or support on the study's design, data collection, analysis, manuscript preparation, or publication decision.

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