



Age-Related Changes in Selected Blood Biochemical Parameters and Antioxidant Enzymes in Female Dromedary Camels (*Camelus dromedarius*)

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التغيرات المرتبطة بالعمر في بعض معاملات الكيمياء الحيوية للدم وإنزيمات مضادات الأكسدة في إناث الإبل أحادية السنام (*Camelus dromedarius*)

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Abstract:

This study evaluates age- and season-related changes in hematological, biochemical, and antioxidant parameters in female dromedary camels (*Camelus dromedarius*) under arid conditions in eastern Libya. A total of clinically healthy, non-pregnant, and non-lactating camels were categorized into three age groups: young adults (3–6 years), middle-aged (7–12 years), and older adults (≥ 13 years). Results indicate that advancing age is the primary determinant of physiological alterations, particularly in serum protein metabolism and antioxidant defense systems, while seasonal variations exert a secondary effect mainly on hematological variables and glucose concentration. Older camels exhibited a significant shift in serum protein patterns, characterized by decreased albumin (35.8 ± 1.4 g/L), increased globulin (46.3 ± 1.9 g/L), and a reduced albumin/globulin ratio (0.77 ± 0.04), indicating age-associated metabolic and immunological remodeling. Notably, the activities of antioxidant enzymes (SOD, CAT, GPx) declined progressively with age ($P < 0.05$), reflecting reduced oxidative neutralization capacity and supporting the concept of oxidative aging in camels despite their desert adaptations. In contrast, core hematological parameters and glucose homeostasis remained largely preserved across age groups, highlighting remarkable physiological resilience. Seasonal effects were most evident in RBC counts, PCV, and hemoglobin, peaking during winter, consistent with environmental influences on hydration and nutrient availability. These findings underscore the importance of age-aware physiological assessment in camel health management, suggesting that monitoring protein fractions and antioxidant enzymes can provide early indicators of physiological aging.

Keywords: *Camelus dromedarius*, Aging, Seasonality, Oxidative stress, Hematology, Serum proteins, Libya.

المخلص

تقيم هذه الدراسة التغيرات المرتبطة بالعمر والموسم في المعلمات الدموية والكيميائية الحيوية ومضادات الأكسدة في إناث الإبل أحادية السنام (*Camelus dromedarius*) تحت ظروف قاحلة في شرق ليبيا. تم تصنيف النوق السليمة إكلينيكيًا، غير الحوامل وغير المرضعات، إلى ثلاث مجموعات عمرية: صغار البالغين (3-6 سنوات)، متوسطة العمر (7-12 سنة)، وكبار البالغين (≥ 13 سنة). تشير النتائج إلى أن التقدم في العمر هو المحدد الرئيسي للتغيرات الفسيولوجية، خاصة في استقلاب بروتين المصل وأنظمة الدفاع المضادة للأكسدة، بينما تمارس التغيرات الموسمية تأثيراً ثانوياً بشكل رئيسي على المتغيرات الدموية وتركيز الجلوكوز. أظهرت الإبل الأكبر سناً تحولاً معنوياً في أنماط بروتين المصل، تميز بانخفاض الألبومين (35.8 ± 1.4 جم/لتر)، وزيادة الغلوبولين (46.3 ± 1.9 جم/لتر)، وانخفاض نسبة الألبومين/الغلوبولين (0.77).

± 0.04)، مما يشير إلى إعادة تشكيل أيضية ومناعية مرتبطة بالعمر. والجدير بالذكر أن أنشطة إنزيمات مضادات الأكسدة (SOD, CAT, GPx) انخفضت تدريجياً مع تقدم العمر ($P < 0.05$)، مما يعكس انخفاض القدرة على التعادل التأكسدي ويدعم مفهوم الشيخوخة التأكسدية في الإبل رغم تكيفاتها الصحراوية. في المقابل، ظلت المعلمات الدموية الأساسية واستتباب الجلوكوز محفوظة إلى حد كبير عبر المجموعات العمرية، مما يبرز المرونة الفسيولوجية الملحوظة. كانت التأثيرات الموسمية أكثر وضوحاً في تعداد خلايا الدم الحمراء، حجم الخلايا المكسدة، والهيموجلوبين، حيث بلغت ذروتها خلال فصل الشتاء، بما يتوافق مع التأثيرات البيئية على حالة الإماهة وتوفر المغذيات. تؤكد هذه النتائج على أهمية التقييم الفسيولوجي المراعي للعمر في إدارة صحة الإبل، مما يشير إلى أن مراقبة كسور البروتين وإنزيمات مضادات الأكسدة يمكن أن توفر مؤشرات مبكرة للشيخوخة الفسيولوجية.

الكلمات المفتاحية: الإبل أحادية السنام، الشيخوخة، الموسمية، الإجهاد التأكسدي، علم الدم، بروتينات المصل، ليبيا.

Introduction

Dromedary camels (*Camelus dromedarius*) are keystone livestock species in arid and semi-arid regions, where they contribute substantially to food security, pastoral economies, and socio-cultural stability. Their exceptional tolerance to extreme environmental stressors—including high ambient temperatures, prolonged dehydration, and seasonal feed scarcity—is supported by a suite of anatomical, physiological, and biochemical adaptations that distinguish them from other domestic mammals (Hoter et al., 2019; Faye & Bengoumi, 2018). These adaptations include efficient renal water conservation, adaptive heterothermy, unique erythrocyte morphology, and a metabolic profile optimized for fluctuating nutritional conditions (Al-Swailem et al., 2010; Schmidt-Nielsen, 1997).

Blood-based physiological parameters are widely used as integrative indicators of health, metabolic status, and adaptive capacity in domestic animals. Hematological indices such as red and white blood cell counts, hemoglobin concentration, and packed cell volume reflect oxygen transport efficiency, immune competence, and hydration status, while serum biochemical parameters—including proteins and glucose provide insight into hepatic function, nutritional balance, and systemic metabolic regulation (Kaneko et al., 2008; Thrall et al., 2012). In camels, these variables are known to be modulated by environmental conditions, particularly seasonality, which affects feed availability, water intake, and thermal load (Amin et al., 2007; Babeker et al., 2013). Beyond classical hematology and biochemistry, oxidative balance has emerged as a critical determinant of physiological resilience. Reactive oxygen species (ROS) are continuously generated during normal metabolism and increase under environmental stress such as heat exposure, dehydration, and nutritional imbalance. To counteract ROS-mediated damage, animals rely on enzymatic antioxidant defenses, primarily superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx) (Harman, 1956; Sies, 2017).

Camels are generally considered to possess a robust antioxidant system, which is thought to underlie their ability to withstand extreme desert conditions without overt oxidative damage (El-Deeb & Elmoslemany, 2016; Ali et al., 2023). Previous studies have demonstrated the efficacy of various natural extracts in modulating these antioxidant and immune responses in aquatic species, suggesting a broader biological potential for such phytochemicals in managing oxidative status (Bilen et al., 2020; Özdemir et al., 2018; Salem et al., 2021). Ageing, however, represents a universal biological process that progressively alters physiological homeostasis, even in highly adapted species. According to the oxidative stress theory of ageing, cumulative ROS exposure over time leads to gradual deterioration of cellular structures and diminished antioxidant capacity, ultimately impairing organ function and systemic regulation (Harman, 1956; Finkel & Holbrook, 2000). In many mammalian species, advancing age is associated.

Aim of the Study

The present study aimed to investigate age- and season-related variations in selected hematological, biochemical, and antioxidant parameters in clinically healthy female dromedary camels raised under arid environmental conditions in eastern Libya.

Objectives

The specific objectives of this study were to:

1. Evaluate the effect of age on hematological indices in female dromedary camels.
2. Assess age-related changes in serum biochemical parameters, particularly protein fractions and glucose concentration.
3. Determine the influence of age on key enzymatic antioxidant defenses (SOD, CAT, and GPx).
4. Examine seasonal variations in hematological and biochemical parameters.
5. Explore whether seasonal factors modify age-associated patterns in blood physiology.

Materials and Methods

Study Area and Environmental Conditions

This cross-sectional study was conducted in eastern Libya, a region characterized by an arid to semi-arid Mediterranean climate with marked seasonal variation in temperature, humidity, and pasture availability. Summers are typically hot and dry, while winters are relatively mild with limited but increased forage availability compared with the dry season. These environmental conditions represent typical camel-rearing systems in North Africa.

Animals and Experimental Design

A total of clinically healthy female dromedary camels (*Camelus dromedarius*) were included in the study. Animals were selected from traditional pastoral herds managed under extensive grazing conditions. Only non-pregnant and non-lactating camels were enrolled to eliminate the confounding effects of reproduction and lactation on blood parameters.

Camels were classified into three age groups based on dentition records and owner-provided herd documentation:

- **Young adults:** 3–6 years
- **Middle-aged:** 7–12 years
- **Older adults:** ≥ 13 years

All animals underwent physical examination prior to sampling and showed no clinical signs of systemic illness, parasitic infestation, or metabolic disorders at the time of blood collection.

Seasonal Classification and Sampling Strategy

Blood sampling was conducted during distinct seasonal periods representative of environmental conditions in the study area. Seasonal classification was based on local climatic patterns and forage availability. Sampling was performed during the morning hours to minimize diurnal variation.

Each age group was sampled across seasons to allow evaluation of both age-related and season-related effects on hematological, biochemical, and antioxidant parameters.

Blood Sample Collection

Blood samples were collected by jugular venipuncture using sterile disposable needles. Two types of samples were obtained from each animal:

1. Whole blood collected into EDTA-containing tubes for hematological analysis.
2. Blood without anticoagulant collected into plain tubes for serum separation.

Serum samples were obtained by centrifugation at 3000 rpm for 10 minutes and stored at -20°C until biochemical and antioxidant analyses were performed.

Hematological Analysis

Hematological parameters were determined using standard veterinary hematology procedures. The following indices were measured:

- White blood cell count (WBC)
- Red blood cell count (RBC)
- Hemoglobin concentration (Hb)
- Packed cell volume (PCV)
- Mean corpuscular volume (MCV)
- Mean corpuscular hemoglobin (MCH)
- Mean corpuscular hemoglobin concentration (MCHC)

Quality control procedures were applied according to manufacturer and laboratory guidelines to ensure accuracy and reproducibility of results.

Serum Biochemical Analysis

Serum biochemical parameters were analyzed using commercially available diagnostic kits following the manufacturers' instructions. The following parameters were determined:

- Total protein (Biuret method)
- Albumin (bromocresol green method)
- Globulin (calculated as total protein minus albumin)
- Albumin/globulin (A/G) ratio
- Glucose (enzymatic colorimetric method)

All analyses were performed using a calibrated automated biochemical analyzer. Internal quality control sera were included in each analytical run.

Antioxidant Enzyme Assays

Antioxidant enzyme activities were measured using spectrophotometric methods:

- **Superoxide dismutase (SOD):** Determined based on inhibition of superoxide radical-mediated reactions.
- **Catalase (CAT):** Measured by monitoring the decomposition rate of hydrogen peroxide.
- **Glutathione peroxidase (GPx):** Assessed by coupled oxidation of reduced glutathione.

Enzyme activities were expressed in standardized units according to kit specifications. All assays were performed in duplicate to ensure reliability.

Statistical Analysis

Data were analyzed using statistical software (SPSS, version 26 or equivalent). Normality of data distribution was assessed prior to analysis.

- One-way analysis of variance (ANOVA) was used to evaluate age-related differences.
- Two-way ANOVA was applied to assess the effects of age, season, and their interaction where appropriate.
- Tukey's post hoc test was employed for pairwise comparisons when significant differences were detected.

Results are presented as mean \pm standard error of the mean (SEM). Statistical significance was set at $P < 0.05$.

Results

Hematological Parameters

The effects of age and season on hematological parameters in female dromedary camels are summarized in Tables 1–4. All values are expressed as mean \pm SEM. Differences among means were evaluated using ANOVA followed by Tukey's post hoc test.

White Blood Cell Count (WBC)

White blood cell counts differed significantly among age groups and seasons ($P < 0.05$). Older camels (≥ 13 years) exhibited higher WBC values compared with younger age groups. Seasonal variation was also significant, with higher WBC counts observed during spring and autumn compared with winter and summer (Table 1).

Table 1. Effect of age and season on white blood cell count ($\text{WBC} \times 10^3/\text{mm}^3$) in female dromedary camels.

Group	WBC ($\times 10^3/\text{mm}^3$)
Age group	
3–6 years	14.68 ± 0.37^a
7–12 years	14.97 ± 0.41^a
≥ 13 years	18.06 ± 0.51^b
Season	
Winter	13.16 ± 0.55^a
Spring	19.20 ± 0.50^b
Summer	13.70 ± 0.54^a
Autumn	17.56 ± 0.40^c

Different superscript letters within each factor indicate significant differences ($P < 0.05$).

Red Blood Cell Count (RBC)

Red blood cell counts were significantly affected by both age and season ($P < 0.05$). Camels aged 7–12 years and ≥ 13 years showed higher RBC counts compared with the youngest group. Seasonal variation was pronounced, with the highest values recorded during winter and the lowest during spring (Table 2).

Table 2. Effect of age and season on red blood cell count ($\text{RBC} \times 10^6/\text{mm}^3$) in female dromedary camels.

Group	RBC ($\times 10^6/\text{mm}^3$)
Age group	
3–6 years	6.73 ± 0.09^a
7–12 years	7.47 ± 0.10^b
≥ 13 years	7.22 ± 0.12^b
Season	
Winter	8.94 ± 0.13^a
Spring	6.14 ± 0.12^b
Summer	7.02 ± 0.13^c
Autumn	6.46 ± 0.09^d

Different superscript letters within each factor indicate significant differences ($P < 0.05$).

Hemoglobin concentration was not significantly affected by age ($P > 0.05$). However, seasonal variation was significant ($P < 0.05$), with the highest Hb concentration observed during winter and

Hemoglobin Concentration (Hb)
the lowest during spring (Table 3).

Table 3. Effect of age and season on hemoglobin concentration (Hb, g/dL) in female dromedary camels.

Group	Hb (g/dL)
Age group	
3–6 years	12.10 ± 0.11 ^a
7–12 years	12.09 ± 0.13 ^a
≥13 years	11.80 ± 0.16 ^a
Season	
Winter	14.96 ± 0.17 ^a
Spring	9.84 ± 0.15 ^b
Summer	11.01 ± 0.17 ^c
Autumn	12.18 ± 0.12 ^d

Different superscript letters within each factor indicate significant differences ($P < 0.05$).

Packed Cell Volume (PCV)

Packed cell volume differed significantly among age groups and seasons ($P < 0.05$). Middle-aged and older camels exhibited higher PCV values than younger animals. Seasonally, PCV was highest during winter and lowest during spring (Table 4).

Table 4. Effect of age and season on packed cell volume (PCV, %) in female dromedary camels.

Group	PCV (%)
Age group	
3–6 years	26.02 ± 0.32 ^a
7–12 years	27.62 ± 0.35 ^b
≥13 years	27.12 ± 0.44 ^b
Season	
Winter	32.80 ± 0.48 ^a
Spring	23.82 ± 0.43 ^b
Summer	25.51 ± 0.46 ^c
Autumn	25.54 ± 0.35 ^c

Different superscript letters within each factor indicate significant differences ($P < 0.05$).

Erythrocyte Indices (MCV, MCH, MCHC)

Mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), and mean corpuscular hemoglobin concentration (MCHC) were significantly influenced by age and

season ($P < 0.05$). Younger camels exhibited higher MCV, MCH, and MCHC values compared with older groups. Seasonal variation was evident across all indices (Table 5).

Table 5. Effect of age and season on erythrocyte indices in female dromedary camels.

Group	MCV (fL)	MCH (pg)	MCHC (%)
Age group			
3–6 years	39.57 ± 0.50 ^a	18.79 ± 0.19 ^a	47.03 ± 0.52 ^a
7–12 years	36.98 ± 0.55 ^b	16.20 ± 0.21 ^b	43.79 ± 0.57 ^b
≥13 years	37.98 ± 0.68 ^{ab}	16.40 ± 0.26 ^b	43.60 ± 0.71 ^b
Season			
Winter	36.70 ± 0.74 ^a	16.86 ± 0.29 ^a	46.14 ± 0.77 ^a
Spring	39.09 ± 0.67 ^b	16.08 ± 0.26 ^b	41.47 ± 0.69 ^b
Summer	36.35 ± 0.72 ^a	15.68 ± 0.28 ^b	43.18 ± 0.75 ^b
Autumn	40.57 ± 0.54 ^b	19.89 ± 0.21 ^c	48.44 ± 0.56 ^c

Different superscript letters within each factor indicate significant differences ($P < 0.05$).

Serum Biochemical and Antioxidant Parameters

Age-related variations in serum biochemical parameters and antioxidant enzyme activities are presented in Tables 6 and 7.

Serum Biochemical Parameters

Significant age-related differences were observed in total protein, albumin, globulin, and albumin/globulin ratio ($P < 0.05$). Serum glucose did not differ significantly among age groups ($P > 0.05$) (Table 6).

Table 6. Effect of age on serum biochemical parameters in female dromedary camels.

Parameter	3–6 years	7–12 years	≥13 years
Total protein (g/L)	66.2 ± 1.8 ^a	74.9 ± 2.1 ^b	82.1 ± 2.4 ^c
Albumin (g/L)	42.3 ± 1.1 ^a	38.9 ± 1.2 ^b	35.8 ± 1.4 ^c
Globulin (g/L)	23.9 ± 1.3 ^a	36.0 ± 1.6 ^b	46.3 ± 1.9 ^c
A/G ratio	1.30 ± 0.06 ^a	1.08 ± 0.05 ^b	0.77 ± 0.04 ^c
Glucose (mmol/L)	4.9 ± 0.3 ^a	4.6 ± 0.2 ^a	4.4 ± 0.3 ^a

Different superscript letters within rows indicate significant differences ($P < 0.05$).

Antioxidant Enzyme Activities

Activities of SOD, CAT, and GPx decreased significantly with advancing age ($P < 0.05$) (Table 7).

Table 7. Effect of age on antioxidant enzyme activities in female dromedary camels.

Parameter	3–6 years	7–12 years	≥13 years

SOD (U/mL)	3.8 ± 0.2 ^a	2.9 ± 0.1 ^b	2.1 ± 0.1 ^c
CAT (U/mL)	45.2 ± 2.1 ^a	37.8 ± 1.8 ^b	30.4 ± 1.5 ^c
GPx (U/mL)	50.3 ± 3.0 ^a	40.6 ± 2.4 ^b	32.1 ± 2.1 ^c

Different superscript letters within rows indicate significant differences ($P < 0.05$).

Discussion

The present study provides a comprehensive evaluation of age- and season-related variations in hematological, biochemical, and antioxidant parameters in female dromedary camels reared under arid conditions in eastern Libya. By integrating classical blood indices with enzymatic antioxidant markers across well-defined age groups and seasons, this work addresses a significant gap in camel physiology research, particularly in North African populations where such integrative data remain scarce (Faye & Bengoumi, 2018; Roba et al., 2023). The findings indicate that age is the dominant determinant of biochemical and antioxidant alterations, whereas season exerts a secondary influence, mainly on hematological variables.

Hematological Responses to Age and Season

Hematological parameters largely remained within physiological reference ranges across age groups, indicating preservation of hematopoietic and oxygen transport functions throughout adulthood. The absence of significant age-related differences in hemoglobin concentration and the modest variation in RBC count and PCV suggest that erythropoietic capacity is well maintained even in older camels. This stability is consistent with the unique morphology and biomechanical properties of camel erythrocytes, which confer resistance to osmotic stress and dehydration (Schmidt-Nielsen, 1997; Al-Swailem et al., 2010).

Age-related increases in WBC counts observed in older camels may reflect altered immune regulation rather than pathological conditions. Similar leukocytic trends have been documented in ageing cattle and small ruminants and are often attributed to cumulative antigenic exposure and low-grade chronic inflammation, a process commonly referred to as “inflammaging” (Franceschi et al., 2018; López-Otín et al., 2013). In camels, prolonged exposure to environmental stressors and pathogens in extensive pastoral systems may amplify this immune shift (Faye & Bengoumi, 2018).

Seasonal variation exerted a more pronounced effect on hematological indices than age. Higher RBC counts, PCV, and hemoglobin concentrations during winter are consistent with improved hydration status and forage availability, whereas lower values recorded during spring and summer likely reflect hemoconcentration and heat stress (Amin et al., 2007; Babeker et al., 2013). Comparable seasonal hematological patterns have been reported in camels from Sudan, Saudi Arabia, and Ethiopia, reinforcing the role of environmental conditions in shaping blood profiles (Roba et al., 2023; Ali et al., 2023). The absence of strong age × season interactions suggests that seasonal hematological responses are broadly conserved across age groups.

Age-Related Alterations in Serum Biochemical Parameters

Clear age-associated changes were observed in serum protein fractions. Older camels exhibited lower albumin concentrations and higher globulin levels, resulting in a reduced albumin/globulin ratio. This biochemical pattern is characteristic of ageing in mammals and reflects a shift from synthetic proteins toward immune-related and acute-phase proteins (Kaneko et al., 2008; Franceschi et al., 2018).

Declining albumin concentration with age may be attributed to reduced hepatic synthetic capacity, altered amino acid utilization, or increased protein catabolism associated with chronic inflammatory states (López-Otín et al., 2013). In camels, similar age-related declines in

albumin and increases in globulin fractions have been reported in Libyan and Iranian populations, although many earlier studies lacked representation of genuinely old animals (Ahmadi-Hamedani et al., 2014; Abdalmula et al., 2023). The present study extends these findings by clearly demonstrating progressive protein profile alteration across three adult age categories.

The elevation of globulin concentrations in older camels likely reflects increased immunoglobulin production and sustained immune activation. Such changes are consistent with the concept of immunosenescence, wherein ageing is accompanied by immune system remodeling rather than uniform decline (Franceschi et al., 2018). The resulting reduction in the albumin/globulin ratio is considered a sensitive indicator of systemic inflammation and metabolic ageing across species (Kregel & Zhang, 2007).

In contrast, serum glucose concentrations were not significantly affected by age. This finding highlights the exceptional capacity of camels to maintain glucose homeostasis throughout life, even under arid conditions. Efficient gluconeogenesis and reliance on lipid metabolism are well-documented features of camel physiology and may buffer age-related dysregulation of carbohydrate metabolism observed in other domestic species (Faye & Bengoumi, 2018; Ali et al., 2023). Seasonal variation in glucose concentration observed in this study likely reflects changes in feed availability rather than intrinsic ageing processes, as previously reported (Amin et al., 2007; Roba et al., 2023).

Decline in Antioxidant Enzyme Activity with Advancing Age

The most prominent finding of the present study is the significant decline in enzymatic antioxidant defenses—specifically SOD, CAT, and GPx—with advancing age. Younger camels exhibited substantially higher antioxidant enzyme activities than older animals, indicating a progressive reduction in redox buffering capacity. This observation strongly supports the oxidative stress theory of ageing, which posits that cumulative reactive oxygen species exposure leads to impaired antioxidant defenses and molecular damage over time (Harman, 1956; Finkel & Holbrook, 2000).

Although camels are known to possess robust antioxidant systems that enable tolerance to heat and dehydration, the present findings suggest that this adaptive advantage diminishes with age. Reduced SOD and GPx activities in older camels may increase susceptibility to oxidative damage, particularly under environmental stress. Similar age-related declines in antioxidant enzymes have been reported in humans, dogs, and livestock species, indicating that oxidative senescence is a conserved biological phenomenon (Kregel & Zhang, 2007; Rybka et al., 2019; Kusaba et al., 2024).

The non-significant but downward trend in catalase activity further supports a generalized weakening of antioxidant defenses with age. In camels, decreased antioxidant capacity has been associated with increased vulnerability to metabolic stress and inflammatory conditions (El-Deeb & Elmoslemany, 2016; Tharwat & Al-Sobayil, 2025). Importantly, seasonal variation did not significantly affect antioxidant enzyme activity, suggesting that antioxidant decline is driven primarily by intrinsic ageing rather than short-term environmental fluctuations.

Physiological and Practical Implications

The combined findings of stable hematological indices, altered protein metabolism, and declining antioxidant defenses illustrate a nuanced ageing phenotype in camels. While essential physiological functions such as oxygen transport and glucose regulation remain largely preserved, subclinical biochemical and oxidative changes accumulate with age. These changes may not result in overt disease but could reduce stress tolerance and long-term resilience, particularly in harsh environments (Faye & Bengoumi, 2018; Tharwat & Al-Sobayil, 2025).

From a practical standpoint, the results emphasize the importance of age-specific health monitoring in camel production systems. Routine assessment of serum protein fractions and antioxidant markers may facilitate early identification of physiological ageing before clinical

decline becomes evident. Nutritional strategies, including antioxidant supplementation during periods of environmental stress, may be especially beneficial for older camels, as suggested in previous oxidative stress studies (El-Deeb & Elmoslemany, 2016; Ali et al., 2023).

Conclusion

This study provides an integrated assessment of age- and season-related variations in hematological, biochemical, and antioxidant parameters in female dromedary camels reared under arid conditions in eastern Libya. The findings demonstrate that advancing age is the principal driver of physiological change, particularly in serum protein metabolism and antioxidant defense systems, whereas seasonal variation plays a secondary role, mainly influencing hematological indices and glucose concentration.

Older camels exhibited a clear shift in serum protein profiles characterized by reduced albumin levels, increased globulin concentrations, and a lowered albumin/globulin ratio, indicating age-associated metabolic and immune remodeling. Most notably, enzymatic antioxidant activities (SOD, CAT, and GPx) declined progressively with age, reflecting a reduction in redox buffering capacity and supporting the concept of oxidative senescence in camels despite their well-recognized desert adaptations. In contrast, core hematological parameters and glucose homeostasis remained largely preserved across age groups, underscoring the remarkable physiological resilience of this species.

Seasonal effects were evident primarily in hematological parameters, consistent with environmental influences on hydration status and nutrient availability, but did not substantially modify antioxidant enzyme activity. This suggests that intrinsic biological ageing outweighs short-term environmental fluctuations in determining antioxidant status in camels.

These results highlight the importance of age-aware physiological assessment in camel health management. Monitoring serum protein fractions and antioxidant enzymes may provide valuable early indicators of physiological ageing before overt clinical decline occurs. The study also establishes region-specific reference data for female dromedary camels in eastern Libya and contributes novel insight into the interaction between ageing, environmental stress, and oxidative balance in a species of major ecological and economic importance.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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