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Age and seasonal-associated changes in the blood profiles of Kalahari Red and Kalawad goat bucks in the tropical climate

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Abstract
Background and Objective: Goat breeds possess unique adaptive traits shaped by their environments. Under tropical conditions, climate variability imposes stress that alters hematological and biochemical responses, potentially compromising animal health and reproductive efficiency. This study assessed the effects of age and seasonal variation on hematological and serum biochemical indices in Kalahari Red (KR) bucks and their crossbreds (Kalawad, KW) under semi-intensive tropical management.

Methodology: A total of 42 bucks (KR = 21; KW = 21) were assigned to three age groups (1< age ≤2, 2< age ≤3, and 3< age ≤4 years) and evaluated across four seasons (early/late rainy and early/late dry) in a 2 × 3 × 4 factorial design. Animals were managed under uniform nutritional conditions for one year. Monthly blood samples were collected to analyze erythrocytic, leukocytic, and serum biochemical parameters. Data were analyzed using three-way ANOVA.

Main Results: Age significantly influenced all hematological and biochemical indices ($P < 0.05$) except glucose, triglyceride, and creatinine. Breed had significant effects only on red blood cell, mean corpuscular volume, mean corpuscular hemoglobin concentration, and globulin. Seasonal effects were evident in all red blood cell differentials, lymphocyte, and eosinophil counts, while white blood cell and other differentials remained unaffected. Age and season also significantly influenced serum protein fractions and cholesterol levels, with the highest cholesterol means observed during the early rainy season at age >3 to ≤4 years. Triglyceride remained largely unaffected.

Conclusions: Age, breed, and season exert significant but variable influences on blood parameters in KR and KW bucks under tropical conditions. These findings highlight the importance of physiological monitoring for managing health and reproductive performance and provide reference values for selection and clinical assessments in heat-stressed environments.

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INTRODUCTION

Goats are resistant to heat stress and may survive in harsh conditions because of changes in their biological activities brought on by the stress, including physiological, hormonal, hematological, and biochemical changes (Bernabucci *et al*., 2010). Animals in the tropics are subjected to unfavorable climatic variations, such as inconsistent in temperature, relative humidity, and solar radiation that pose both direct and indirect effects on animals, consequent upon climate change (Sejian *et al*., 2012). In order to successfully cope with the discomfort caused by these stressful environmental cues, which could alter the functions of cells, tissues, and organs; the animals frequently developed a variety of coping mechanisms, such as genetic or biological adaptation, phenotypic or physiological adaptation, acclimatization, acclimation, and habituation (Olafadehan, 2011; Gaughan, 2012; Chaidanya *et al*., 2015). This consequently leads to increase organs functions and promotes the survival of the fittest among and between the breeds of animals. Therefore, a number of factors can influence an animal's reaction to stress, including the length and severity of the stress, the animal's prior exposure to the stressors, its physiological state, and the current environmental restrictions (Etim *et al*., 2014). For the animals to be able to retain sound health or reproduce effectively again, they need to maintain homeostasis and adapt to the current climate. The efficiency of health status and productiveness of an animal could be compromised as a result of these evolved adaptive mechanisms.

According to Amakiri *et al*. (2012), it is exceedingly challenging to evaluate an animal's current state of health without carefully examining its blood. Hemato-biochemical indices, blood electrolytes, and production performances in livestock are significantly impacted by both genetic and non-genetic factors, both directly and indirectly (Onasanya *et al*., 2015). According to Saki *et al*. (2018), hemato-biochemical indices show how responsive an animal is to both its internal and external environments. Nonetheless, cross-examining blood profiles offers the chance to clinically explore the existence of multiple body metabolites and other components; helpful for diagnosing a range of disorders or diseases in livestock

(Etim *et al*., 2014). When combined with medical history and physical examination, blood indices offer a solid foundation for disease diagnosis (Tibbo *et al*., 2004).

Season, age, sex, time of day, physiological stage, movement, hydration, feed intake, and digestion are some of the factors that generally affect the physiological variables in animals (Ribeiro *et al*., 2016; 2018; Leite *et al*., 2018). The blood system is a key indicator of physiological reactions to stimuli and is sensitive to temperature fluctuations. The pattern of hematological values can be influenced by a number of variables, including species, breed, sex, age, nutrition, illnesses, physiological stage of development, and seasonal fluctuations (Piccione *et al*., 2010; Bhat *et al*., 2011; Al-Eissa *et al*., 2012). Temperature differences have a direct impact on animals, altering their physiological processes and functions (Ribeiro *et al*., 2015); heat stress is linked to changes in blood cell morphology and quantity (Ribeiro *et al*., 2018). Due to the human activities like deforestation, industrialization, environmental harms (pollutions), etc.; that lead to severe climate changes, livestock particularly goats are usually more vulnerable to physiological, immunological, hemato-biochemical, morphological, and anatomical damages. In addition, the knowledge of biochemical blood variables is required to describe the biochemical profile, energy metabolism, metabolism disorders, liver function, and bone abnormalities as well as assessing the degree of animal adaptation to climatic adversities (Swenson and Reece, 2006). The Kalhari Red goat is an indigenous goat breed originating from Southern Africa. The name is derived from their red coat and the Kalahari Desert in South Africa with average temperature of 27°C and 18°C in summer and winter respectively, but the extreme temperature ranges from 3°C in winter to 36°C in the height of summer. Its desirable traits are that it is very adaptable to arid and semi-arid savannah; they have very good foraging abilities and are reputed to have excellent mothering abilities (Kotze *et al*., 2004; Coleman, 2019). Kalawad refers to the offspring resulting from the crossing of Kalahari Red goat buck and West African Dwarf doe. The name was invented by the KRG research team in the Institute of Food Security, Environmental Resources and Agricultural Research of the Federal University of Agriculture, Abeokuta, Ogun state, Nigeria in year 2013 with average temperature range of 25.71–30.05°C depending on the season which is classified as early rainy, late rainy, early dry and late dry (Odeyemi *et al*., 2024). They are strong, trypano-tolerant with very good mothering ability and possess medium body size when compared with Kalahari Red goat and West African Dwarf goats with mature live weight of 45–60 and 40–50 kg for male and female respectively. Therefore, research into the blood profiles to establish the health status of exotic breed - Kalahari Red (KR) and crossbred - Kalawad (KW) bucks in tropical environments is necessary. In other words, a comprehensive review is required to determine the degree to which age could affect goats of the same or distinct breeds under the same nutritional regime (KR and KW) at the same or different physiological, environmental or seasonal conditions/variations.

MATERIALS AND METHODS

Experimental Sites

The research was conducted at the Kalahari Red Goat Unit of the Institute of Food Security, Environmental Resources and Agricultural Research; and Department of Animal Physiology Laboratory both at Federal University of Agriculture, Abeokuta (FUNAAB). The location is 76 m above sea level and lies within the following latitude and longitude coordinates: 7° 13’ 49’’ N and 3° 26’ 12’’ E (Google Earth, 2023). The region has a humid climate and is part of the forest zone of South Western Nigeria. The rainfall pattern in Abeokuta is bimodal, with a typical peak occurring in July and September and a break of two to three weeks in August. The lowest nighttime temperature is approximately 24°C during the harmattan period between December and February. Daytime highs are typically between 28 and 30°C during the rainy season of the year and between 30 and 34°C during the dry season. During the rainy season, relative humidity is higher, ranging from 63% to 96%, whereas during the dry season, it is between 55% and 84% (FUNAAB, 2020).

Experimental Animals and Management

A total of forty-two (42) bucks were chosen at random from the herds consist of twenty-one (21) each of KR and KW goat bucks with three (3) different age groups according to breeding records. Each group contained seven (7) animals each. The grouping includes: bucks of seven (7) months old to one year old (≤1 year), thirteen (13) months old to two years (>1 to ≤ 2 years), and bucks above two years to three years (>2 to ≤3) of age at the onset of experiment, with body weight of about 35–40, 45–55, and 60–80 kg for KR and 25–30, 35–45, and 45–55 kg for KW, respectively. However, at the end of experiment, the age grouping had shifted to >1 to ≤ 2, >2 to ≤ 3, and >3 to ≤ 4 years with average body weight of about 45–58, 62–84, and 85–88 kg for KR and 35–45, 45–55, and 55–60 kg for KW, respectively. Apparently healthy animals were used for this study. KR is an indigenous breed of South Africa imported to Nigeria for the purpose of improving the meat and milk quality of the indigenous breeds. KW is the crossbred emerged from crossing KR buck and West African Dwarf (WAD) doe. The animals were managed semi-intensively in an open-ventilated goat house consist of 12 pens of 10 × 8 f each with concrete floor under natural light and maintained under a uniform and constant nutritional regime. Animals were allowed to graze on a paddock solely planted with *Chloris gayana, Brachiaria ruzizensis*, and *Stylosanthes hamata ad libitum* on rotational basis and supplemented at 2% body weight dry matter with concentrate feed contained maize (15%), soybean meal (5%), groundnut cake (4%), palm kernel cake (23.5%), wheat offal (50%), bone meal (1%), sodium chloride, salt (1%), premix (0.5%) with crude protein (16.49%), dry matter (88.19%), ether extract (2.48%), crude fiber (27.50%), ash (10.98%), nitrogen free extract (41.74%), organic matter (89.02%), and metabolizable energy (12.27 MJ/kg DM). Water was also given *ad libitum*. The experiment lasted for twelve (12) months, from July 1, 2021, to June 30, 2022.

Experimental Design

The experimental design for this experiment was a 2 × 3 × 4 factorial design where 2 depicts two breeds of goat, 3 indicates three different age group, and 4 implies four different seasons with hematological and biochemical indices as the dependent variables while age, breed, and season series as independent variables.

Climatic Conditions

Two seasons each were considered in both rainy and dry seasons (early and late rainy and early and late dry seasons) as classified by Akinseye *et al*. (2012). The early rainy season covers the month of April to June, while the late rainy season spans between July and September. The early dry season extended from October to December, and the late dry season from January to March. Daily meteorological data of the experimental location were taken from FUNAAB Agrometrological Station and analyzed which include mean temperature, dry bulb temperature (Tdb), wet bulb temperature, and relative humidity (RH) while temperature humidity index (THI) was calculated using the formula for ruminants.

$$THI = (0.8 \times Tdb) + [(RH/100) \times (Tdb - 14.4)] + 46.4$$

Detail information is presented in Table 1. The model described by Armstrong (1994) could be used to assess whether the animals were under heat stress, where THI below 72 indicates no heat stress; 72–78 indicates mild stress; 79–88 indicates moderate stress; and 89–98 indicates severe stress.

Table 1 Descriptive statistics of meteorological observations throughout experimental period

Season	Mean temperature (°C)	Dry bulb temperature (°C)	Wet bulb temperature (°C)	Relative humidity (%)	THI
Early rainy	28.63 ± 0.16^b	27.23 ± 0.21^c	23.67 ± 0.31^b	70.71 ± 1.24^b	77.26 ± 0.52^c
Late rainy	29.52 ± 0.16^a	28.89 ± 0.17^b	24.85 ± 0.24^a	71.18 ± 1.22^b	79.83 ± 0.33^b
Early dry	28.38 ± 0.14^b	30.42 ± 0.33^a	24.99 ± 0.12^a	72.07 ± 1.71^b	82.28 ± 0.47^a
Late dry	26.38 ± 0.15^c	28.53 ± 0.36^b	23.78 ± 0.09^b	81.36 ± 0.89^a	80.72 ± 0.61^a

Note: Means within the same row followed by different superscript letters (a, b, c) are significantly different ($P < 0.05$). Values are presented as mean ± standard deviation. THI = temperature humidity index.

Hematological and Biochemical Analysis

Blood samples were taken once in each month throughout the experimental period. Using vacutainer needles and tubes, a pair of 5 mL of blood were taken from the goats' jugular veins: one for serum biochemistry and the other for hematological examination. Blood samples were drawn, dispensed in tubes containing ethylene diamine-tetra-acetate (EDTA), labeled and then kept in an icing cooler. Within a half hour of blood collection, the tubes were taken to the laboratory and examined using a hematology analyzer (DxH 800, Beckman Coulter, Inc.) to determine erythrocytes parameters, including hemoglobin concentration (Hb), red blood cell count (RBC), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), and mean corpuscular hemoglobin concentration (MCHC); as well as leukocyte parameters, including white blood cell (WBC) count and differential counts of neutrophils (N), lymphocytes (L), eosinophils (E), basophils (B), and monocytes (M).

Blood tubes without anticoagulant were centrifuged for 10 min at 3,500 rpm, then stored at -20°C for biochemical analysis after being allowed to coagulate in kaylite holders at 37°C for serum separation. Using appropriate kits for the determination of total protein (TP), albumin (ALB), globulin (GLO), cholesterol (CHOL), glucose (GLU), triglyceride (TRI), and creatinine (CRE) in the serum, an automated spectrophotometer (VITROS® 350 Chemistry System) was used to determine various chemical components in serum. However, the manufacturer's instructions of both machine and the kits were strictly followed while calibration controls were obtained from Labtest Diagnosis (Lagoa Santa, Minas Gerais, Brazil).

Data Analysis

Data obtained were analyzed in a three-way Analysis of Variance using SAS (1999). Duncan's multiple range test of the package was used to compare the means.

Model:

$$y_{ijkl} = \mu + A_i + B_j + S_k + AB_{ij} + AS_{ik} + BS_{jk} + ABS_{ijk} + \varepsilon_{ijkl}$$

where y_{ijkl} is the value of parameter of interest, μ is the overall mean, A_i is the effect of ith age (i = 1, 2, 3), B_j is the effect of jth breed (j = 1, 2), S_k is the effect of kth season (k = 1, 2, 3, 4), AB_{ij} is the effect of ijth interaction between age and breed, AS_{ik} is the effect of ikth interaction between age and season, BS_{jk} is the effect of jkth interaction between breed and season, ABS_{ijk} is the effect of ijkth interaction between age, breed, and season, and ε_{ijkl} is the residual error associated with each record.

Statement of Animal Rights

All applicable international, national, and institutional guidelines for the care and use of animals were followed in the conduct of this research. An agreement among people, nation and institution to recognize that animals are sentient and can suffer, to respect their welfare needs, and to end animal cruelty – for good was applied. The manuscript does not contain clinical studies or patient data.

RESULTS AND DISCUSSION

Effect of Breed on Hematological and Biochemical Parameters of Kalahari and Kalawad Goat Bucks

The effect of breed on hematological and biochemical parameters of goat bucks is presented in Table 2. All parameters considered were not significantly influenced by breed except RBC, MCV, and MCHC. KW had significantly higher mean values of RBC, MCV, and MCHC than KR ($P < 0.05$). Also, least square means showing the effect of breed on biochemical parameters of goat bucks reveled that all the parameters considered were not significantly ($P > 0.05$) affected by breed except globulin.

Table 2 Effects of breed on hemato-biochemical parameters of Kalahari and Kalawad goat bucks

Parameters	Breed		P-value	Reference value
	Kalahari Red	Kalawad		
PCV (%)	21.73 ± 3.49	21.89 ± 2.85	0.631	22–38
Hb (g/dL)	9.14 ± 1.41	8.94 ± 1.35	0.060	8–12
RBC (10^6/mL)	6.06 ± 0.70[b]	6.21 ± 0.67[a]	0.039	8–18
WBC (10^3/µL)	5.19 ± 2.63	4.82 ± 1.65	0.109	4–13
MCV (fL)	15.43 ± 1.12[b]	16.68 ± 1.43[a]	0.001	16–25
MCH (pg)	7.65 ± 0.76	7.79 ± 0.70	0.090	5.2–8.0
MCHC (g/dL)	35.72 ± 0.77[b]	36.60 ± 0.88[a]	0.001	30–36
N (%)	30.87 ± 6.14	29.84 ± 6.10	0.112	30–48
L (%)	66.12 ± 5.72	66.71 ± 6.15	0.348	50–70
E (%)	0.72 ± 0.74	0.71 ± 0.75	0.832	1–8
B (%)	0.61 ± 0.59	0.56 ± 0.55	0.408	0–1
M (%)	0.97 ± 0.95	1.06 ± 1.00	0.418	0–4
TP (g/dL)	6.39 ± 0.95	6.27 ± 0.88	0.224	6–7
ALB (g/dL)	3.46 ± 0.54	3.40 ± 0.49	0.325	2.3–3.6*
GLO (g/dL)	3.28 ± 0.92[a]	2.98 ± 0.61[b]	0.001	2.7–3.8*
CHOL (mg/dL)	70.71 ± 11.19	68.93 ± 9.92	0.113	61.5–76.1
GLU (mg/dL)	58.46 ± 9.06	57.37 ± 8.44	0.241	50–75
TRI (mg/dL)	57.69 ± 6.99	57.22 ± 7.03	0.528	-
CRE (mg/dL)	0.73 ± 0.39	0.73 ± 0.38	0.935	1.2–1.9

Note: Means within the same row followed by different superscript letters (a, b) are significantly different ($P < 0.05$). Values are presented as least square means ± standard error. PCV = packed cell volume, Hb = hemoglobin concentration, RBC = red blood cell, WBC = white blood cell, MCV = mean corpuscular volume, MCH = mean corpuscular hemoglobin, MCHC = mean corpuscular hemoglobin concentration, N = neutrophils, L = lymphocytes, E = eosinophils, B = basophils, M = monocytes, TP = total protein, ALB = albumin, GLO = globulin, CHOL = cholesterol, GLU = glucose, TRI = triglyceride, CRE = creatinine. Reference values adapted from Radostits *et al*. (2000) and * Stewart (2016).

Due to environmental and genetic factors, hemato-biochemical parameters are a valuable tool in the assessment of an animal's physiological and health condition (Njidda *et al*., 2014). The hematological and biochemical parameters found in this study, with the exception of a few minor variations in PCV (22–38%), RBC (8–18 × 10^6/mL), MCV (16–25 fL), and GLO (2.7–3.8 g/dL) were generally within the normal range for goats as reported by previous studies (Wang *et al*., 2008; Goat-link, 2009; Zumbo *et al*., 2011; Mohammed *et al*., 2016; Stewart, 2016; Malecky *et al*., 2017). However, other parameters considered during the experiment were not influenced by breed. The significant breed-specific variations in RBC, MCV, and MCHC that this study revealed are consistent with the findings of Eckersall (2008). The breed-specific non-significant results on PCV, Hb, WBC, MCV, MCH, and WBC differential are not consistent with Tibbo *et al*. (2004) findings. This may be explained by the fact that erythrocytes can change shape as they go through capillaries, but their width and thickness can vary depending on the breed and nutritional state of the animal.

Hemoglobin concentration was comparable to 8.45 ± 0.03 g/dL reported by Ramprabhu *et al*. (2010) and was somewhat higher in KR (9.14 ± 1.41 g/dL) than in KW (8.94 ± 1.35 g/dL), but the difference was not statistically significant. However, both values fall within the reference range of 8–12 g/dL reported by Stewart (2016). The variation in RBC found in this investigation is comparable to the findings of Borjesson *et al*. (2000) who worked on hematological reference intervals for free-ranging desert bighorn sheep and reported decrease values from the normal range without the case of anemia. According to Awodi *et al*. (2005) and Chineke *et al*. (2006) who reported that PCV, Hb concentration, and MCH are major indices for evaluating circulatory erythrocytes and are significant in the diagnosis of anemia and also serve as useful indices of the bone marrow capacity to produce RBC in mammal. The hemoglobin concentrations observed in this study was within normal reference value. This may be due to proper utilization of Hb during formation and supply of sufficient iron (Fe) in the body. This finding agreed with Olafadehan (2011) who attributed normal hemoglobin concentration to suggest absence of microcytic hypochromic anemia which is associated with iron deficiency and improper utilization during the formation of Hb, MCV, MCH, and MCHC are diagnostic blood indices indicative of anemic animals. When they fall within normal ranges (Sirois, 1995), it suggests that the goats are not anemic (Olafadehan, 2011).

The values of TP (6.27–6.39 g/dL) in this study were higher than 5.2 g/dL for West African Dwarf goats reported by Opara *et al*. (2010) and 5.5–5.8 g/dL reported by Soul *et al*. (2019) but fall within normal range 6.0–7.0 g/dL (Malecky *et al*., 2017). However, the value was lower than the findings of Wang *et al*. (2008) and Mohammed *et al*. (2016) who recorded that TP value in goat serum can go as high as 7.50 g/dL under extensive production systems. Also, these values were slightly higher to the finding by Carlos *et al*. (2015) in sheep with a body condition score of 2.5 and that recorded by Opara *et al*. (2010) of 5.2 g/dL for West African Dwarf goats. According to Akinrinmade and Akinrinde (2012) goats with a TP value below 4.2 g/dL show rumen compaction, this was therefore not the case in this study. Lower protein values could occur because animals failed to consume any considerable amount of grain because high serum protein levels are an indication of high intake of grains (Sandabe and Chaudhary, 2000), dehydration or high temperature as a result of kidney failure. Meanwhile, Okoruwa and Igene (2015) also reported high TP of 7.65 g/dL. Increase in TP indicates improvement through consumption of whole grains or used in compounding the concentrate and suggests that more amino acids were absorbed from the dietary protein and undegradable methionine, and similar trend was also observed by Abdelrahman and Aljumaah (2014). The albumin and globulin content were similar to the findings of Bobade *et al*. (2020), with values ranging from 3.36–3.40 and 3.38–3.57 g/dL, respectively, in goats raised under extensive or semi-intensive systems. The values were within the normal range of 2.3–3.6 and 2.7–4.1 g/dL for goat reported by Stewart (2016). But Tripathi *et al*. (2007) reported that low serum albumin concentration is indicative of liver dysfunction, nonetheless other indicators of liver function. Therefore, the constant nutritional regime that the animals were subjected to did not pose any negative effect on the liver. The globulin levels of the goats were maintained in this study. The steady values obtained may be attributed to routine deworming treatment of the animals which was aimed to protect the goats against internal parasites because high globulin values could be an indication of parasitic infestations or feeding on tannin-rich pastures especially during the dry seasons when most of the pastures have become lignified (Gwaze *et al*., 2010; Chikwanda and Muchenje, 2017). This also attests to the fact that treatment diets did not result in any inflammatory response in goats. According to Saxena *et al*. (2013), a decrease in cholesterol concentration over time could have been caused by the presence of phytochemicals particularly in forages as these have the capacity to reduce the synthesis and absorption of cholesterol, this was not the case in this study. Reduced blood cholesterol and lipids such as creatinine, alanine aminotransferase (ALT), alkaline phosphatase (ALP), and gamma-glutamyl transferase (GGT) level has been reported to be consequent upon some of the biological relationships of phenolic acids, but the values obtained in this study fall within normal range for healthy goats. The cholesterol values (70.71 ± 11.19 and 68.93 ± 9.92 mg/dL) observed in this study for KR and KW were higher than the values 59.50 ± 1.30 and 53.00 ± 21.80 mg/dL reported in other breeds of goats by Ramprabhu *et al*. (2010) and Pérez *et al*. (2003), respectively. The glucose values observed in both KR and KW (58.46 ± 9.06 and 57.37 ± 8.44 mg/dL) were higher than the value (47.00 ± 0.53 mg/dL) reported by Ramprabhu *et al*. (2010) but lower than the value (126.10 ± 66.00 g/dL) reported by Pérez *et al*. (2003). The differences could be attributed to metabolic activity of individual animals and the plane of nutrition.

The Effects of Age and Season on Hemato-biochemical Parameters of Kalahari and Kalawad Goat Bucks

The main effects of age and season is presented in Table 3. All hematological and biochemical indices considered were significantly influenced ($P < 0.05$) by age except glucose, triglyceride, and creatinine. Results also indicated that all RBC differentials were influenced ($P < 0.05$) by seasons while other erythrocytic indices were not significantly influenced ($P > 0.05$) by seasons. Only lymphocyte and eosinophil were seasonal affected ($P < 0.05$) while WBC and other differentials considered were not influenced by seasons. Also, results reveled that all the biochemical indices considered were significantly influenced ($P < 0.05$) by seasons except triglyceride.

The blood profile of animals is sensitive to changes in the environmental temperature, and it is an important indicator of physiological responses to the stressor (Okoruwa, 2014). Blood indices determination may be crucial in determining the impact of heat stress at various ages and seasons. In this study, age and season have effects on animals as shown by changes in hemato-biochemical parameters. The change of values with respect to age(s) of all the hematological parameters in KR and KW in this study is in line with previous reports that either compared groups of young and adult goats (Daramola *et al*., 2005; Pampori *et al*., 2010), goats of many age groups (Tibbo *et al*., 2004; Ramprabhu *et al*., 2010; Shaikat *et al*., 2013) and sheep (Şimşek *et al*., 2015a; 2015b) or studied changes in growing animals as in calves (Knowles *et al*., 2000; Anton and Pavel, 2009) and swine (Miller *et al*., 1961).

Table 3 Effects of age and season on hemato-biochemical parameters of Kalahari and Kalawad goat bucks

Parameter	Age (year)			P-value	Season				P-value	Reference value
	>1 to ≤2	>2 to ≤3	>3 to ≤4		Early rainy	Late rainy	Early dry	Late dry		
PCV (%)	20.97 ± 0.26^{b}	21.43 ± 0.31^{b}	23.04 ± 0.26^{a}	0.001	22.41 ± 0.35	21.77 ± 0.34	21.59 ± 0.32	21.49 ± 0.33	0.205	22–38
Hb (g/dL)	8.73 ± 0.09^{b}	8.93 ± 0.15^{b}	9.46 ± 0.12^{a}	0.001	8.77 ± 0.15	9.16 ± 0.14	9.12 ± 0.14	9.11 ± 0.15	0.197	8–12
RBC (10^6/mL)	5.89 ± 0.05^{c}	6.12 ± 0.07^{b}	6.41 ± 0.06^{a}	0.001	6.16 ± 0.08	6.05 ± 0.07	6.19 ± 0.07	6.17 ± 0.07	0.520	8–18
WBC (10^3/µL)	4.63 ± 0.14^{b}	5.41 ± 0.24^{ab}	4.96 ± 0.21^{a}	0.022	5.35 ± 0.29	4.87 ± 0.22	4.66 ± 0.17	5.12 ± 0.24	0.166	4–13
MCV (fL)	15.89 ± 0.12^{b}	15.94 ± 0.13^{b}	16.34 ± 0.14^{a}	0.028	15.47 ± 0.18^{b}	16.09 ± 0.11^{a}	16.35 ± 0.15^{a}	16.32 ± 0.14^{a}	0.001	16–25
MCH (pg)	7.49 ± 0.06^{c}	7.70 ± 0.07^{b}	7.97 ± 0.06^{a}	0.001	7.67 ± 0.08^{b}	7.49 ± 0.07^{b}	8.02 ± 0.07^{a}	7.71 ± 0.08^{b}	0.001	5.2–8.0
MCHC (g/dL)	35.60 ± 0.07^{c}	35.89 ± 0.08^{b}	36.18 ± 0.07^{a}	0.001	35.87 ± 0.11^{b}	36.19 ± 0.08^{a}	35.81 ± 0.08^{b}	35.68 ± 0.07^{b}	0.004	30–36
N (%)	32.30 ± 0.46^{a}	29.36 ± 0.57^{b}	29.40 ± 0.61^{b}	0.001	29.22 ± 0.63	30.73 ± 0.62	31.17 ± 0.71	30.29 ± 0.63	0.172	30–48
L (%)	65.13 ± 0.47^{b}	67.05 ± 0.56^{a}	67.05 ± 0.58^{a}	0.015	67.51 ± 0.56^{a}	65.67 ± 0.62^{bc}	65.17 ± 0.71^{c}	67.30 ± 0.59^{ab}	0.014	50–70
E (%)	0.61 ± 0.07^{b}	0.87 ± 0.07^{a}	0.67 ± 0.07^{b}	0.019	0.60 ± 0.07^{b}	0.72 ± 0.08^{ab}	0.87 ± 0.08^{a}	0.67 ± 0.08^{ab}	0.045	1–8
B (%)	0.57 ± 0.05^{ab}	0.49 ± 0.06^{b}	0.68 ± 0.04^{a}	0.032	0.53 ± 0.05	0.60 ± 0.06	0.64 ± 0.07	0.54 ± 0.05	0.535	0–1
M (%)	0.81 ± 0.06^{b}	1.34 ± 0.09^{a}	0.89 ± 0.09^{b}	0.001	1.02 ± 0.11	1.01 ± 0.10	1.00 ± 0.10	1.02 ± 0.10	0.998	0–4
TP (g/dL)	6.01 ± 0.07^{c}	6.36 ± 0.08^{b}	6.61 ± 0.09^{a}	0.001	6.59 ± 0.11^{a}	6.29 ± 0.09^{bc}	6.39 ± 0.09^{ab}	6.05 ± 0.08^{c}	0.001	6–7
ALB (g/dL)	3.43 ± 0.04^{b}	3.57 ± 0.05^{a}	3.30 ± 0.05^{b}	0.003	3.43 ± 0.07^{ab}	3.43 ± 0.05^{ab}	3.52 ± 0.05^{a}	3.34 ± 0.05^{b}	0.050	2.3–3.6*
GLO (g/dL)	2.81 ± 0.05^{c}	3.01 ± 0.07^{b}	3.57 ± 0.08^{a}	0.001	3.32 ± 0.11^{a}	3.06 ± 0.08^{b}	3.01 ± 0.06^{b}	3.14 ± 0.08^{ab}	0.040	2.7–3.8*
CHOL (mg/dL)	68.45 ± 0.93^{b}	69.42 ± 1.04^{ab}	71.59 ± 0.91^{a}	0.050	78.54 ± 1.10^{a}	69.38 ± 1.05^{b}	64.16 ± 0.94^{c}	67.20 ± 0.74^{b}	0.001	61.5–76.1
GLU (mg/dL)	56.83 ± 0.87	57.94 ± 0.84	58.97 ± 0.67	0.169	61.24 ± 1.19^{a}	59.11 ± 0.92^{a}	55.70 ± 0.65^{b}	55.60 ± 0.70^{b}	0.001	50–75
TRI (mg/dL)	57.28 ± 0.66	56.88 ± 0.78	58.22 ± 0.43	0.314	56.42 ± 0.73	57.31 ± 0.78	58.17 ± 0.69	57.92 ± 0.75	0.345	-
CRE (mg/dL)	0.77 ± 0.03	0.67 ± 0.03	0.74 ± 0.04	0.158	0.65 ± 0.04^{b}	0.68 ± 0.04^{b}	0.72 ± 0.03^{b}	0.87 ± 0.04^{a}	0.001	1.2–1.9

Note: Means within the same row followed by different superscript letters (a, b, c, d) are significantly different ($P < 0.05$). Values are presented as mean ± standard deviation. PCV = packed cell volume, Hb = hemoglobin concentration, RBC = red blood cell, WBC = white blood cell, MCV = mean corpuscular volume, MCH = mean corpuscular hemoglobin, MCHC = mean corpuscular hemoglobin concentration, N = neutrophils, L = lymphocytes, E = eosinophils, B = basophils, M = monocytes, TP = total protein, ALB = albumin, GLO = globulin, CHOL = cholesterol, GLU = glucose, TRI = triglyceride, CRE = creatinine. Reference values adapted from Radostits *et al*. (2000) and * Stewart (2016).

The results on seasonal changes on hematological parameters in this study partly agreed with the findings of Alam *et al*. (2011) and Okoruwa (2014) who reported that when goats are exposed to environmental hardship, goats showed an increased amount of RBC, PCV, Hb, WBC, neutrophil, eosinophil, lymphocyte, and monocyte. Thus, higher erythrocytic indices especially PCV and Hb values is the adaptive mechanism of animals to supply the appropriate amount of water, whereby more water is delivered into the circulatory system, necessary for the processes of evaporative cooling (Al-Haidary, 2004). Additionally, the increase in PCV and Hb levels could be either increased un-attack of free radicals on the red blood cells membrane, which is rich in lipid content, and ultimate lysis of red blood cell or availability of adequate nutrients for synthesis of hemoglobin as the animal consumes more feed or decreases voluntary intake under harsh environment (Srikandakumar *et al*., 2003; Gupta *et al*., 2013).

Seasons influenced all the blood biochemical parameters of KR and KW bucks except triglyceride. This result is not in agreement with Dangi *et al*. (2012) and Helal *et al*. (2010) who observed decreased in TP, ALB, and globulin when goats were exposed to heat stress but agreed with Okoruwa (2014) who reported that TP and ALB concentrations of goats increased under heat stress. Bobade *et al*. (2020) reported 6.78 ± 0.03 and 6.93 ± 0.04 g/dL total protein levels for goats raised under both semi-intensive and extensive system respectively and the values obtained in this study throughout all the seasons fall within the reference value for goats (6.0–7.0 g/dL). This may be due to an increase in serum/plasma volume as a result of heat stress, which results in a decrease in plasma protein concentration and increase in values could be due to dehydration which has been reported to occur as a result of increased respiration rate. Glucose and cholesterol levels show greater differences under different seasons in this study and the results during the dry seasons are in line with the findings of Ocak *et al*. (2009) who recorded decrease glucose and cholesterol levels in goats subjected to heat stress. The decrease in glucose level during the dry seasons could be related to the decrease in availability of nutrients and lower rate of propionate production (Mohamed, 2012), or due to the increase in plasma glucose utilization to provide energy for muscular expenditure required for high muscular activity associated with increased respiration rate (Sejian and Srivastava, 2010) and increased physical activity during grazing. The decrease in cholesterol level may have a relation with the increase in total body water or the decrease in acetate concentration, which is the primary precursor for the synthesis of cholesterol (Gupta *et al*., 2013). Extreme seasonal conditions occasioned by high environmental factors like ambient temperatures, relative humidity, etc. are the major constraint to animal performance. Therefore, it is important to be aware of weather extremes during all reproductive stages. There are two mechanisms by which seasonal harshness could lead to infertility in animals (Aggarwal and Upadhyay, 2013). The first mechanism is what actually causes reproductive problems through a direct effect of hyperthermia on the reproductive axis. The second mechanism is the indirect effect of heat stress on feed intake (decreased by heat stress) in order to reduce metabolic heat production leading to changes in energy balance and nutrient availability.

Interaction Effect of Age and Breed on Hemato-biochemical Parameters of Kalahari and Kalawad Goat Bucks

The interaction effect of age and breed on hemato-biochemical parameters of goat bucks is presented in Table 4. PCV and Hb concentrations had no significant differences between age group >1 to ≤2 years and >2 to ≤3 years among the breeds while age >3 to ≤4 years differs ($P < 0.05$) to other age groups. RBC had no significant difference between breeds at 3 years of age.WBC had similar values

Table 4 Interaction effect of age and breed on hemato-biochemical parameters of goat bucks

Parameters	Age (year)						P-value	Reference value
	>1 to ≤2		>2 to ≤3		>3 to ≤4			
	KR	KW	KR	KW	KR	KW		
PCV (%)	20.57 ± 3.35^{b}	21.37 ± 2.22^{b}	21.55 ± 3.76^{ab}	21.32 ± 3.11^{b}	23.08 ± 2.87^{a}	23.00 ± 2.85^{a}	0.001	22–38
Hb (g/dL)	8.81 ± 1.07^{b}	8.65 ± 1.11^{b}	9.09 ± 1.68^{ab}	8.77 ± 1.58^{b}	9.51 ± 1.35^{a}	9.39 ± 1.21^{a}	0.001	8–12
RBC (10^6/mL)	5.79 ± 0.60^{d}	5.99 ± 0.58^{cd}	6.03 ± 0.73^{cd}	6.21 ± 0.73^{bc}	6.36 ± 0.67^{ab}	6.46 ± 0.63^{a}	0.001	8–18
WBC (10^3/μL)	4.54 ± 1.69	4.72 ± 1.26	5.63 ± 3.22	5.19 ± 1.92	5.39 ± 2.67	4.54 ± 1.65	0.120	4–13
MCV (fL)	15.36 ± 0.86^{c}	16.42 ± 1.41^{b}	15.30 ± 1.24^{c}	16.59 ± 1.32^{ab}	15.64 ± 1.20^{c}	17.03 ± 1.49^{a}	0.001	16–25
MCH (pg)	7.43 ± 0.74^{c}	7.55 ± 0.63^{bc}	7.63 ± 0.78^{bc}	7.78 ± 0.75^{ab}	7.91 ± 0.70^{a}	8.04 ± 0.66^{a}	0.001	5.2–8.0
MCHC (g/dL)	35.40 ± 0.72^{d}	35.82 ± 0.79^{bc}	35.71 ± 0.79^{c}	36.07 ± 0.93^{ab}	36.04 ± 0.69^{ab}	36.32 ± 0.85^{a}	0.001	30–36
N (%)	32.20 ± 4.55^{a}	32.40 ± 5.55^{a}	30.32 ± 6.39^{ab}	28.40 ± 5.87^{b}	30.08 ± 7.08^{ab}	28.72 ± 6.15^{b}	0.003	30–48
L (%)	65.58 ± 4.97^{ab}	64.68 ± 5.35^{b}	66.55 ± 6.05^{ab}	67.55 ± 6.22^{ab}	66.22 ± 6.10^{ab}	67.88 ± 6.43^{a}	0.030	50–70
E (%)	0.58 ± 0.72	0.63 ± 0.78	0.88 ± 0.78	0.85 ± 0.68	0.70 ± 0.69	0.63 ± 0.78	0.140	1–8
B (%)	0.55 ± 0.62	0.58 ± 0.56	0.53 ± 0.68	0.45 ± 0.57	0.73 ± 0.45	0.63 ± 0.52	0.130	0–1
M (%)	0.80 ± 0.66^{b}	0.82 ± 0.70^{b}	1.20 ± 0.70^{ab}	1.48 ± 1.07^{a}	0.92 ± 1.03^{b}	0.87 ± 1.07^{b}	0.002	0–4
TP (g/dL)	6.03 ± 0.74^{b}	5.99 ± 0.68^{b}	6.37 ± 0.91^{ab}	6.35 ± 0.89^{ab}	6.76 ± 1.05^{a}	6.46 ± 0.99^{ab}	0.001	6–7
ALB (g/dL)	3.47 ± 0.47^{ab}	3.39 ± 0.39^{ab}	3.58 ± 0.59^{a}	3.55 ± 0.53^{a}	3.33 ± 0.54^{ab}	3.27 ± 0.51^{b}	0.004	2.3–3.6*
GLO (g/dL)	2.88 ± 0.56^{cd}	2.75 ± 0.47^{d}	3.13 ± 0.85^{bc}	2.91 ± 0.59^{cd}	3.84 ± 1.02^{a}	3.31 ± 0.63^{b}	0.001	2.7–3.8*
CHOL (mg/dL)	69.15 ± 10.66	67.75 ± 9.64	70.43 ± 12.12	68.40 ± 10.73	72.53 ± 10.66	70.65 ± 9.26	0.150	61.5–76.1
GLU (mg/dL)	57.45 ± 9.65	56.22 ± 9.41	58.32 ± 9.71	57.57 ± 8.75	59.60 ± 7.69	58.33 ± 7.01	0.420	50–75
TRI (mg/dL)	57.27 ± 7.14	57.28 ± 7.29	57.28 ± 8.60	56.47 ± 8.58	58.52 ± 4.71	57.92 ± 4.71	0.710	-
CRE (mg/dL)	0.75 ± 0.38	0.78 ± 0.36	0.69 ± 0.38	0.66 ± 0.35	0.74 ± 0.42	0.74 ± 0.43	0.550	1.2–1.9

Note: Means within the same row followed by different superscript letters (a, b, c, d) are significantly different ($P < 0.05$). Values are presented as mean ± standard deviation. PCV = packed cell volume, Hb = hemoglobin concentration, RBC = red blood cell, WBC = white blood cell, MCV = mean corpuscular volume, MCH = mean corpuscular hemoglobin, MCHC = mean corpuscular hemoglobin concentration, N = neutrophils, L = lymphocytes, E = eosinophils, B = basophils, M = monocytes, TP = total protein, ALB = albumin, GLO = globulin, CHOL = cholesterol, GLU = glucose, TRI = triglyceride, CRE = creatinine. Reference values adapted from Radostits *et al.* (2000) and * Stewart (2016).

(P > 0.05) for both breeds and different ages. MCV had higher mean values at age >2 to ≤3 and >3 to ≤4 years (P > 0.05) in KW while KR had the least values at all age groups. MCH was not significantly different in both breed at age >3 to ≤4 years and their values were not different from value obtained in KW at age >2 to ≤3 years (P > 0.05). MCHC had the lowest value (35.40 ± 0.72 g/dL) in KR at age >1 to ≤2 years while the highest value (36.32 ± 0.85 g/dL) was obtained in KW at age >3 to ≤4 years (P < 0.05). Neutrophil did not differ (P > 0.05) among the breeds and different age group except in KW at age >2 to ≤3 and >3 to ≤4 years. Lymphocyte had no significant difference between the breeds and different age groups except in KW at age >3 to ≤4 years. Monocytes had highest (1.48 ± 1.07% and 1.20 ± 0.70%) at age >2 to ≤ 3 years. The normal WBC and RBC components recorded in this study as age increased showed the evidence of a healthy and well-developed immune system in adult bucks and this trend had been reported by Njidda *et al*. (2014) that immune system in sheep increases with age.

It is noted that TP and ALB were not significantly different between the breeds and the different age groups except KR and KW age >3 to ≤4 years with highest (6.76 ± 1.05 g/dL) and least (3.27 ± 0.51 g/dL) values respectively. Globulin was at peak (3.84 ± 1.02 g/dL) in KR at age >3 to ≤4 years while the least (2.75 ± 0.47 g/dL) mean value (P < 0.05) was obtained in KW at age >1 to ≤2 years. The findings in the present study showed non-significant slight decrease in both breeds as age increased which disagreed with Carlos *et al*. (2015) and Lima *et al*. (2015), when comparing sheep with different age groups (from less than six months to over 24 months). They observed an increase in creatinine concentrations with advancing age which may be due to expansion of creatinine reservoirs as a consequence to an increase in muscular mass deposition with growth, or a possible reduction in serum thyroxine levels that would trigger a decrease in glomerular filtration rate. However, decrease could be attributed to a well-developed healthy renal apparatus with functional renal clearance.

Interaction Effect of Breed and Season on Hemato-biochemical Parameters of Kalahari and Kalawad Goat Bucks

The interaction effect of breed and season on hematological parameters of goat bucks is presented in Table 5. Among all the parameters considered, PCV, basophil, and monocyte were not influenced by both breeds and seasons (P > 0.05). Hb concentration mean values obtained in KR during the early rainy, early dry and late dry seasons were not significantly different from mean values obtained in KW during the late rainy and late dry seasons. RBC was similar (P > 0.05) in KW throughout the seasons and in KR during the early and late dry seasons (P > 0.05). The highest mean values (5.99 ± 3.57 × 10^3/µL and 5.32 ± 2.54 × 10^3/µL) for WBC were obtained in KR and KW during early rainy and late dry seasons respectively. MCV was at peak in KW during the dry seasons and the least value (15.74 ± 2.00 fL) at early rainy season (P < 0.05) was not significantly different from the mean values obtained in KR throughout all seasons. MCH had the high mean values in both breeds during the early dry season, and the value was not significantly different from the value obtained in KW during the early rainy season. MCHC was at the peak (P > 0.05) in KW during the rainy seasons while the least (35.54 ± 0.69 g/dL) value (P < 0.05) obtained during late dry season was not different from value obtained in KR during the early rainy season. Neutrophil had the highest (33.27 ± 7.07%) mean value (P < 0.05) during the early dry season in KR and was not statistically different from the value (31.96 ± 5.91%) obtained during the late dry season while KW had peak value (32.07 ± 6.21%) during the late rainy season. Lymphocytes had peak (68.22 ± 5.73%) value (P < 0.05) in KW during early rainy season while KR

Table 5 Interaction effect of breed and season on hemato-biochemical parameters in goat bucks

Parameters	Kalahari Red				Kalawad				P-value	Reference value
	Early rainy	Late rainy	Early dry	Late dry	Early rainy	Late rainy	Early dry	Late dry		
PCV (%)	22.18 ± 3.87	21.87 ± 3.40	21.78 ± 3.56	21.11 ± 3.09	22.64 ± 2.59	21.67 ± 3.11	21.40 ± 2.34	21.87 ± 3.20	0.457	22–38
Hb (g/dL)	9.16 ± 1.56^{ab}	8.82 ± 1.48^{bc}	9.43 ± 1.36^{ab}	9.15 ± 1.20^{ab}	8.38 ± 1.15^{c}	9.51 ± 1.13^{a}	8.80 ± 1.26^{bc}	9.07 ± 1.59^{ab}	0.002	8–12
RBC (10^6/mL)	5.90 ± 0.77^{b}	5.96 ± 0.68^{b}	6.18 ± 0.64^{ab}	6.21 ± 0.69^{ab}	6.41 ± 0.68^{a}	6.13 ± 0.68^{ab}	6.19 ± 0.60^{ab}	6.12 ± 0.70^{ab}	0.023	8–18
WBC (10^3/µL)	5.99 ± 3.57^{a}	5.29 ± 2.54^{b}	4.54 ± 2.04^{b}	4.92 ± 1.89^{b}	4.71 ± 1.07^{b}	4.45 ± 1.39^{b}	4.78 ± 1.05^{b}	5.32 ± 2.54^{ab}	0.016	4–13
MCV (fL)	15.19 ± 1.32^{c}	15.75 ± 0.72^{c}	15.20 ± 1.01^{c}	15.59 ± 1.25^{c}	15.74 ± 2.00^{c}	16.43 ± 1.13^{b}	17.49 ± 0.61^{a}	17.05 ± 0.92^{a}	0.001	16–25
MCH (pg)	7.52 ± 0.77^{cd}	7.44 ± 0.70^{d}	7.97 ± 0.79^{ab}	7.68 ± 0.70^{bcd}	7.82 ± 0.64^{abc}	7.54 ± 0.72^{cd}	8.07 ± 0.60^{a}	7.71 ± 0.76^{bcd}	0.001	5.2–8.0
MCHC (g/dL)	35.32 ± 0.88^{c}	35.86 ± 0.76^{b}	35.86 ± 0.63^{b}	35.82 ± 0.69^{b}	36.41 ± 0.87^{a}	36.53 ± 0.68^{a}	35.76 ± 0.86^{b}	35.54 ± 0.69^{bc}	0.001	30–36
N (%)	28.84 ± 5.27^{c}	29.40 ± 5.21^{bc}	33.27 ± 7.07^{a}	31.96 ± 5.91^{ab}	29.60 ± 6.55^{bc}	32.07 ± 6.21^{ab}	29.07 ± 5.65^{c}	28.62 ± 5.57^{c}	0.003	30–48
L (%)	66.80 ± 4.79^{ab}	66.80 ± 4.79^{ab}	63.67 ± 6.56^{c}	67.20 ± 5.97^{ab}	68.22 ± 5.73^{a}	64.53 ± 6.71^{bc}	66.67 ± 6.35^{ab}	67.40 ± 5.32^{a}	0.004	50–70
E (%)	0.51 ± 0.58^{c}	0.56 ± 0.58^{bc}	1.04 ± 0.79^{a}	0.78 ± 0.88^{abc}	0.69 ± 0.76^{bc}	0.89 ± 0.86^{ab}	0.69 ± 0.76^{bc}	0.56 ± 0.59^{bc}	0.007	1–8
B (%)	0.56 ± 0.50	0.58 ± 0.49	0.78 ± 0.77	0.51 ± 0.55	0.51 ± 0.51	0.62 ± 0.68	0.51 ± 0.51	0.58 ± 0.49	0.366	0–1
M (%)	0.93 ± 0.96	1.09 ± 1.04	0.89 ± 0.88	0.98 ± 0.92	1.11 ± 1.02	0.93 ± 0.91	1.11 ± 1.02	1.07 ± 1.05	0.912	0–4
TP (g/dL)	6.69 ± 1.05^{a}	6.50 ± 0.95^{abc}	6.24 ± 0.82^{bcd}	6.11 ± 0.91^{cd}	6.49 ± 0.93^{abc}	6.08 ± 0.87^{d}	6.53 ± 0.85^{ab}	5.98 ± 0.75^{d}	0.001	6–7
ALB (g/dL)	3.40 ± 0.68	3.49 ± 0.52	3.59 ± 0.48	3.36 ± 0.47	3.46 ± 0.57	3.38 ± 0.50	3.45 ± 0.45	3.32 ± 0.44	0.325	2.3–3.6*
GLO (g/dL)	3.53 ± 1.13^{a}	3.29 ± 0.90^{abc}	2.99 ± 0.54^{bcd}	3.32 ± 0.96^{ab}	3.12 ± 0.89^{bcd}	2.83 ± 0.48^{d}	3.03 ± 0.54^{bcd}	2.95 ± 0.40^{cd}	0.004	2.7–3.8*
CHOL (mg/dL)	78.87 ± 11.18^{a}	69.91 ± 12.77^{b}	65.67 ± 8.60^{cd}	68.38 ± 6.88^{bc}	78.22 ± 9.87^{a}	68.84 ± 5.94^{bc}	62.64 ± 9.05^{d}	66.02 ± 6.96^{bcd}	0.001	61.5–76.1
GLU (mg/dL)	61.96 ± 11.27^{a}	59.98 ± 9.51^{ab}	55.42 ± 6.66^{c}	56.47 ± 6.58^{bc}	60.53 ± 11.42^{a}	58.24 ± 7.94^{abc}	55.98 ± 5.59^{c}	54.73 ± 6.71^{c}	0.001	50–75
TRI (mg/dL)	56.09 ± 6.88	57.62 ± 6.63	58.71 ± 6.99	58.34 ± 7.38	56.76 ± 6.97	57.00 ± 8.10	57.62 ± 6.20	57.51 ± 6.92	0.717	-
CRE (mg/dL)	0.59 ± 0.36^{c}	0.57 ± 0.37^{c}	0.85 ± 0.40^{ab}	0.89 ± 0.34^{a}	0.69 ± 0.43^{bc}	0.79 ± 0.37^{ab}	0.58 ± 0.29^{c}	0.84 ± 0.38^{ab}	0.001	1.2–1.9

Note: Means within the same row followed by different superscript letters (a, b, c, d) are significantly different ($P < 0.05$). Values are presented as mean ± standard deviation. PCV = packed cell volume, Hb = hemoglobin concentration, RBC = red blood cell, WBC = white blood cell, MCV = mean corpuscular volume, MCH = mean corpuscular hemoglobin, MCHC = mean corpuscular hemoglobin concentration, N = neutrophils, L = lymphocytes, E = eosinophils, B = basophils, M = monocytes, TP = total protein, ALB = albumin, GLO = globulin, CHOL = cholesterol, GLU = glucose, TRI = triglyceride, CRE = creatinine. Reference values adapted from Radostits et al. (2000) and * Stewart (2016).

had the least (63.67 ± 6.56%) mean value during early dry season. Eosinophil was at peak in KR during early dry season (1.04 ± 0.79%) and in KW during late rainy seasons (0.89 ± 0.86%).

The interaction effect of breed and season on biochemical parameters of goat bucks are presented in Table 5. TP was at peak (P > 0.05) in both breeds during the early rainy season while the lowest value was observed during the late dry season in both breeds. ALB was not significantly different between breeds and seasons except in KW during late dry season. Globulin had the highest value (3.53 ± 1.13 g/dL) in KR during early rainy season while the lowest value was obtained in KW during the late rainy season. KW had the lowest (62.64 ± 9.05 mg/dL) cholesterol value during the early dry season. Glucose had the peak values during the early rainy season, and the values were not significantly different from those obtained during late rainy season in both breeds. Triglyceride was not influenced by breeds and seasons. KR had the highest mean value of creatinine during dry seasons while KW had the highest mean value during late rainy and late dry seasons.

The study indicated slight drop in red blood cell levels and slightly increase in hemoglobin concentrations across the seasons could perhaps be attributed to the stresses and exercise, which accelerate oxygen release, contribute to an increase in oxygen consumption and, as a result, an increase in hemoglobin concentration. When environmental temperature rises, the animal loses liquid through the respiratory tract, reducing the blood plasma volume and increasing the PCV concentration according to Swenson and Reece (2006). However, when the heat stress is prolonged, dehydration occurs, and thus, loss of fluids by the evaporative process, resulting in increased PCV but the PCV reported in this study was constant throughout the seasons. According to El-Nouty *et al*. (1990), there could be significant depression in PCV due to effect of hemodilution during extreme heat stress, however, the study recorded no reduction in the PCV values.

Seasonal variations have been observed in most of biochemical parameters of both KR and KW with higher values during the rainy seasons compared to dry seasons and this could be attributed to variations in dietary protein intake from the forages particularly during the dry seasons with high temperatures leading to fluid loss (dehydration). These findings agreed with Hussain *et al*. (2003) who found season to have a pronounced effect on some biochemical parameters with higher values during short-rainy and after long rainy seasons in Arsi-Bale, central highland goats and long eared Somali goats relative to dry season. The values of total protein in this study for both KR and KW during rainy and dry (early and late) seasons were similar to 6.85 ± 0.04, 6.85 ± 0.04, and 6.87 ± 0.04 g/dL reported by Bobade *et al*. (2020) for rainy, winter, and summer seasons respectively for goats raised under semi-intensive system. The values of serum total protein observed in the present study irrespective of the season were within the normal range of 6.0 to 7.5 g/dL for goats. Sakha *et al*. (2008) also reported 7.0 g/dL value for total protein in goat which was similar to the results reported by Inbaraj *et al*. (2018). The values of serum albumin were found to be within the normal range for goat. The values are in close agreement to those of 3.3 g/dL as reported by Zubcic (2001) in grazing German fawn goats and Bobade *et al*. (2020) recorded 3.60 ± 0.04, 3.41 ± 0.08, and 3.20 ± 0.05 g/dL during rainy, winter, and summer seasons respectively in Osmanabadi goats raised under semi-intensive system. The normal albumin levels are the indicator of adequate nutritional regime as well as the sound health status of the animal while low albumin concentration indicates health compromise or immunological weakness leading to sickness (Solaiman *et al*., 2010). The values of serum globulin in both KR and KW goats were found to be within the normal range for goat irrespective of the seasons. This finding is in agreement with Bobade *et al*. (2020), values were within the normal range of serum globulin for goat. Increased globulin values above normal range could be due to increased number and activities of pathogenic parasites (Gwaze *et al*., 2010). The finding in this study shows that the cholesterol and glucose levels in both breeds slightly dropped during early and late dry seasons. This is in line with the report of Ocak and Güney (2010) and Ribeiro *et al*. (2016; 2018) who recorded reduction in blood levels of cholesterol and glucose in an atmosphere with high temperatures and attributed it to be an indicator of failure in homeostasis. The liver, extrahepatic tissues, and hormones such as insulin, glucagon, cortisol, adrenaline, and thyroid hormones are responsible for maintaining steady blood glucose levels (Swenson and Reece, 2006). Heat stress has a bigger impact on total cholesterol levels. This could be because animals under heat stress use more fatty acids to produce energy as a result of their reduced glucose concentration (Mundim *et al*., 2007). Results in this finding indicated that triglyceride was not influenced by seasons. This may be attributed to the fact that there were no serious glucose failure requirements in both breeds because triglycerides are mobilized as a source of energy. Also, the results in this study indicated that TP increased in KR during rainy seasons and in KW during both early rainy and early dry seasons. Albumin increased in KR during dry seasons and early rainy season while increased during early rainy and early dry seasons while globulin increased during rainy seasons and during late dry season but increased in KW during both earl rainy and early dry seasons This finding is partly in tandem with the reports of Al-Eissa *et al*. (2012) and Ribeiro *et al*. (2016; 2018) who reported increase in proteins levels of goats when subjected to heat stress and Helal *et al*. (2010) who recorded decrease in plasma total proteins, albumin, and globulin when Balady goats were subjected to heat stress.

Interaction Effect of Age, Breed and Season on Hematological Parameters of Kalahari and Kalawad Goat Bucks

Interaction effect of age, breed and season on hematological parameters of goat bucks is shown in Figure 1. PCV had inconsistent statistical values ($P < 0.05$) between age, breeds and seasons. KR and KW had the highest (23.87%) PCV mean values at age 3 during the early rainy season respectively. MCV maintained a consistent statistical values ($P > 0.05$) among age and breeds during rainy seasons; thereafter, KW mean values increased ($P < 0.05$) during the dry seasons while there was no significant difference in KR values throughout all the seasons. MCH, MCHC, RBC, WBC, and eosinophils had similar linear patterns which showed the effect of seasons on breeds and age ($P > 0.05$). Lymphocytes and neutrophils had similar zig zag patterns in opposite direction ($P > 0.05$). Hb concentration, basophils and monocytes were not significantly affected by age, breeds and seasons.

Although KR and KW bucks of different ages raised in different seasonal and environmental settings under the same management conditions exhibit discernible differences in the erythrogram's contents, they nonetheless fall within the published reference value for goats. According to de Souza *et al*. (2011), Oliveira *et al*. (2012), and Ribeiro *et al*. (2016), the variability in PCV levels and MCV in this study are comparable.

Interaction Effect of Age, Breed and Season on Biochemical Parameters of Kalahari and Kalawad Goat Bucks

The interaction effect between age, breed and season on biochemical parameters of goat bucks is shown in Figure 2. Cholesterol and glucose fluctuated or showed inconsistent pattern across seasons ($P < 0.05$), but values were not significant within age group. The cholesterol highest (80.67 and 80.13 mg/dL) mean value for KR and KW respectively were observed during early rainy season at age >3 to ≤ 4 years. TP, ALB, globulin, and creatinine had consistent statistical values in both breeds as affected by age and season ($P > 0.05$). Triglyceride maintained gradual increase non-significant mean values ($P > 0.05$). The peak (60.40 and 59.53 mg/dL) mean values for triglyceride were observed in both KR and KW respectively at age >3 to ≤ 4 years during the late dry season.

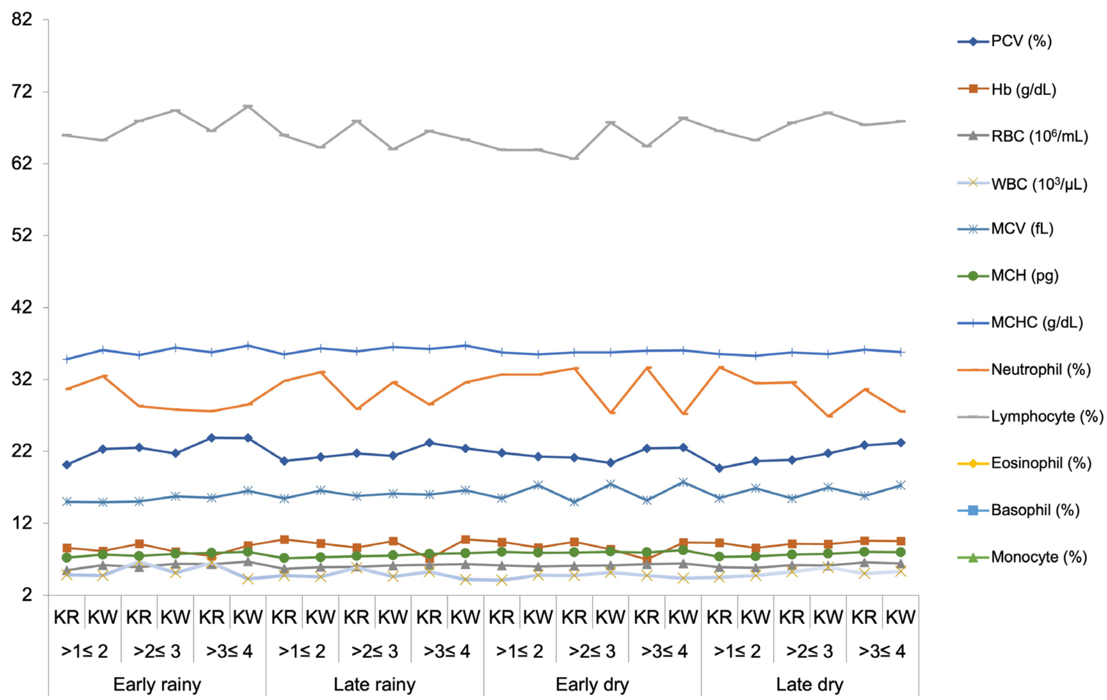

Figure 1 Interaction effect between age, breed and season on hematological parameters of goat bucks. KR = Kalahari Red goat, KW = Kalawad goat (crossbred), PCV = packed cell volume, Hb = hemoglobin concentration, RBC = red blood cell, WBC = white blood cell, MCV = mean corpuscular volume, MCH = mean corpuscular hemoglobin, MCHC = mean corpuscular hemoglobin concentration.

The results of this study fall within normal range reported for healthy goats irrespective of breed and age. The proteins in both breeds were not influenced negatively by both age and season. The variations in glucose levels observed in this study in respect to age, breed and season is in line with the report of Sakha *et al*. (2008) who reported that the serum glucose level is influenced by many factors including nutrition, age, sex, breed, and environment. The fluctuations in cholesterol concentration and consistent values of triglyceride as age increased in KR and KW is in line with the reports of some researchers (Helal *et al*., 2010; Al-Eissa *et al*., 2012; Oliveira *et al*., 2012; Ribeiro *et al*., 2016; 2018) when goats were exposed to heat stress. Results indicated that oldest bucks in both breeds were more challenged with risk of maintaining internal balance during early rainy season. This could be attributed to the fact that high-temperature environment increases various physiological, behavioral, and physical activities leading to rapid depletion of glucose leading to decrease in cholesterol in the blood, this implies inability of animal to regulate homeostasis.

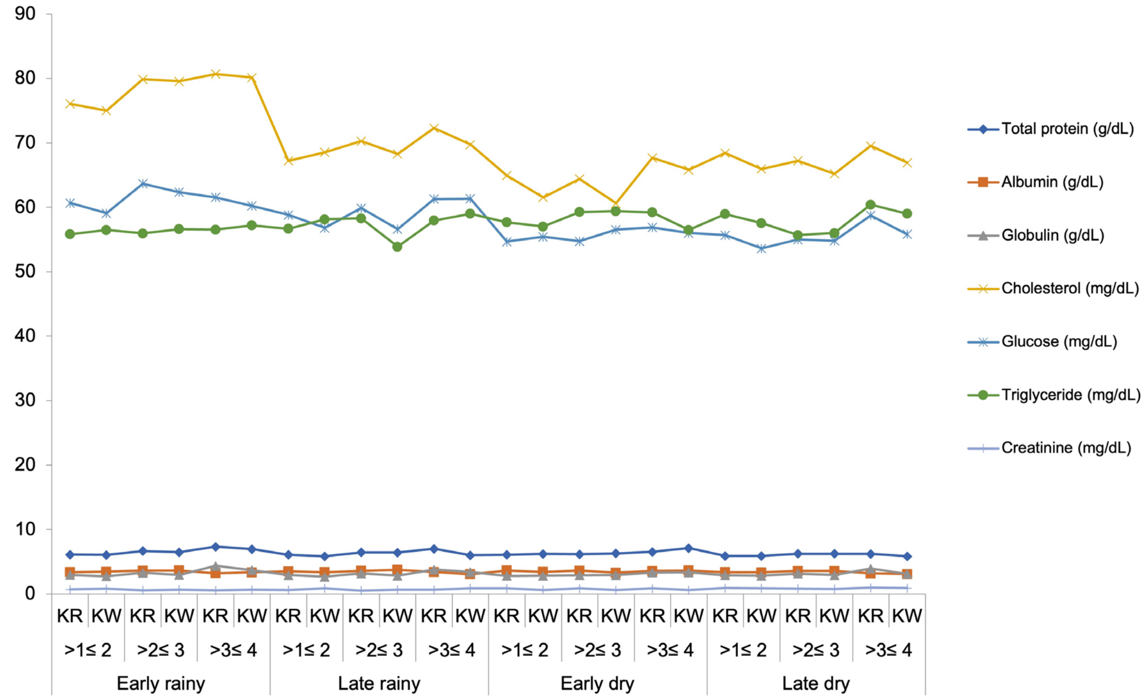

Figure 2 Interaction effect between age, breed, and season on biochemical parameters of goat bucks. KR = Kalahari Red goat, KW = Kalawad goat (crossbred).

CONCLUSIONS

All hematological and biochemical indices considered were significantly influenced by age except glucose, triglyceride and creatinine. All RBC differentials were influenced by seasons while other erythrocytic indices were not significantly influenced by seasons. Both lymphocyte and eosinophil were seasonally affected but WBC and other differentials considered were not influenced by seasons. Only globulin was not influenced by breed. TP, ALB, GLOB, and glucose were affected by age. The biochemical indices considered were significantly influenced by seasons except triglyceride. There were seasonal variations observed in most of biochemical parameters of both breeds with higher values during the rainy seasons compared to dry seasons and some were highly influenced by age. These findings provide the reference values in KR breed and the KW crossbred and may be helpful for breeding and diagnosis purposes in these animals.

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