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Variation in Blood and Serum Parameters in Local Omani Sheep Breeds

Ihab Shaat[1,2*], Asila Al Naabi[1], Kareema Al Senani[3] and Abdel Aziz Al Shegaibi[4]

[1]Oman Animal and Plant Genetic Resources Center (Mawarid), Ministry of Higher Education, Research and Innovation, Oman.
[2]Animal Production Research Institute, Agriculture Research Center, Ministry of Agriculture, Cairo, Egypt.
[3]Livestock Research Center, Directorate General for Agricultural and Livestock Research, Ministry of Agriculture, Fisheries and Water Resources, Oman.
[4]Salalah Livestock Research Station, Directorate General for Agricultural and Livestock Research, Ministry of Agriculture, Fisheries and Water Resources, Oman.

ABSTRACT

In Oman, there are two indigenous sheep breeds: the Northern and Southern Omani sheep. To assess the variation in hematological and serum biochemical parameters due to breed, sex, age, birth type, and birth year, blood samples were collected from sheep at the Wadi Quriyat and Salalah Livestock Research Stations. The hematological parameters examined included seven red blood cell/hemoglobin-related traits and six white blood cell-related traits. The biochemical parameters assessed included total protein (with detailed components such as albumin, globulin, bilirubin, creatinine, and six enzyme activities), glucose, three electrolytes, calcium, arsenate, and chlorine. The experimental design was optimized across the fixed effects, and a mixed-model analysis was used to estimate and test the fixed effects as well as the proportion of variance attributable to birth year. Overall, the Southern breed displayed greater variability than the Northern breed. Amongst the studied parameters, several showed high variability, particularly the enzyme activities and those related to immunologically important white blood cell groups. In contrast, vital red blood cell indices, mean cell hemoglobin, and diet-dependent glucose exhibited low variability. There were correlations among the hematological parameters. The study provides a baseline reference for hematological and serum biochemical parameters, which will be useful for understanding and improving the production and health features of sheep in the targeted geographical region.

Keywords: hematology, serology, plasma components, ovine, *Ovis aries*, Western Asia.
*Corresponding Author Email: ihab.m.shaat@gmail.com

INTRODUCTION

Sheep are the second most abundant livestock in the Sultanate of Oman and are valued for their high-quality meat. Of the two native sheep breeds, the Northern breed (commonly referred to as "Omani sheep") is widely distributed across the northern governorates, while the Southern breed, predominantly found in the Dhofar Governorate in southern Oman, remains less well studied. These two breeds are exposed to distinctly different environmental conditions in their respective geographic regions. The Southern breed benefits from favorable weather, including regular rainy seasons and abundant pasture throughout the year, whereas the Northern breed is exposed to hot weather and a harsh, arid environment (Shaat and Al-Habsi, 2016). Sheep and goats typically exhibit increased growth and production when proper management and dietary supplements are provided. It is important to determine blood hematological and serum biochemical parameters because they provide considerable insight into an animal's health, immunity, and physiological state. Variation in these parameters can be influenced by several factors, such as breed, sex, age, and nutritional and health status (Etim et al., 2014; Njidda et al., 2014). They also reflect vital biological functions in animals such as growth, stress response, symptoms of disease, and changes in behavior or metabolism (Madan et al., 2016). Understanding the impacts of age and sex on blood hematological and serum biochemical parameters is crucial for establishing reliable reference values in animals, thereby improving the statistical analysis of data variation arising from many sources (Ljubičić et al., 2022).

Sexual maturity, growth requirements, and productivity are particularly significant and can be understood through the associated key biochemical and hematological traits (Arfuso et al., 2016). Despite their importance, limited research exists on the variation of these factors in the Omani indigenous sheep breeds. This study aims to investigate the effects of breed, sex, age, birth type, and birth year on the variation in selected serum biochemical and hematological parameters of the two Omani sheep breeds.

Materials and Methods

Blood sampling and analysis

Blood samples were collected in 2021 from the jugular vein of the individual sheep using disposable syringes with sterile needles and were transferred into serum tubes. In Oman, there is no centralized national animal ethics committee; instead, individual institutions operate their own ethics committees to oversee and approve the use of animals in research. The study was conducted at the Livestock Research Stations under the Directorate General of Agriculture and Livestock Research, Ministry of Agriculture, Fisheries, and Water Resources, Muscat, Sultanate of Oman. The research ethics were reviewed and approved by the Internal Animal Ethics Committee of the Ministry of Agriculture, Fisheries, and Water Resources.

The study excluded any animals that were affected by disease. At the Livestock Research Stations, a resident veterinarian oversees animal health and welfare, whose responsibilities include maintaining a healthy environment, administering periodic vaccinations against infectious diseases, conducting daily health checks, and diagnosing illnesses. When a specific disease is identified, affected animals are isolated in a designated veterinary quarantine area and treated according to established protocols. Additionally, animals are periodically treated with antiparasitic dips or sprays to manage external parasites.

The blood samples collected were centrifuged immediately, and the serum was frozen at -20 °C. Hematological parameters were obtained from the whole blood samples using a Cell-Dyn 3700 automated blood analyzer (Abbott Laboratory, Diagnostic Division, Abbott Park, IL 60064, USA). The parameters included: red blood cells, red cell distribution width, hematocrit, hemoglobin concentration, mean cell hemoglobin, mean cell hemoglobin concentration, mean corpuscular volume, white blood cells, lymphocytes, monocytes, neutrophils, eosinophils, and basophils. Serum biochemical parameters were obtained using UniCel DxC 600 chemistry analyzer (Beckman Coulter, Inc., USA). The parameters included: albumin, globulin, total bilirubin, creatinine, alkaline phosphatase, creatine kinase, activity of five enzymes (gamma-glutamyl transferase, aspartate aminotransferase, alanine aminotransferase and lactate dehydrogenase), glucose, magnesium, sodium, potassium, calcium arsenate, and chlorine. All the analyses for the two breeds were also carried out in 2021 in the same laboratory belonging to the Ministry of Agriculture, Fisheries and Water Resources.

Data Collection

The laboratory analyses were obtained from both Northern and Southern local Omani sheep breeds. The study was carried out on a total of 74 animals of the Northern sheep breed raised at Wadi Quriyat Livestock Research Station in Dakhlyiah Governorate, and a total of 93 animals of the Southern sheep breed raised at Salalah Livestock Research Station in Dhofar Governorate. The stations belong to the Ministry of Agriculture, Fisheries, and Water Resources. The animals in the stations were fed twice daily with a conventional concentrate containing 14% crude protein and 11.97 MJ/kg dry matter of metabolizable energy. Rhodes grass (*Chloris gayana*) was provided ad libitum as a source of roughage, and the animals had continuous access to fresh water. The quantity of concentrate varied based on the animals' physiological stage and age. During the dry period, the animals received a minimum of approximately 300 g/head/day of concentrate, while the amount was increased to up to 750 g/head/day for animals in the late stages of pregnancy or for growing animals.

Information collected included the animals' breed, sex, birth year, and age, and these data were extracted from the database for the Northern and Southern sheep, with each animal assigned a unique accession number. The birth years recorded were 2013 and 2016–2021. Age was classified into three groups: adult (1.5 to 5 years), growing (6 to 18 months), and lamb (< 6 months). Birth type was categorized as single, twin, or triple.

Statistical Analysis

Statistical analysis was performed to identify the factors influencing variation in the biochemical and

Table 1: Number of males and females used in the analysis of Northern and Southern sheep breeds for serum biochemical and hematological parameters.

Breed	Sex	Biochemical parameters	Hematological parameters
Southern	Male	38	40
	Female	42	53
Northern	Male	35	33
	Female	39	37

Table 2: The overall numbers used in the analysis of serum biochemical and hematological parameters in both studied sheep breeds across age and birth type classes and year of birth.

Factor	levels	Hematological parameters	Biochemical parameters
Age	Adult	53	46
	Growing	67	67
	Lamb	43	41
Birth type	Single	67	72
	Twin	88	73
	Triple	8	9
Year of birth	2013	4	4
	2016	9	4
	2017	17	11
	2018	10	14
	2019	36	40
	2020	64	62
	2021	23	19

hematological parameters ($\boldsymbol{y}$). The statistical model used was

$$y_{ijklmn} = \mu + breed_i + sex_j + birth\,type_k + age_l + birth\,year_m + e_{ijklmn} \quad (1.1)$$

Where μ represents the overall mean, and the fixed effects include *breed* with two classes (i = N, S for Northern and Southern sheep), sex with male and female (j = 1, 2), $birth\ type$ with three classes (k = 1, 2 and 3 for single, twin and triple) and age with three classes (l = A, G, L for adult, growing and lamb). The random effects included birth year ($m = 1, \ldots, 7$), covering the years 2013 and 2016–2021. These effects were assumed to be independent and identically distributed, following a normal distribution $N(0, I\sigma^2_{\text{year}})$, where $I$is the identity matrix and σ^2_{year} is the variance attributable to birth year. The residual effect (e_n) accounted for variation within the fixed-effect classes, with the subscript $n$running from 1 to the total number of animals in the analysis. Residuals were also assumed to be independent and identically distributed, following $N(0, I\sigma^2_e)$, where σ^2_erepresents the residual variance-that is, the variance in the analyzed trait not explained by the specified fixed and random effects-because the animals in the study were unrelated.

In the mixed model cases, estimates of the fixed effects and the variance due to birth year were solved using restricted maximum likelihood (REML). The significance of the fixed effect estimates was tested with Satterthwaite's method (Moser et al., 1989), and intra-class correlation was used to express the proportion of the variance due to birth year in the total variance. The similarity in variation patterns among the parameters was assessed using correlation analysis on parameter values adjusted for the estimated fixed effects and predicted random effects from the mixed-model analysis, with significance tests performed for each correlation. The statistical analyses were performed using the publicly available R software (R Core Team, 2021). The mixed-model analyses were carried out using the lmer function from the lme4 package (Bates et al., 2015) with REML estimation. The correlation matrix was generated using the corrplot package (Wei and Simko, 2024), which provided a graphical display of the results.

RESULTS AND DISCUSSION

The experimental design aimed to sample an equal number of animals from each breed, as well as from male and female sheep. As a result, the animals were relatively evenly distributed across both breeds and sexes (Table 1).

With respect to age, main birth types, and birth years, a satisfactory sampling design was obtained (Table 2).

The distribution of animals across the age classes was nearly symmetric, with high numbers in each class. The predominant birth types were single and twin, with relatively few animals born as triples. In 2021, when the study was conducted, the available age classes were represented, and the distribution of birth years was slightly skewed, as expected.

Blood hematological parameters

Variability of parameters

The analysis of the parameters showed variation within the laboratory reference values typically reported for sheep cf. https://www.merckvetmanual.com/multimedia/table/hematology-complete-blood-count-reference-ranges. In addition to the mean and standard deviation, the coefficient of variation (CV) was used to assess variability, as it allows for comparison of data measured in different units or with largely differing means (Table 3). Overall, immunologically relevant parameters, particularly white blood cells, exhibited high variability, with the highest values observed in parameters involved in defense against infections or allergens.

A clear difference was observed between the breeds, with the Southern breed exhibiting much higher variability. The most variable parameters were eosinophils, with CVs of 67.3% and 106% in the Northern and Southern breeds, respectively, while many related parameters also showed CVs above 30%. For red blood cell–related parameters, the CVs were around 10%, with the least variable being red blood cells and mean cell hemoglobin, both with CVs of approximately 5%. Substantial differences in breed means were noted for white blood cells (8.62 vs. 4.46 in Northern and Southern breeds, respectively) and neutrophils (3.83 vs. 1.72, respectively). Other parameters require detailed statistical analysis to identify potential deviations.

Results from mixed model analysis

Physiological factors, such as blood hematological parameters, provide insight into the effect of feeding regimes on animals, reflecting the quality, type and amount of available feed with respect to animals' condition and metabolic requirements (Odetola et al., 2012). Hemoglobin concentration is a good indicator of an oxygen-carrying capacity in an individual's blood (Daramola et al., 2005). The deviating blood profiles are essentially affected by genetic potential and physiological homeostasis, with a strong influence of external factors (Alonso, 1997).

In our study, breed had a significant effect on most of the hematological parameters analyzed (Table 4), likely reflecting differences in climate conditions and related stress factors. The parameter values were within a similar range to those reported by Rahman et al. (2018) for indigenous sheep in Bangladesh, and somewhat higher than values reported by Binuomote and Babayemi (2017) in a feeding trial with West African Dwarf sheep. The hemoglobin concentrations observed in this study were consistent with the high values reported by Azimzadeh and Javadi (2020) for Iranian Red Sheep.

Sex also had a significant effect on the variation of many hematological parameters, although no clear pattern could be distinguished in how male or female animals influenced specific types of parameters. Similar findings were reported by Egbe–Nwiyi et al. (2000) in sheep and goats raised in arid areas of Nigeria. Additionally, Daramoa et al. (2005) in West African Dwarf goats and Shumaila et al. (2012) in small ruminants of Pakistan also investigated the effect of sex on hematological parameters.

Age classes influenced the variation of many hematological parameters, particularly eosinophils. Milder deviations were observed for parameters related to red blood cells, including red cell distribution width, hemoglobin concentration, and mean cell hemoglobin. Several parameters were affected by both sex and age, notably red blood cell–related traits, eosinophils, and the neutrophil-to-lymphocyte ratio. Birth type caused significant deviations only for the mean corpuscular hemoglobin concentration. Similar investigations have been conducted by Khazaal et al. (2023), who examined the use of hematological parameters as indicators of litter size in Awassi sheep in Iraq.

The proportion of variance attributable to birth year (intra-class correlation) was generally low, exceeding 0.10 only for hematocrit, mean corpuscular volume, and white blood cells. The variance component due to birth year was negligible for red blood cells, where the fixed effect of birth year was also not significant (results not shown). For some parameters, treating birth year as a random effect rather than a fixed effect caused previously non-significant age effects to become highly significant, likely due to confounding between birth year and age. A similar pattern was observed for eosinophils, where the random birth year effect produced an intra-class correlation of only 0.04.

Correlation analysis

There was much variation in the estimated correlation coefficients amongst the hematological parameters (Figure 1). The main feature was a high (absolute) value of correlation amongst red blood cell / hemoglobin-related parameters and amongst white blood cell-related parameters in both the Northern and Southern breeds. On the other hand, correlations between these two major groups were generally low, although they were

Table 3: Mean (a), standard deviation (b), and coefficient of variability (c, %) of the blood hematological parameters for Southern and Northern sheep breeds.

Hematological parameter	Northern n=70	Southern n=93
Red blood cells (×10^6/μL)	10.7[a]	10.59
	0.69[b]	1.07
	6.46[c]	10.1
Red cell distribution width (%)	28.75	31.95
	2.74	7.77
	9.51	24.3
Hematocrit (%)	29.46	31.74
	2.62	3.62
	8.88	11.4
Haemoglobin concentration (g/dl)	12.98	14.38
	1.23	1.62
	9.51	11.2
Mean cell haemoglobin (pg)	12.11	13.64
	0.65	1.58
	5.34	11.6
Mean corpuscular haemoglobin concentration (g/dL)	44.10	45.67
	3.04	6.08
	6.89	13.3
Mean corpuscular volume (fL)	27.55	30.08
	2.05	3.19
	7.44	10.6
White blood cells (×10^3/μL)	8.63	4.46
	2.85	2.79
	33.1	62.7
Monocytes (×10^3/μL)	0.87	0.40
	0.43	0.27
	49.9	67.5
Lymphocytes (×10^3/μL)	3.32	1.97
	2.28	1.39
	68.6	70.2
Neutrophils (×10^3/μL)	3.83	1.72
	1.33	1.56
	34.7	90.7
Neutrophils/Lymphocytes	1.60	0.88
	1.01	0.72
	62.9	81.6
Eosinophils (×10^3/μL)	0.26	0.26
	0.18	0.27
	67.3	106
Basophils (×10^3/μL)	0.36	0.11
	0.26	0.086
	73.6	77.5

somewhat higher in the Southern breed, where overall correlations exceeded those observed in the Northern breed. Our results provide a clearer pattern than those reported by Aliyu et al. (2022), who found associations of varying degrees among the hematological parameters.

Serum biochemical parameters

Variability of parameters

The analysis of the serum biochemical parameters for Northern and Southern sheep breeds generally aligns with reference values reported in the Merck Veterinary Manual for sheep /https://www.merckvetmanual.com/multimedia/table/serum-biochemical-analysis-reference-ranges), except for elevated glucose, sodium, chloride, and activities of several enzymes, including alkaline phosphatase, creatine kinase, gamma-glutamyl transferase, lactate dehydrogenase, and alanine aminotransferase in Northern sheep.

The substantial differences in enzyme activities, particularly alanine aminotransferase, creatine kinase,

Table 4. Blood hematological parameters of Northern and Southern Omani sheep, analyzed using a mixed model.

	Breed		Sex		Birth type			Age			Year
Parameters	***P***	**S – N**	***P***	**Female - Male**	***P***	**2 - 1**	**3 - 1**	***P***	**G – L**	**A - L**	**proportion of variance**
Red blood cells (×10^6/μL)	ns		ns		ns			***	0.37	-0.31	0.00
Red cell distribution width (%)	**	3.90	***	3.98	ns			*	0.91	0.84	0.034
Hematocrit (%)	**	2.050	o	0.84	ns			ns			0.13
Hemoglobin concentration (g/dl)	***	1.40	**	0.724	ns			*	-0.14	-1.06	0.061
Mean cell haemoglobin (pg)	***	1.61	***	0.86	ns			*	-0.64	-0.76	0.026
Mean corpuscular hemoglobin concentration (g/dL)	o	1.72	o	1.36	**	2.41	2.37	ns			0.037
Mean corpuscular volume (fL)	***	2.50	**	1.07	o	-0.78	-0.92	*	-1.51	-0.72	0.22
White blood cells (×10^3/μL)	***	-4.31	ns		ns			ns			0.15
Monocytes (×10^3/μL)	***	-0.48	**	-0.14	ns			ns			0.23
Lymphocytes (×10^3/μL)	***	1.39	ns		ns			ns			0.050
Neutrophils (×10^3/μL)	***	-2.15	**	-0.74	ns			o	-0.33	-0.97	0.021
Neutrophils/Lymphocytes (%)	***	-0.72	**	-0.43	ns			*	-0.25	-0.61	0.068
Eosinophils (×10^3/μL)	ns		***	-0.13	ns			***	-0.0020	-0.22	0.037
Basophils (×10^3/μL)	***	-0.24	ns		ns			o	0.093	0.096	0.037

Legend: The parameters were analyzed using ANOVA, with the significance of fixed effects (breed, sex, birth type, and age) reported from the mixed-model analysis. Estimates represent deviations from the reference level within each effect. Levels included: breed—Southern (S) and Northern (N); sex—female and male; birth type-single (1), twin (2), and triple (3); age adult (A), growing (G), and lamb (L). The variance component attributable to the random effect of birth year is expressed as a proportion of the total variance. The significance (*** P<0.001, ** P <0.01, * P<0.05, ° P<0.10, ns non-significant) of the fixed effect estimation is given by *F* test.

and lactate dehydrogenase, suggest breed-specific metabolic or stress responses, potentially influenced by diet, management, or genetics. The high variability in enzyme levels indicates individual differences within the breeds, which may warrant further investigation into environmental or physiological factors.

Overall, the enzyme related parameters are the most variable ones amongst the biochemical parameters (Table 5). The highest variability is seen in creatine kinase activity (CV=83 and 111% in N and S, resp.) and alkaline phosphatase activity (CV=47 and 64% in N and S, resp.). For other parameters the coefficient of variation ranges roughly from about 10 to 30% with glucose and electrolytes at the lower end. The least variable parameter is calcium arsenate (CV=4.9% and 8.5% in N and S, resp.). A striking difference between breeds was observed only for alanine aminotransferase activity, with mean values of 35.57% and 12.99% in Northern and Southern breeds, respectively, while the other parameters were similar between breeds. No pronounced differences in variability were observed between the breeds.

Although the nutritional composition was the same at both research stations, alanine aminotransferase levels were approximately three times higher in sheep at Wadi Quriyat Livestock Research Station (Northern breed) compared to those at Salalah Livestock Research Station (Southern breed). This difference may be attributed to geographical location, liver stress, or metabolic differences between breeds, with factors such as climate or genetic adaptation potentially contributing.

Results from mixed model analysis

The mixed model analysis was performed to assess the variation in the serum biochemical parameters (Table 6). All the fixed effects had a significant effect on many of the parameters studied. In particular, the breed was commonly found to have an effect on the variation. Amongst the studied biochemical parameters, total bilirubin and sodium were exceptions and did not exhibit any differences attached to the studied fixed effects. In addition to these two, the variation in glucose and gamma-glutamyl transferase activity was not affected by breed.

The observed differences between the two sheep breeds could be attributed to the environmental conditions in their main geographic locations. The Southern breed

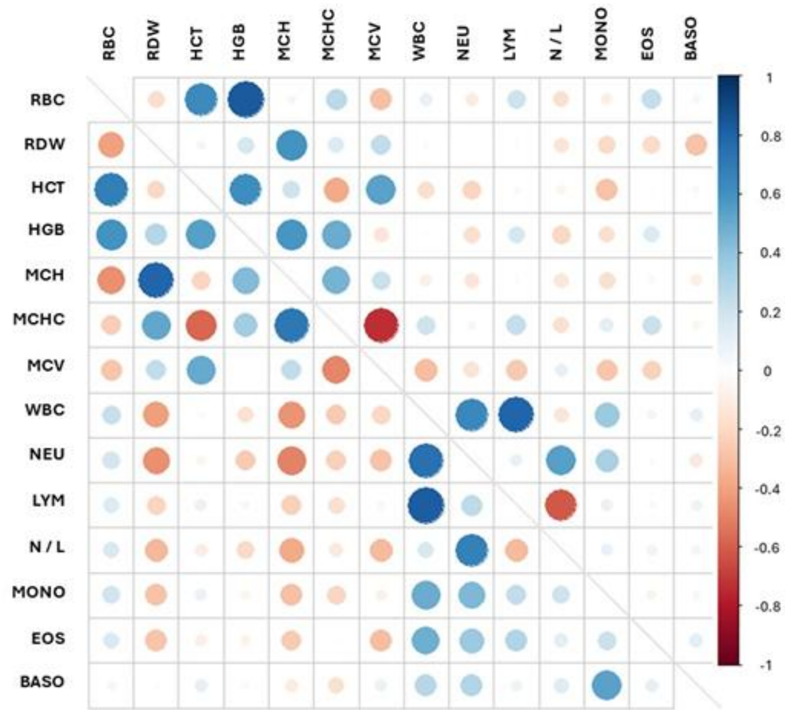

Figure 1. Correlation (from -1 via non-significant values with *P*>0.05 to +1 with respective colour from blue via blank to red with the size of circle proportional to the absolute value) between blood hematological parameters in Northern (upper triangle) and Southern (lower triangle) breed. The parameters are grouped as red blood cell / hemoglobin-related parameters (red blood cells RBC, red cell distribution width RDW, hematocrit HCT, hemoglobin concentration HGB, mean cell hemoglobin MCH, mean cell hemoglobin concentration MCHC, mean corpuscular volume MCV) and white blood cell related parameters (white blood cells WBC, lymphocytes LYM, neutrophils NEU, the ratio between neutrophils and lymphocytes N/L, monocytes MONO, eosinophils EOS, basophils BASO).

benefits from favorable weather and abundant pastures throughout the year, whereas the Northern breed is exposed to hot weather and a harsher environment (Shaat and Al-Habsi, 2016). Similarly, Oramari et al. (2014) reported differences in biochemical parameters among three Iraqi sheep breeds-Karadi, Awassi, and Naimy. Sex had a limited influence on variation, with no significant effect observed for the majority of biochemical parameters. Similarly, birth type showed a significant effect only on three enzyme activity parameters and albumin. Our findings on the moderate effect of sex on biochemical parameters are consistent with results reported by Oramari et al. (2014) in Iraqi sheep, as well as Ljubicic et al. (2022) in Dalmatian Pramenka lambs. The effect of sex may be breed-specific, as noted in Brazilian Morada Nova sheep (Carlos et al., 2015), Turkish Akkaraman sheep (Aksoy et al., 2018), and Iranian Red Sheep (Azimzadeh and Javadi, 2020).
Birth type had no significant effect on most biochemical parameters analyzed, consistent with findings by Mohammed and Abass (2021), who investigated the influence of birth type and age on selected biochemical parameters in Awassi sheep in Iraq.
Age, however, had a significant effect on many traits, particularly in the Northern breed. These findings align with observations by Antunovic et al. (2005), Oramari et al. (2014), Mohammed and Abass (2021), and Ljubicic et al. (2022). Increased total protein during intensive growth periods may be due to the anabolic effects of growth hormones and the high energy requirements of growing animals (El-Barody et al., 2002).
Statistical analyses indicated confounding between the effects of birth year and age. For example, in the case of creatinine and potassium, changing from a fixed to a random birth year effect removed the variance component of birth year and amplified the deviations attributed to age (results using fixed birth year effects are not shown). No birth year–mediated variance was observed for creatinine, sodium, and potassium. The proportion of the variance component relative to total variation was high for total bilirubin and the activities of alkaline phosphatase and gamma-glutamyl transferase.

Correlation analysis

Substantial variation was observed in the correlations between parameters, and no clear conclusions could be drawn (Figure 2), primarily because the functional roles

Table 5: Mean (a), standard deviation (b) and coefficient of variability (c, %) of the serum biochemical parameters for Southern and Northern sheep breeds.

Parameter	Northern n=74	Southern n=80
	3.05[a]	2.49
Albumin (g/dl)	0.49[b]	0.11
	16.0[c]	4.53
	5.03	4.15
Globulin (g/dl)	1.00	0.62
	19.9	14.9
	0.33	0.27
Total bilirubin (mg/dl)	0.12	0.071
	36.6	26.4
	1.44	1.59
Creatinine (mg/dl)	0.24	0.231
	17.0	20.0
	575.25	573.68
Alkaline phosphatase (U/L)	270.96	366.81
	47.1	63.9
	300.65	269.41
Creatine kinase (U/L)	248.48	297.98
	82.6	111
	61.98	73.48
Gamma-glutamyl transferase (U/L)	13.21	26.10
	21.3	35.5
	115.58	110.90
Aspartate aminotransferase (U/L)	26.05	40.19
	22.5	36.2
	35.57	12.99
Alanine aminotransferase (U/L)	12.49	3.92
	35.1	30.2
	1647.78	1577.03
Lactate dehydrogenase (U/L)	404.60	379.59
	24.6	24.1
	89.76	86.72
Glucose (mg/dl)	11.02	16.59
	12.3	19.1
	2.94	2.54
Magnesium (mg/dl)	0.51	0.26
	17.2	10.3
	160.63	162.33
Sodium (mmol/L)	20.06	13.04
	12.5	8.03
	10.47	12.22
Potassium (mg/dl)	2.40	2.50
	22.9	20.4
	11.07	11.12
Calcium arsenate (mg/dl)	0.54	0.95
	4.85	8.53
	122.86	131.61
Chlorine (mmol/L)	16.39	28.80
	13.3	21.9

of the related factors-from proteins to enzymes and electrolytes-are highly heterogeneous. The absolute values of the correlations in Northern sheep (upper triangle) were generally higher, with positive correlations observed within proteins and enzymes. These protein and enzyme parameters were, in turn, negatively correlated with sodium and chlorine. The results highlight the patterns of correlation among the biochemical parameters.

Conclusions

The study focuses on the use of an extensive set of

Table 6: Serum biochemical parameters of Northern and Southern Omani sheep analyzed using a mixed model.

	Breed		**Sex**		**Birth type**			**Age**			**Year**
Parameters	***P***	**S - N**	***P***	**Female-Male**	***P***	**2 - 1**	**3 - 1**	***P***	**G - A**	**L - A**	**proportion of variance**
Albumin (g/dl)	***	-0.54	o	0.10	*	0.025	0.32	*	0.081	-0.18	0.089
Globulin (g/dl)	ns		***	0.072	ns			ns			0.49
Total bilirubin (mg/dl)	ns		ns		ns			ns			0.42
Creatinine (mg/dl)	***	-0.18	*	-0.080	ns			***	-0.055	-0.40	0.00
Alkaline phosphatase (U/L)	**	-215.74	ns		ns			**	283.24	375.78	0.42
Creatine kinase (U/L)	*	-95.12	*	-75.65	ns			ns			0.032
Gamma-glutamyl transferase (U/L)	ns		ns		ns			*	2.87	19.38	0.23
Aspartate aminotransferase (U/L)	*	-11.37	ns		**	8.89	36.65	ns			0.057
Alanine aminotransferase (U/L)	***	-22.62	*	-3.12	***	2.01	17.43	o	3.47	-2.41	0.064
Lactate dehydrogenase (U/L)	***	-312.19	ns		**	13.46	481.24	**	392.23	622.24	0.004
Glucose(mg/dl)	ns		ns		o	2.45	11.24	**	3.73	14.42	0.13
Magnesium (mg/dl)	***	-0.42	ns		ns			*	0.064	-0.18	0.10
Sodium (mmol/L)	ns		ns		ns			ns			0.00
Potassium (mg/dl)	***	2.16	o	0.82	ns			***	0.50	-2.07	0.00
Calcium arsenate (mg/dl)	**	-0.46	*	0.23	ns			***	0.66	1.19	0.15
Chlorine (mmol/L)	***	40.16	ns		o	-8.70	-5.42	o	-13.35	-24.04	0.30

Legend: Parameters were analyzed using ANOVA, with the significance of fixed effects from the mixed-model analysis (P-values) reported below the table. Estimates represent deviations from the reference (first) level within each effect. Levels include: breed-Southern (S) and Northern (N); sex—female and male; birth type—single (1), twin (2), and triple (3); age-adult (A), growing (G), and lamb (L). The variance component due to the random effect of birth year is expressed as a proportion of the total variance. The significance (*** P<0.001, ** P <0.01, * P<0.05, ° P<0.10, ns non-significant) of the fixed effect estimation is given by *F* test.

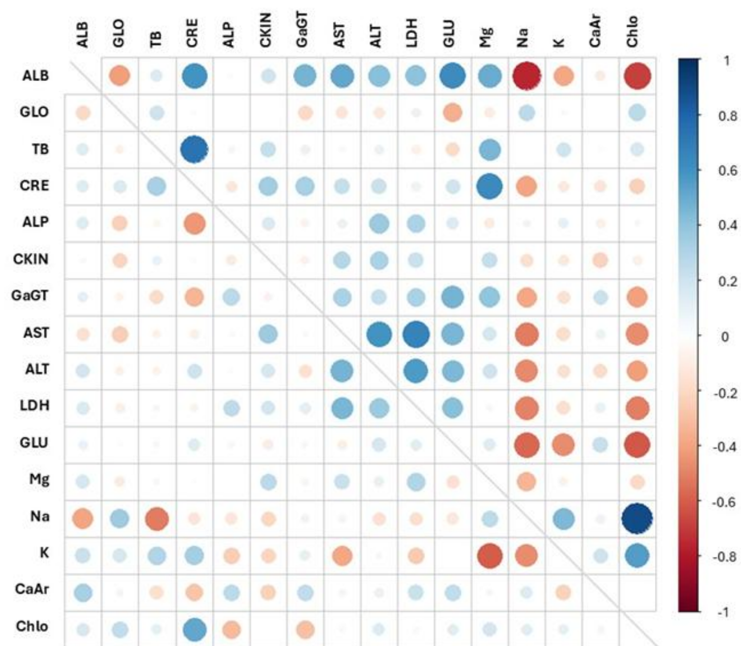

Figure 2. Correlation (from –1 via non-significant values with P > 0.05 to +1, with respective colors from blue through blank to red, and the size of each circle proportional to the absolute value) between biochemical parameters in Northern (upper triangle) and Southern (lower triangle) Omani sheep, with diagonal elements of correlation equaling 1.00 omitted. Parameters are grouped as proteins (albumin ALB, globulin GLO, total bilirubin TB, creatinine CRE), six enzymes (alkaline phosphatase ALP, creatine kinase CKIN, gamma-glutamyl transferase GaGT, aspartate aminotransferase AST, alanine aminotransferase ALT, lactate dehydrogenase LDH), glucose (Glu), electrolytes (magnesium Mg, sodium Na, potassium K), calcium arsenate (CaAr), and chlorine (Chlo).

biochemical and hematological parameters in analyzing differences in two indigenous Omani sheep breeds. The experimental design and the total number of observations provided a strong ability to detect potential differences between breeds, with sampled individuals distributed across error-causing factors (sex, age, and birth litter type) optimally to reduce bias and minimize residual variation.

In the statistical analysis, a mixed model approach is used to separate any major factors causing differences and test their significance. The implementation of REML analysis also provides a means to estimate the variation between the birth years of the sampled animals. The latter provides a way for assessing the likely confounding effects between age and birth year.

The Southern breeds display overall higher variability than the Northern breeds. Amongst the studied parameters, several show high variability, such as enzymes and those in an immunologically important white blood cell group. In contrast, vital red blood cells and mean cell hemoglobin, and diet-dependent glucose exhibit low variability.

This study provides a baseline reference for blood hematological and serum biochemical parameters, which can aid in understanding and improving the production and health of sheep in the Arabian Gulf region. The parameters form a heterogeneous group, and correlations are evident among the hematological traits, which can be utilized to select practical parameters among redundant ones.

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