Review Article:

BLOOD HAEMATOLOGIC AND BIOCHEMISTRY VALUES OF HIGH ALTITUDE AND TRANSHUMANT PASTORAL ANIMALS AS A REFERENCE FOR THE METABOLIC STUDIES

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ABSTRACT

Transhumant grazing is a unique system of rearing domestic animals in the Himalayas. Migration to high elevations during summer is regarded as a strategy to increase energy intake, and it has been suggested that there is increased forage quality at high elevations. This led to the prediction that body weight is positively correlated with the proportion of high-altitude habitats. There are distinct physiological and metabolic changes in domestic animals during transhumance. Cold stress might further contribute to the physiological and metabolic differences at the same time as the low-altitude conditions of the animals. These changes have been further driven by genetic and nongenetic factors. This review provides few insights on such changes, which may help elucidate the scientific reasons behind the performance of sheep in the Himalayas. The physiological disposition of the animals to their nutrition could be monitored by hematology and serum biochemistry assays. Furthermore, changes in physiological states, such as the respiration rate and heart rate, are the simplest indirect measures of the stress tolerance of the animals during high-altitude grazing conditions, whereas blood metabolites can be observed as adaptive phenomena. Research reports on common physiological and metabolic traits and the reasons behind these changes under high-altitude conditions have been compiled in the present review.

Key words: Biochemistry, haematology, high altitude physiology, metabolic traits.

INTRODUCTION

Transhumance grazing is associated with the cyclical, annual movement of livestock between distinctive seasonal pastures from settlements within the same area (Vallentine, 2001). Transhumant grazing systems still operate in many parts of the world where vegetation growth is strongly seasonal (Tulachan et al., 2000). It is an integral part of livestock production in many parts of the world and takes several forms, including moving livestock from lowlands to mountainous pastures or from dry to humid areas (Eckert et al.,1994). This practice is a strategy to cope with low temperatures and a shortage of fodder (Moktan et al., 2008). The vertical movement of flocks from a low-elevation winter range to a high-elevation summer range is the most common pattern of migration. At different elevations during migration, *goths* (temporary sheds made of local resources) are established at stopover points, and their livestock are grazed in nearby *kharkas* (natural grazing rangelands) (Aryal et al., 2014; Barsila et al., 2014b). Forests in foothills with patches of grasslands are traditional winter grazing sites for transhumant animals (Gurung, 2008). Some herders, however, move their animals to the adjoining district, and the movement of the transhumance flock is restricted continuously, mostly within the district (Joshi & Shrestha, 2010). Migration to high elevations during summer is regarded as a strategy to increase energy intake, and it has been suggested that there is increased forage quality at high elevations. This led to the prediction that body weight is positively correlated with the proportion of high-altitude habitats. Alternatively, cervids may benefit from prolonged access to newly emerged forage as they migrate along an altitudinal gradient (Mysterud et al., 2001).

Physiological alterations in transhumant animals

Respiration rate (RR) and heart rate (HR)

The process of oxygen uptake and release of carbon dioxide is termed respiration (Schmidt, 1997). HR in healthy individuals represents the net interaction between vagal (which reduces HR) and sympathetic (which increases HR) regulation (Hainsworth,1995). At rest, vagal regulation dominates whereas increasing physical activity is frequently characterized by decreasing vagal and increasing sympathetic influences. A rise in heart rate is caused mainly by an increase in sympathetic activity (Hainsworth, 1995). Like many other physiological parameters, heart rate variability is influenced by a variety of factors, such as sex, age, respiration, posture and physical activity (Von Borell et al., 2007). High-altitude environments pose several unique physiological challenges to animal life. In addition to being characterized by cold temperatures, high-altitude environments are also characterized by lower partial pressures of oxygen (PO_2) than low-altitude environments at similar latitudes (Chineke et al., 2006). RR and HR variability are used as indicators of energy expenditure and, in general, unspecific stress imposed by the environment and altitudinal, climatic and nutritional constraints. The variation in environmental temperature and relative humidity also causes variations in physiological responses, blood metabolites, and hormones. An increase in skin temperature (ST) and pulse rate (PR) was observed during the summer and hot humid seasons over the spring season (Bhan et al., 2013).

Performance under high-altitude hypoxia is enhanced by increases in the capacity to transport oxygen along the oxygen cascade, which comprises ventilation, pulmonary oxygen diffusion, circulation of oxygen in the blood, and tissue oxygen diffusion and utilization (Ivy & Scott, 2015). The hypoxic ventilator response (HVR) is initiated within one breath of a reduction in arterial PO_2 and involves an increase in breathing that helps maintain O_2 transport (Brutsaert, 2007; Powell et al., 1998). Heart rate, cardiac output, and femoral vasoconstrictor responses (acute hypoxia or catecholamines) are elevated in mammals that develop and are tested at high altitudes (Graf et al., 2022; Herrera et al., 2010).

The average respiration rate increased as the temperature of the natural environment increased from cool to moderate to warm. There was a linear increase in the mean respiration rate when the ambient temperature increased in goats (Bianca et al., 1978). The compensatory mechanism in animals involves the activation and transmission of neural signals to the hypothalamus, thereby increasing the respiratory and heart rates (Hafez, 1968).

Metabolic blood profile

Blood parameters are important indices of physiological and pathological changes in an organism (Mitruka & Rawnshey, 1977). With good blood composition, animals are likely to perform well (Isaac et al., 2013). The opportunity to investigate the presence of several metabolites and other constituents involves the examination of blood, which plays a vital role in determining the physiological, nutritional and pathological status of an organism (Aderemi, 2004; Doyle, 2006).

Hematological components

Hematology includes the number and morphology of the cellular elements of the blood and has been used as an indicator of high altitude distress in many studies. Hematological components include the erythrocyte count, pack cell volume (PCV), hemoglobin level, total leukocyte count (TLC) and differential leukocyte count (DLC). Furthermore, the haematological components included the mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH), mean plasma volume (MPV) and mean corpuscular haemoglobin concentration (MCHC).

The haematological values of farm animals are influenced by age, sex, breed, climate, geographical location, season, day length, time of day, nutritional status, life habits of species, the present status of an individual and other factors (Afolabi, et al. 2010). Hematological studies of ecological and physiological interest help to understand the response of blood constituents to the environment (Ovuru & Ekweozor, 2004). In addition, they help to determine body status in the context of stress due to environmental, nutritional and/or pathological factors (Afolabi et al., 2010). The haenatological reports by different authors has been compiled in Table 1.

Table 1. Reference hematological values of sheep in different studies

Parameters	Radostits et al., (2006)	Cork & Halliwell, (2002)	Wang et al., (2015)	Barsila et al., (2020**)	Barsila et al. (2024)
Haemoglobin (g/dl)	9.0-15.0	8-16	9.08-16.01	15.68-17.53	10.10-10.82
PCV (%)	27-45	24-50	16.6-53.2	-	30.57-32.0
RBC (x10^{6}µL)	9.0-15.0	8-15	3.75-12.6	9-11.48	9.03-9.95
Platelets (x10^{3}µL)	250-750	-	-		422-465
WBC(x10^{3}µL)	4-12	4-12	3.5-18.0	5.66-7.66	6.60-7.92
Neutrophil %	10-50	10-50	26.3-70.1		38.25-42.17
Lymphocyte	40-75	40-75	35.2-71.0	56.5-67.31	55.75-60.25
Monocyte	0-6	0-6	0.2-4.5	-	-
Eosinophil	0-10	0-10	0.9-5.1	-	-
Basophil	0-3	0-3	0-0.4	-	-

**data from 32 healthy Baruwal sheep were selected and divided into four groups: male (8) below 1 year, male (8) greater than 1 year, female (8) below 1 year, and female (8) greater than 1 year,study report from Jumla Nepal (2431-3885 m asl).

Erythrocytic (RBC) alteration in transhumant animals

Red blood cells (erythrocytes) serve as carriers of haemoglobin (Table 1). Elevation of RBC levels is an important physiological event that occurs in transhumant animals to cope with environmental factors at high altitudes. At high altitudes, an increase in RBC and a decrease in MCV occurred simultaneously in the total count, so the total surface area of the RBC was enlarged, which was advantageous for hemoglobin binding to oxygen (Bunn & Poyton, 1996; Wu et al., 2005). Therefore, an increase in RBC and a decrease in the MCV area are common hematological mechanisms by which mammals and birds adapt to high-altitude hypoxia (Wu et al., 2005).

Hypoxic conditions at high altitudes regulate the partial pressure of oxygen in arteries, altering physiological phenomena either by changing the haemoglobin concentration in the blood or by changing the oxygen-binding affinity of haemoglobin (Storz, 2007; Storz & Moriyama, 2008). The oxygen pressure (POL) at 3000 m is 68% of the value at sea level, and it further decreases with increasing altitude (Sarkar et al., 1999). To cope with the hypoxic conditions at high altitudes, the animal has some compensatory adaptations, such as an increase in erythropoietin production, which in turn enhances red blood cell production and the synthesis of haemoglobin

(Dover, 1979). Decreased oxygen in circulation enhances erythropoiesis under the influence of the hormone erythropoietin, which stimulates the proliferation and differentiation of red cell precursors and increases erythropoiesis in hemopoietic tissues, ultimately producing erythrocytes (Gonzales, 2011). Yersin et al. (1992) also reported that an increase in RBC, Hband haematocrit percentage is a compensatory mechanism of reduced oxygen saturation. Storz (2007) reported that haemoglobin, which has high oxygen affinities, is more abundant in high-altitude species than in lowland relatives.

Leukocytic alterations in transhumant animals

White blood cells (WBCs), also called leucocytes, are the cells of the immune system that are involved in the defense mechanism of the body. White blood cells are produced and derived from multi-potent cells in the bone marrow known as hematopoietic stem cells (Maton et al., 1993). Animals with low white blood cell counts are at high risk of disease infection, whereas those with high counts are capable of generating antibodies in the process of phagocytosis and have a high degree of resistance to diseases (Soetan et al., 2013).

The stress imposed on an animal during transhumancy can release stress hormones, resulting in elevated levels in several leukocytes via activation of the hypothalamic–pituitary–adrenal axis, resulting in increased cortisol levels (Dantzer & Mormede, 1983). These stress hormones, particularly cortisol and adrenaline, are well known for their ability to increase WBC (white blood cell) counts and exert differential effects on leukocyte subset counts (Cupps & Fauci, 1982). Researchers have suggested that acute activation of stress hormones enhances immune function by directing leucocytes to exit the spleen and bone marrow and enter the bloodstream (Dhabar & McEwen,1997). A study conducted by Chandra et al. (2013) reported a greater level of cortisol at a higher temperature during the summer than during the spring (Table 1). However, chronic activation of stress hormones suppresses cell-mediated immunity by decreasing leukocyte deployment to the peripheral bloodstream, which negatively impacts the ability of the immune system to respond to an immunological challenge (Beidleman et al., 2006). Cortisol levels also increase when animals are exposed to cold stress due to lipolysis and the utilization of brown adipose tissue for heat production (Himms-Hagen, 1990).The details of leukocyte concentration in sheep blood has been presented in Table 1.

Hemoglobin (Hb)

Hemoglobin is an iron-containing oxygen-transporting protein in the red blood cells of vertebrates. The deficiency of haemoglobin in red blood cells decreases blood oxygen-carrying capacity, leading to anaemia (Aaron et al., 2005). Hemoglobin has the physiological function of transporting oxygen to the tissues of the animal for the oxidation of ingested food to release energy for other body functions as well as transporting carbon dioxide out of the body of the animal (Ugwuene, 2011). Packed cell volume, haemoglobin and mean corpuscular haemoglobin are major indices for evaluating circulatory erythrocytes (Table 1), are significant in the diagnosis of anaemia and serve as useful indices of the bone marrow capacity to produce red blood cells, as in mammals (Awodi et al., 2005; Chineke et al.,2006).

Biochemical components of blood

Total protein (TP)

TP indicates total protein in the serum (see Table 2 for detail reports of different authors). Albumin, globulin, and fibrinogen are three major protein fractions contained in blood plasma (Murray, 2003). The major share in the blood plasma of humans, sheep, goats, rabbits, and rats is Albumin, whereas in the blood of horses, pigs, and cattle, globulin prevails (Gentry, 2004).

The basis of cell structure, maintenance of colloidal osmotic pressure, catalysis of biochemical reactions, buffer action, regulation of hormones, participation in blood coagulation, proffer immunity, nutrition, and transportation of most of the plasma constituents are formed by the protein (Kaneko, 2008). Total plasma protein is elevated by the anabolic effects of hormones such as growth hormone, estrogens, and testosterone and is reduced by the catabolic effects of hormones such as thyroxin and cortisol (Kaneko, 2008).

Table 2. Reference biochemical values of sheep available in some of the literature

Parameters	Radostits et al. (2006)	Kaneko et al. (2008)	Wang et al. (2015)*	Barsila et al. (2024)**
Glucose (mg/dl)	50-80	50-80	27-126	72.17-77.33
Triglyceride (mg/dl)	-	-	-	51.44-71.92
Cholesterol (mg/dl)	43-103	52-76	120-309	53.29-66.59
Total Protein (g/dl)	6-7.9	6.0-7.9	4.2-7.4	5.71-5.91
Albumin (g/dl)	2.4-3.0	2.4-3.0	1.5-4.7	3.28-3.36
Creatinine (mg/dl)	1.2-1.9	1.2-1.9	0.35-2.37	0.92-0.99
Urea (mg/dl)	17.1-42.8	36.6-92.2	10-114	45.17-48.25

* Converted values (US units to SI units) in Tibetan sheep,

**24 adult animals, 18 nonpregnant and nonlactating females and 6 intact males in Solukhumbu Nepal(2393-3391 m asl).

Source: Barsila et al (2024), Kaneko et al. (2008c), Radostits et al. (2006), Wang et al. (2015)

Albumin

Albumin is the most abundant protein in human plasma, constituting 50% of the total plasma protein content and accounting for 70% of the oncotic pressure of plasma. The synthesis of albumin is governed by changes in plasma colloidal osmotic pressure but is also regulated by nutritional status and hormones, including insulin, glucagon, cortical, and thyroid hormones (Farrugia, 2010). The serum ALB concentration is a good indicator for predicting an animal's protein status. A decrease in albumin levels is observed in ruminants with low dietary protein intake. In ruminants with low dietary protein intake, a decrease in the serum ALB concentration is observed (Caldeira et al., 1999; Sykes, 1978). Decreased values of serum ALB are observed in conditions such as malnutrition, hepatic diseases, protein deficiency, starvation, and malignancy; these conditions can decrease (Keser et al., 2008). Depression of protein synthesis in the liver under low oxygen tension at relatively high altitudes can also reduce the synthesis of serum albumin in animals (Monge et al., 1991). The details of blood albumin reports have been presented in Table 2.

Glucose

Glucose in the blood is produced by the intestinal absorption of dietary glucose or by the hepatic production of glucose from its precursors, such as glycogen, fructose, galactose, glucogenic amino acids, etc. (Kaneko, 2008). The glucose level reported in previous studies is associated with cold stress. The increase in glucose levels in cold-stressed lambs was observed as a compensatory mechanism to produce heat for the neonate by depleting glycogen stores. The increase in glucose levels under cold stress is associated with increased energy requirements during weather. The mobilization of lipids and glycogen to provide energy precursors needed for thermogenesis (Himms-Hagen, 1990), which in turn elevates glucose levels in hypothermic animals, is associated with an increase in rectal temperature in calves (Godfrey et al., 1991).

Plasma glucose may differ significantly between the groups with the highest concentration in animals growing in a hot and humid environment. Higher glucose levels may be due to the greater requirement of energy sources in the form of glucose to support the effort of physiological mechanisms for thermoregulation(see all blood glucose reports by different authors in Table 2). Furthermore, the cortisol levels in these stressed animals are relatively high, which favours hepatic gluconeogenesis to supply more glucose for respiratory muscular activities to dissipate more heat (Sejian & Srivastava, 2010).

Factors influencing blood parameters

Both genetic and nongenetic factors influence the haematology and serum biochemical indices of various livestock. Genetic factors include breed characteristics, whereas age, sex, management system, health status and environmental factors such as nutrition, hormones, and climate are regarded as nongenetic parameters. The haematological values of farm animals are influenced by age, sex, breed, climate, geographical location, season, day length, time of day, nutritional status, life habits of the species, the present status of the individual and other factors (Afolabi et al., 2010).

Breed and genotype

A study conducted by Chineke et al. (2006) to determine the haematological parameters of rabbit breeds and crosses in the humid tropics reported that the genotype influences on the PCV, WBC, MCH, and ESR and that the RBC, HBC and MCHC values were identical across all the genotypes, indicating similar cellular haemoglobin contents in the blood samples obtained. A study on haematological parameters in goat kids reported that breed had a significant effect on PCV (Ekiz & Yalcintan, 2013). Schalm et al. (1975) reported that haematological studies of farm animals either revealed significant or no significant breed effects. Ologunowa et al. (2000) reported no significant breed effect on blood parameters in their study.

Genetic factors

Effect of altitude

Various studies have addressed the effects of high altitude on haemoglobin, erythropoietin, and platelets (Singh & Chohan, 1972). At high altitudes, an increase in the haemoglobin level secondary to an increase in the erythropoietin level has been confirmed (Abbrecht & Littell, 1972). The ascent to high altitudes is associated with the expansion of red cell counts, which is well documented. Furthermore, with increasing altitude, erythropoietin levels increase rapidly (Faura et al., 1969).

Yaks (*Bos grunniens*) have been proven to be better adapted to high altitudes than their first-generation hybrids Dimjos (*B. grunniens* × *B. indicus*) and Urangs (*B. taurus* × *B. grunniens*); in research conducted in Nepalese Yaks and their hybrids, the former is better adapted than the latter (Barsila, 2014a; Barsila et al., 2015), which indicates higher haemoglobin levels and better oxygen uptake capacity at high altitudes (Bianca et al., 1978; Hays et al., 1978).

Effect of nutrition

The physiological disposition of the animals to their nutrition is determined by haematology and serum biochemistry assays of livestock (Menon et al., 2013). Swenson et al. (2005) suggested that diet affects serum vitamin, protein and lipid concentrations. The humorous discrepancy in the hematological and serum biochemical profiles of livestock animals is triggered by a deficiency of both macro- and micronutrients (Onasanya et al., 2015).

Effect of the management system

Olayemi et al. (2000) reported higher PCV, Hb and MCV in intensively managed animals than in extensively managed animals in a study conducted to determine the hematology of West African dwarf sheep under two management systems in Nigeria. Omani goats reared under an intensive system with commercial feeds reportedly have higher levels of serum vitamin B_{12} than their counterparts reared under an extensive system with greens forages (Al-Zadjali et al., 2004). Compared with animals reared in intensive systems, those reared in extensive systems tend to have a lower glucose index (Onasanya et al., 2015). The sedentary lifestyle of intensively cared animals may not involve increased consumption of blood glucose; however, for physical and ranging activities, animals under extensive care might consume this blood glucose. Compared with modern husbandry practices, sheep and goats managed under traditional husbandry practices have low haematological values regardless of age, sex and climate (Coles, 1986; Schalm et al., 1975). The management system under which animals are reared**,** therefore, greatly affects a wide range of hematological and serum biochemical parameters.

Effect of season

The physiological response of an animal to its surrounding environment is reflected by haematological and biochemical parameters. The effect of cold stress on changes in the blood profile of lambs was presented by Maurya et al. (2013), who reported significantly increased levels of PCV, Hb, and glucose in cold-stressed lambs. Similarly, increased values of haematological indices such as haematocrit and haemoglobin levels in sheep were observed at a relatively low temperature during the winter season by Šoch et al. (2011). The increase in glucose levels represents a regulatory mechanism for the requirement of more energy to fight cold stress during the winter in animals. The mobilization of lipids and glycogen provides the energy precursors needed for thermogenesis, which in turn elevates glucose levels in hypothermic animals. (Himms-Hagen, 1990).

Seasonal variability has an impact on the physiological, haematological and biochemical parameters of growing and adult animals. Bhan et al. (2013) reported a significant increase in haematological parameters, viz. packed cell volume (PCV) and haemoglobin (Hb) in Karanfriesian cattle during summer compared with other seasons of the year. Variation in environmental temperature and relative humidity also causes variations in physiological responses, blood metabolites, and hormones. The magnitude of the increase in the heart rate and temperature of animals during summer was significantly greater than that in spring Bhan et al. (2013). Similarly, Das et al. (1999) reported increases in respiration rates and pulse rates in young buffalo calves exposed to solar radiation. Mirzadeh et al. (2010) reported lower WBC counts in different breeds of cattle during summer than in spring. Changes in these parameters due to climatic variability may help in designing strategies for combining stress and maximizing production.

Effect of stress and release of hormones

A factor that elicits defence mechanisms in animals is considered stress (Scope et al., 2002). Therefore, any condition that stimulates protective responses in animals is a stress stimulus. The combination of the situation in which the animal lives may act as a stressor. In mammals, to prevent hyperthermia, increased respiration for the expulsion of more carbon dioxide and elimination of moisture from the respiratory tract is a major adaptive mechanism under high ambient temperature. Thermal stressors negatively influence physiological activities in the form of environmental heat stress. It increases overall performance, e.g., growth, feed intake, lactation, conception, gestation, etc., if the animal suffers difficulty in dissipating excess heat load from the body (Onasanya et al., 2015).

Stress, hydration status, hormonal influences, dietary/nutritional differences, adaptations to a desert environment or adaptations to a high mountain environment may also cause differences in red blood cell (RBC) counts (Borjesson et al., 2000). In addition to the decrease in total white blood, basophil and lactate dehydrogenase levels observed in clinical practice, stress increases glucose and creatine kinase levels and decreases uric acid levels (Scope et al., 2002). Conversely, monocytes, eosinophils, aspartate aminotransferase, total protein, and the packed cell volume are not influenced by stress (Scope et al., 2002). Hence, various changes in hematological and biochemical indices due to increased stimulation by corticoids could be induced by the introduction of abrupt or sudden stress.

Effect of age

In animals aged 3–10 years, with increasing age, the mean corpuscular volume, haemoglobin concentration, and mean corpuscular haemoglobin concentration increase, and the leukocyte count and lymphocyte count decrease (Watson et al., 1993). The values of blood cholesterol, triglycerides, urea, creatinine, total protein, and globulin are affected by age (Antunovic et al., 2002; Carlos et al., 2015). In young animals, the total protein concentration is lower (Marco et al., 1997) and reduces the amount of protein added to the diet, whereas a possible increase in globulin and a slight decrease in albumin are attributed to a slightly greater total protein level in older ewes (Perk & Lobl, 1960). With increasing age, there is a decrease in albumin and an increase in globulin concentrations, which have been linked with a decrease in protein synthesis (albumin) by the liver and increased exposure to different antigens and/or diseases over time, thus stimulating the entry of additional antibodies (globulins) into the bloodstream (Dubreuil et al., 2005). In mature ewes, the lower glucose concentration could be associated with a lower rate of recovery of glucose (Radostits et al., 2006).

Effect of sex

Sex had a significant effect on the Hb concentration; females had higher mean corpuscular Hb concentration values than males did. Sex influences lymphocytes and neutrophils in West African dwarf (WAD) male goats and Nepalese mountain sheep (Barsila et al., 2020) compared with their female counterparts (Daramola et al., 2005).

CONCLUSION

The physiological and metabolic changes in high-altitude-adapted animals are unique to the study of biological processes. The associated changes could lead to alterations in the productive and reproductive performance of domestic animals. These changes are compensated for by multiple genetic and nongenetic factors. However, indirect measurements of physiological parameters and metabolic blood profiles may reveal the biochemical changes associated with high-altitude pastoralism and stress, including nutritional deficiencies, in pastoral areas.

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REFERENCES

Aaron, S., Kumar, S., Vijayan, J., Jacob, J., Alexander, M., & Gnanamuthu, C. (2005). Clinical and laboratory features and response to treatment in patients presenting with vitamin B12 deficiency-related neurological syndromes. *Neurology India, 53*(1), 55.

Abbrecht, P. H., & Littell, J. K. (1972). Plasma erythropoietin in men and mice during acclimatization to different altitudes. *Journal of Applied Physiology, 32*(1), 54-58.

Aderemi, F. A. (2004). Effects of replacement of wheat bran with cassava root sieviate supplemented or unsupplemented with enzyme on the haematology and serum biochemistry of pullet chicks. *Trop. J. Anim. Sci, 7*(1), 147-153.

Afolabi, K. D., Akinsoyinu, A. O., Abdullah, A. R. O., Olajide, R., & Akinleye, S. B. (2010). Haematological parameters of the Nigerian local grower chickens fed varying dietary levels of palm kernel cake. *Poljoprivreda, 17*(1), 74-78.

Al-Zadjali, A., Johnson, E. H., & Srikandakumar, A. (2004). Serum vitamin B12 levels in Omani goats. *Tropical Animal Health and Production, 36*, 473-482.

Antunovic, Z., Sencic, D., Speranda, M., & Liker, B. (2002). Influence of the season and the reproductive status of ewes on blood parameters. *Small Ruminant Research, 45*(1), 39-44.

Aryal, S., Maraseni, T. N., & Cockfield, G. (2014). Sustainability of transhumance grazing systems under socioeconomic threats in Langtang, Nepal. *Journal of Mountain Science, 11*(4), 1023-1034.

Awodi, S., Ayo, J. O., Atodo, A. D., & Dezende, T. (2005). Some haematological parameters and the erythrocyte osmotic fragility in the Laughing Dove (Streptopella senegalensis) and the village Weaver bird (Ploceus cucullatus). In: Dairo, F.A, Fajemilehin, S.O.K, and Onibi, G.E. (Eds), *Proceedings of the 10th Annual Conference of Animal Science Association of Nigeria*, held on 12–15 September at University of Ado Ekiti, Nigeria, 384–387.

Barsila, S. R., Bhatt, K., Devkota, B., & Devkota, N. R. (2020). Haematological changes in transhumant Baruwal sheep (Ovis aries) grazing in the western Himalayan mountains in Nepal. *Pastoralism*, 10 (1), 4.

Barsila, S. R., Devkota, N. R., & Barshila, I. (2014b). Transhumant migration of Baruwal sheep (Ovis aries): A case study from the Kanchenjunga conservation Area of Nepal. *African Journal of Agricultural Research, 9*(40), 3011-3017.

Barsila, S. R., Devkota, N. R., Kreuzer, M., & Marquardt, S. (2015). Effects of different stocking densities on performance and activity of cattle× yak hybrids along a transhumance route in the Eastern Himalaya. *SpringerPlus, 4*(1), 1-12.

Barsila, S. R., Kreuzer, M., Devkota, N. R., Ding, L., & Marquardt, S. (2014a). Adaptation to Himalayan high altitude pasture sites by yaks and different types of hybrids of yaks with cattle. *Livestock Science, 169*, 125-136.

Barsila, S. R., Neupane, G., & Chhetri, R. K. (2024). Blood Metabolic Profile of Transhumant Baruwal Sheep Grazing Pastures of Two Different Altitudes at Similar Temperature Humidity Index. *Journal of Agriculture and Resource Management, 1*, 192-212.

Beidleman, B. A., Muza, S. R., Fulco, C. S., Cymerman, A., Staab, J. E., Sawka, M. N., ... & Skrinar, G. S. (2006). White blood cell and hormonal responses to 4300 m altitude before and after intermittent altitude exposure. *Clinical Science, 111*(2), 163-169.

Bhan, C., Singh, S. V., Hooda, O. K., Upadhyay, R. C., & BEENAM, B. (2013). Influence of temperature variability on physiological, hematological and biochemical profiles of growing and adult Karan Fries cattle. *ICAR*. https://agris.fao.org/agris-search/search.do?recordID=IN2022008210.

Bianca, W., & Kunz, P. (1978). Physiological reactions of three breeds of goats to cold, heat and high altitude. *Livestock Production Science, 5*(1), 57-69.

Borjesson, D. L., Christopher, M. M., & Boyce, W. M. (2000). Biochemical and hematologic reference intervals for free-ranging desert bighorn sheep. *Journal of Wildlife Diseases, 36*(2), 294-300.

Brutsaert, T. D. (2007). Population genetic aspects and phenotypic plasticity of ventilatory responses in high altitude natives. *Respiratory Physiology & Neurobiology, 158*(2-3), 151-160.

Bunn, H. F., & Poyton, R. O. (1996). Oxygen sensing and molecular adaptation to hypoxia. *Physiological Reviews, 76*(3), 839-885.

Caldeira, R. M., Almeida, M. A., Santos, C. C., Vasques, M. I., & Portugal, A. V. (1999). Daily variation in blood enzymes and metabolites in ewes under three levels of feed intake. *Canadian Journal of Animal Science*, *79*(2), 157-164.

Carlos, M. M. L., Leite, J. H. G. M., Chaves, D. F., Vale, A. M., Façanha, D. A. E., Melo, M. M., & Soto-Blanco, B. (2015). Blood parameters in the morada nova sheep: influence of age, sex and body condition score. *Journal of Animal & Plant Sciences, 25*(4), 950-955.

Chandra, A., Copen, C. E., & Stephen, E. H. (2013). Infertility and impaired fecundity in the United States, 1982-2010: data from the National Survey of Family Growth (No. 2013). *US Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Health Statistics, 2013*.

Chineke, C. A., Ologun, A. G., & Ikeobi, C. O. N. (2006). Haematological parameters in rabbit breeds and crosses in humid tropics. *Pakistan Journal of Biological Sciences, 9*(11), 2102-2106.

Coles, E. H. (1986). *Veterinary Clinical Pathology* (4th ed.). Philadelphia: WB Saunders Co.

Cork, S. C., & Halliwell, R. W. (2002). Veterinary Laboratory and Field Manual. Nottingham, UK: Nottingham University Press.

Cupps, T. R., & Fauci, A. S. (1982). Corticosteroid-mediated immunoregulation in man. *Immunological Reviews, 65*, 133-155.

Dantzer, R., & Mormède, P. (1983). Stress in farm animals: a need for reevaluation. *Journal of Animal Science, 57*(1), 6-18.

Daramola, J. O., Adeloye, A. A., Fatoba, T. A., & Soladoye, A. O. (2005). Haematological and biochemical parameters of West African Dwarf goats. *Livestock Research for Rural Development, 17*(8), 95.

Das, S. K., Upadhyay, R. C., & Madan, M. L. (1999). Heat stress in Murrah buffalo calves. *Livestock Production Science, 61*(1), 71-78.

Dhabhar, F. S., & McEwen, B. S. (1997). Acute Stress Enhances while Chronic Stress Suppresses Cell-Mediated Immunity in Vivo: A Potential Role for Leukocyte Trafficking. *Brain, Behavior, and Immunity, 11*(4), 286–306. https://doi.org/10.1006/brbi.1997.0508.

Dover, G. J., Boyer, S. H., & Zinkham, W. H. (1979). Production of erythrocytes that contain fetal hemoglobin in anemia: transient in vivo changes. *The Journal of Clinical Investigation, 63*(2), 173-176.

Doyle, D. (2006). William Hewson (1739–74): the father of haematology. *British Journal of Haematology, 133*(4), 375-381.

Dubreuil, P., Arsenault, J., & Belanger, D. (2005). Biochemical reference ranges for groups of ewes of different ages. *Veterinary Record*, *156*(20), 636-638.

Eckert, J., & Hertzberg, H. (1994). Parasite control in transhumant situations. *Veterinary Parasitology, 54*(1-3), 103-125.

Ekiz, E. E., & Yalcintan, H. (2013). Comparison of certain haematological and biochemical parameters regarding preslaughter stress in Saanen, Maltese, Gokceada and hair goat kids. *Istanbul Üniversitesi Veteriner Fakültesi Dergisi, 39*(2), 189-196.

Farrugia, A. (2010). Concerning Chapter 5–Human Albumin; in Cross-Sectional Guidelines for Therapy with Blood Components and Plasma Derivatives, Transfus Med Hemother 2009; 36 (6): 399–407. Transfusion Medicine and Hemotherapy, 37(2), 98.

Faura, J., Ramos, J., Reynafarje, C., English, E., Finne, P. E. R., & Finch, C. A. (1969). Effect of altitude on erythropoiesis. *Blood, 33*(5), 668-676.

Gentry, P. A. (2004). Comparative aspects of blood coagulation. *The Veterinary Journal*, *168*(3), 238-251.

Godfrey, K. M., Redman, C. W. G., Barker, D. J. P., & Osmond, C. (1991). The effect of maternal anaemia and iron deficiency on the ratio of fetal weight to placental weight. *BJOG: An International Journal of Obstetrics & Gynaecology, 98*(9), 886-891.

Gonzales, G. F., Tapia, V., Gasco, M., Rubio, J., & Gonzales-Castañeda, C. (2011). High serum zinc and serum testosterone levels were associated with excessive erythrocytosis in men at high altitudes. *Endocrine, 40*, 472-480.

Graf, L. C., Furian, M., Bitos, K., Mademilov, M., Abdraeva, A., Buenzli, J., ... & Bloch, K. E. (2022). Effect of altitude and acetazolamide on sleep and nocturnal breathing in healthy lowlanders 40 y of age or older. Data from a randomized trial. *Sleep, 46(4), zsac269*.

Gurung, K. (2008). Sheep Transhumance in Humla: A Declining Practice. *Methodology, 19*, 22. Retrieved October 05, 2016 from http://www.socialinclusion.org.np/new/contentResources.

Hafez, E. S. E. (1968). Adaptation of domestic animals. Philadelphia: Lea and Febiger.

Hainsworth, R. (1995). The control and physiological importance of heart rate. In *Heart Rate Variability* (eds M Malik and A.J. Camm), pp. 3–19. Futura Publishing, Armonk, USA.

Hays, F. L., Bianca, W., & Näf, F. (1978). Effects of exercise on young and adult cattle at low and high altitude. *International Journal of Biometeorology, 22*, 147-158.

Herrera, E. A., Riquelme, R. A., Ebensperger, G., Reyes, R. V., Ulloa, C. E., Cabello, G., & Llanos, A. J. (2010). Long-term exposure to high-altitude chronic hypoxia during gestation induces neonatal pulmonary hypertension at sea level. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 299*(6), R1676-R1684.

Himms-Hagen, J. (1990). Brown adipose tissue thermogenesis: interdisciplinary studies. *The FASEB Journal, 4*(11), 2890-2898.

Isaac, L. J., Abah, G., Akpan, B., & Ekaette, I. U. (2013). Haematological properties of different breeds and sexes of rabbits. In *Proceedings of the 18th Annual Conference of Animal Science Association of Nigeria* (pp. 24-27).

Ivy, C. M., & Scott, G. R. (2015). Control of breathing and the circulation in high-altitude mammals and birds. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, 186*, 66-74.

Joshi, B. R., & Shrestha, B. S. (2010). Livelihood Support to the Farmers of Darchula by improving productivity and income from sheep and goats (NARDF PP 321/05/06). NARC, Nepal.

Kaneko, J. J., Harvey, J. W., & Bruss, M. L. (Eds.). (2008). *Clinical Biochemistry of Domestic Animals*. Academic press.

Keser, G. B., & Ekmen, N. Evaluation of the relationship between disease activity and serum bilirubin, albumin, and uric acid levels in Crohn's disease. *Journal of Health Sciences and Medicine*, *4*(5), 639-645.

Marco, I., Vinas, L., Velarde, R., Pastor, J., & Lavin, S. (1997). Effects of capture and transport on blood parameters in free-ranging mouflon (Ovis ammon). *Journal of Zoo and Wildlife Medicine*, 428-433.

Maton, A., Jean, H., Charles, W., McLaughlin, S. J., Maryanna, Q. W., David, L., Wright, J. D. (1993). *Human biology and health*. Englewood Cliffs, New Jersey, USA: Prentice Hall.

Maurya, V. P., Sejian, V., & Naqvi, S. M. K. (2013). Effect of cold stress on growth, physiological responses, blood metabolites and hormonal profile of native Malpura lambs under hot semiarid tropics of India. *Indian Journal of Animal Science*, 83, 370-373.

Menon, D. G., Bennett, D. C., Schaefer, A. M., & Cheng, K. M. (2013). Hematological and serum biochemical profile of farm Emus (Dromaius novaehollandiae) at the onset of their breeding season. *Poultry Science*, 92(4), 935-944.

Mirzadeh, K. H., Tabatabaei, S., Bojarpour, M., & Mamoei, M. (2010). Comparative study of hematological parameters according to strain, age, sex, physiological status, and season in Iranian cattle. *Journal of Animal and Veterinary Advances*, 9(16), 2123-2127.

Mitruka, B. M., & Rawnsley, H. M. (1977). Clinical biochemical and hematological reference values in normal experimental animals. Oklahoma: Massion Publishing.

Moktan, M. R., Norbu, L., Nirola, H., Dukpa, K., Rai, T. B., & Dorji, R. (2008). Ecological and social aspects of transhumant herding in Bhutan. *Mountain Research and Development*, 28(1), 41-48.

Monge, C., & León-Velarde, F. A. B. I. O. L. A. (1991). Physiological adaptation to high altitude: oxygen transport in mammals and birds. *Physiological Reviews*, *71*(4), 1135-1172.

Mysterud, A., Yoccoz, N. G., Stenseth, N. C., & Langvatn, R. (2001). Effects of age, sex, and density on body weight of Norwegian red deer: evidence of density–dependent senescence. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 268(1470), 911-919.

Olayemi, F. O., Farotimi, J. O., & Olayemi, O. A. (2000). Haematology of the West African dwarf sheep under two different management systems in Nigeria. *African Journal of Biomedical Research*, 3(3), 197-198.

Ologunowa, E. O. (2000). Rabbit breeds analysis for haematological indices (Doctoral dissertation, Federal University of Technology Akure).

Onasanya, G. O., Oke, F. O., Sanni, T. M., & Muhammad, A. I. (2015). Parameters influencing haematological, serum, and biochemical references in livestock animals under different management systems. *Open Journal of Veterinary Medicine*, 5(08), 181.

Ovuru, S. S., & Ekweozor, I. K. E. (2004). Haematological changes associated with crude oil ingestion in experimental rabbits. *African Journal of Biotechnology*, 3(6), 346-348.

Perk, K., & Lobl, K. (1960). Chemical and paper electrophoretic analysis of normal sheep serum proteins and lipoproteins. *British Veterinary Journal*, 116, 167-174.

Powell, F. L., Milsom, W. K., & Mitchell, G. S. (1998). Time domains of the hypoxic ventilatory response. *Respiration Physiology*, 112(2), 123-134.

Radostits, O. M., Gay, C. C., Hinchcliff, K. W., & Constable, P. D. (Eds.). (2006). *Veterinary Medicine: A Textbook of the Diseases of Cattle, Horses, Sheep, Pigs, and Goats*. Elsevier Health Sciences.

Sarkar, M., Niranjan, N., & Banyal, P. K. (2017). Mechanisms of hypoxemia. *Lung India: Official Organ of Indian Chest Society*, 34(1), 47.

Schalm, O. W., Jain, N. C., & Carroll, E. J. (1975). *Veterinary Haematology* (3rd edition). Lea and Febiger, Philadelphia. Pp 32-606.

Schmidt, I., & Herpin, P. (1997). Postnatal changes in mitochondrial protein mass and respiration in skeletal muscle from the newborn pig. *Comparative Biochemistry and Physiology Part B: Biochemistry and Molecular Biology*, 118(3), 639-647.

Scope, A., Filip, T., Gabler, C., & Resch, F. (2002). The influence of stress from transport and handling on hematologic and clinical chemistry blood parameters of racing pigeons (Columba livia domestica). *Avian Diseases*, 46(1), 224-229.

Sejian, V., & Srivastava, R. S. (2010). Effects of pineal proteins on biochemical, enzyme profile, and nonspecific immune response of Indian goats under thermal stress. *Animal Production Research Advances*, 6, 1-6.

Singh, I., & Chohan, I. S. (1972). Blood coagulation changes at high altitude predisposing to pulmonary hypertension. *British Heart Journal*, 34(6), 611.

Šoch, M., Brouček, J., & Šrejberová, P. (2011). Hematology and blood microelements of sheep in south Bohemia. *Biologia*, 66, 181-186.

Soetan, K. O., Akinrinde, A. S., & Ajibade, T. O. (2013). Preliminary studies on the haematological parameters of cockerels fed raw and processed guinea corn (Sorghum bicolor). *Proceedings of the 38th Annual Conference of Nigerian Society for Animal Production*, pp 49-52.

Storz, J. F. (2007). Hemoglobin function and physiological adaptation to hypoxia in high-altitude mammals. *Journal of Mammalogy*, 88(1), 24-31.

Storz, J. F., & Moriyama, H. (2008). Mechanisms of hemoglobin adaptation to high altitude hypoxia. *High Altitude Medicine & Biology*, 9(2), 148-157.

Swenson, M. J. (2005). Physiological properties, cellular, and chemical constituents of blood. In M. J. Swenson (Ed.), *Dukes' Physiology of Domestic Animals* (9th ed., pp 14-35). New Delhi: CBS Publishers & Distributors Pvt. Ltd.

Sykes, A. R. (1978). An assessment of the value of plasma urea nitrogen and albumin concentrations as monitors of the protein status of sheep. *BSAP Occasional Publication*, *1*, 143-154.

Tulachan, P. M., Tej, P., Maki-Hokkonen, J., Mohamed, S., & Beryl, R. (2000). Livestock in the mountains and highlands of Asia, Africa, and South America: an overview of research and development issues and challenges. In *Contribution of Livestock to Mountain Livelihoods*. Proceedings of the International Symposium on Livestock in Mountain/Highland Production Systems: Research and Development Challenges into the Next Millennium, Pokhara, Nepal, 7-10 December, 1999 (pp. 3-31). International Centre for Integrated Mountain Development.

Ugwuene, M. C. (2011). Effect of dietary palm kernel meal for maize on the haematological and serum chemistry of broiler turkey. *Nigerian Journal of Animal Science*, 13, 93-103.

Vallentine, J. F. (2001). *Grazing Management*, 2nd edn. Academic Press, San Diego.

Von Borell, E., Langbein, J., Després, G., Hansen, S., Leterrier, C., Marchant-Forde, J., & Veissier, I. (2007). Heart rate variability as a measure of autonomic regulation of cardiac activity for assessing stress and welfare in farm animals—A review. *Physiology & Behavior*, 92(3), 293-316.

Wang, H., Huang, M., Li, S., Wang, S., Dong, S., Cui, D., & Liu, Y. (2015). Hematologic, Serum Biochemical Parameters, Fatty Acid and Amino Acid of Longissimus dorsi Muscles in Meat Quality of Tibetan Sheep. *Acta Scientiae Veterinariae*, 43.

Watson, T. D. G., Burns, L., Packard, C. J., & Shepherd, J. (1993). Effects of pregnancy and lactation on plasma lipid and lipoprotein concentrations, lipoprotein composition and postheparin lipase activities in Shetland pony mares. *Journal of Reproduction and Fertility*, 97(2), 563-568.

Wu, T., Wang, X., Wei, C., Cheng, H., Wang, X., Li, Y., & Wang, Z. (2005). Hemoglobin levels in Qinghai–Tibet: different effects of gender for Tibetans vs. Han. *Journal of Applied Physiology*.

Yersin, A. G., Huff, W. E., Kubena, L. F., Elissalde, M. H., Harvey, R. B., Witzel, D. A., & Giroir, L. E. (1992). Changes in hematological, blood gas, and serum biochemical variables in broilers during exposure to simulated high altitude. *Avian Diseases*, 189-196.