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RESEARCH ARTICLE

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Seasonal Adaptability of Black Bengal Goats: A Four-season Study of Serum Biochemical, Mineral, Hormonal and Oxidative Stress Biomarkers

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ABSTRACT

Background: Climate change increasingly threatens global ecosystems, with livestock in developing countries like India being particularly vulnerable. Variations in temperature and humidity throughout the seasons significantly affect animal health, adaptability and productivity. Black Bengal goats, an important genetic resource in Bihar, are noted for their resilience and economic value. Understanding their physiological and biochemical responses to seasonal stress is crucial for creating effective management strategies.

Methods: This study investigated the seasonal adaptability of Black Bengal goats by evaluating various physiological and biochemical parameters across four distinct seasons: summer, monsoon, post-monsoon and winter. Twenty healthy female goats were chosen and blood samples were collected in each season. The temperature-humidity index (THI) was calculated to assess heat stress conditions. Key biomarkers analyzed included biochemical (blood urea nitrogen, albumin, globulin, glucose), hormonal (cortisol, TSH, T3, T4), mineral and oxidative stress markers (glutathione, malondialdehyde [MDA], catalase, total antioxidant capacity [TAC] and superoxide dismutase [SOD]).

Result: The THI values showed severe heat stress during the summer and monsoon seasons (THI > 85), moderate stress in the post-monsoon period (THI 78) and comfortable conditions in winter (THI 63). Significant seasonal variations were observed in biochemical parameters, with the most notable changes occurring in summer. Cortisol levels were higher during summer and monsoon, indicating heat-induced stress, while thyroid hormones (TSH, T3 and T4) were elevated in winter and post-monsoon, suggesting thermoregulatory adaptations. Oxidative stress markers also varied significantly, with increased oxidative damage and antioxidant enzyme activity during hotter seasons. These findings emphasize the impact of seasonal stress on goat physiology and highlight the need for season-specific strategies to improve resilience and productivity.

Key words: Goat, Mineral, Hormone, Oxidative stress, Season, Temperature-humidity index.

INTRODUCTION

Climate change presents a major risk to global ecosystems, with forecasts indicating that unusual weather patterns may cause the extinction of approximately 8% of animal species worldwide (Joy *et al*., 2020). Over the last hundred years, India has experienced temperature increases in all seasons-summer, monsoon, post-monsoon and winter-with notable warming during the post-monsoon and winter periods (Tesfaye *et al.,* 2017). The rise in minimum temperatures in India has exceeded the maximum temperatures, leading to a reduced diurnal temperature range across the country (Roy and Balling, 2005). In developing nations such as India, goats, referred to as the "poor man's cow," are vital to rural populations' livelihoods, providing income and nutrition (Gupta and Mondal, 2019). Goats exhibit exceptional resilience to climate fluctuations compared to larger ruminants because of their physiological, behavioral and morphological adaptations (Nair *et al.,* 2021). India hosts various region-specific livestock breeds, each suited to distinct macroclimatic conditions (Ramachandran and Sejian, 2022). The Black Bengal goat, native to Bangladesh and eastern India, is valued for its small size, high reproductive efficiency and superior meat and skin qualities (Chowdhury *et al*., 2010). Despite their adaptive characteristics, goat productivity can be affected by extreme weather

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conditions (Lima *et al*., 2022). Evaluating adaptability involves immediate physiological responses, such as changes in rectal temperature, respiratory rate, pulse rate and sweating, as well as long-term biochemical adaptations, including changes in blood chemistry and heat resistance-related gene expression (Leite *et al*., 2021). Blood biochemistry indicates an animal's health, metabolic patterns and adaptive responses to environmental conditions (Leite *et al*., 2021). Endocrine responses and antioxidant status are crucial metrics for assessing heat stress adaptability in livestock (Sejian *et al*., 2021). The temperature-humidity index (THI) is used to evaluate heat stress in livestock. Various THI models have been used to assess heat stress in goats. Srivastava *et al*. (2021) compared THI models to evaluate environmental stress in goats under semi-arid conditions and identified suitable models for these regions. Understanding the relationship between physio-biochemical parameters and THI is essential for predicting the environmental impacts across seasons in goats. Although the Black Bengal goat is adapted to arid and semi-arid regions (Leite *et al*., 2021), research on its year-round adaptability is limited. Most studies have focused on summer, monsoon and winter, with a gap in comparative evaluations across all seasons. This study aimed to compare the adaptability of Black Bengal goats across all four seasons by evaluating biochemical, mineral and hormonal parameters and oxidative stress indicators.

MATERIALS AND METHODS

The study was conducted at the Instructional Livestock Farm of Bihar Animal Sciences University, Patna, India (latitude 25°35′N, longitude 85°05′E, elevation 53 meters). The climate experiences temperatures from 6°C to 42°C, with relative humidity between 30% and 75%. Twenty healthy female Black Bengal goats, weighing 30-35 kg and aged 1.5-2 years, were selected. Standard vaccination and deworming procedures were followed. The goats were managed under a semi-intensive system, grazing daily from 7:00 to 11:30 a.m. Consistent management practices and hygiene were maintained. The Institutional Animal Ethics Committee approved all protocols. The study covered four seasons: summer (May-June), monsoon (July-August), post-monsoon (October-November) and winter (December-January). Physiological measurements and blood samples were collected between 12:00 and 1:00 PM each season. Meteorological data, including rainfall, dry and wet bulb temperatures and maximum and minimum temperatures, were obtained from Patna Airport meteorological station, one kilometer from the site. Relative humidity was calculated using a psychrometric chart and bulb temperatures. The Temperature-Humidity Index (THI) was determined using the formula by Srivastava *et al*. (2021):

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

Where

Tdb = Represents dry bulb temperature (°C).

RH = Denotes relative humidity (%).

A total of 160 blood samples were collected from 20 goats at 15-day intervals. Serum was separated by centrifugation at 800 × g for 15 min and stored at -20°C. Serum metabolites, including total protein, albumin, glucose, blood urea nitrogen (BUN), creatinine and enzymes like alanine aminotransferase (ALT) and aspartate aminotransferase (AST), were measured using Coral Clinical Systems diagnostic kits. Electrolytes and minerals were assessed with these kits following manufacturer's guidelines. Hormone levels, including T3, T4, TSH and cortisol, were evaluated using Bioassay Technology Laboratory ELISA kits. Lipid peroxidation was determined by quantifying malondialdehyde (MDA) concentration (Stock and Dormandy, 1971). Serum superoxide dismutase (SOD) activity was measured using the MTT reduction method (Madesh and Balasubramanian, 1998). Catalase (CAT) activity was assessed by measuring hydrogen peroxide decomposition rate (Aebi, 1983). Reduced glutathione (GSH) concentration and total antioxidant capacity (TAC) were determined (Prins and Loos, 1969; Benzie and Strain, 1996). Repeated measures ANOVA analyzed seasonal variations, with significant differences identified at 95% confidence using Duncan's multiple range test in SPSS Statistical software 29.

RESULTS AND DISCUSSION

Table 1 outlines the average monthly and seasonal meteorological variables recorded during the study. The Temperature-Humidity Index (THI) was high (>85) in the summer and monsoon seasons, moderate (>77) in the post-monsoon season and within the comfort range (<65) during winter. These THI values indicate that goats experienced severe heat stress in the summer and monsoon seasons, moderate heat stress in the post-monsoon season and were in a thermocomfort zone during winter (Hamzaoui *et al.,* 2013). Consequently, conserving and promoting locally adapted breeds is an effective approach to counteract the effects of climate change, as these native breeds often show enhanced resilience to specific climatic challenges (Inbaraj *et al*., 2018). Although goats are known for their hardiness (Nair *et al*., 2021), prolonged exposure to high temperatures and humidity still induces physiological stress (El-Tarabany *et al*., 2017).

The THI is a useful metric to evaluate environmental stress. Specific THI values above 77 denote moderate stress, while those above 85 indicate severe stress (Silanikove, 2000). Our study observed THI values exceeding 85 during the summer and monsoon, aligning with severe heat stress conditions and THI values around 78 and 63 in the post-monsoon and winter, respectively, indicating moderate and thermocomfort conditions. These findings support earlier reports that high THI values are associated with adverse physiological and biochemical changes (El-Tarabany *et al*., 2017).

Table 2 presents the average concentrations of serum biochemical, mineral, hormonal and antioxidant parameters.

Statistical analysis revealed no significant seasonal differences in total protein concentration, in agreement with Perveen *et al*. (2019), who also reported stable protein levels across seasons. However, other studies (Bobade *et al.,* 2020) noted increased protein levels during heat stress, possibly due to the involvement of plasma proteins in gluconeogenesis, which may lead to decreased albumin levels (Yue *et al*., 2020; Mehaba *et al*., 2021). Our findings of lower albumin and higher globulin levels in summer support this mechanism and suggest hemoconcentration due to plasma volume reduction under heat stress (Nohara *et al*., 2022). Increased activity in hot conditions might also lower albumin levels (Scharf *et al.,* 2010). Blood glucose levels were significantly higher in winter and lowest in summer ($P<0.05$), likely due to increased glucose demand and reduced intake during heat stress (Scharf *et al*., 2010; Banerjee *et al*., 2015). BUN levels varied significantly across seasons ($P<0.05$), with higher levels during monsoon and lower in winter, which may reflect increased protein breakdown and reduced renal blood flow due to dehydration (Indu *et al*., 2014; Chaudhary *et al*., 2015). Impaired ammonia utilization by rumen microflora may also contribute (Yadav *et al*., 2022). Creatinine levels were significantly higher during the post-monsoon and winter seasons, with the lowest levels in monsoon. ALT activity showed a seasonal decline, being significantly higher in summer and lower in winter, while AST activity remained unchanged. Heat stress results in a significant increase in serum ALT and AST activities (Soni *et al*., 2022).

Sodium and potassium concentrations were significantly higher ($P<0.05$) in summer, monsoon and post-monsoon compared to winter, possibly due to dehydration and

Table 1: Metrological condition during experiment.

Season	Summer	Monsoon	Post-Monsoon	Winter
Average maximum temperature (°C)	40.2±0.36	33.55±0.39	30.49±0.27	20.87±0.84
Average minimum temperature (°C)	27.61±0.26	26.82±0.2	20.32±0.42	1.01±0.37
Average relative humidity (%)	45.43±1.93	74.21±1.28	63.99±1.36	71.23±1.53
Average THI	85.57±0.27	85.22±0.28	78.01±0.40	63.88±0.67
Total rain fall (mm)	73.40	701.60	4.40	47.00

Table 2: Seasonal variation in serum biochemical, mineral, hormonal and antioxidant parameters.

Season	Summer	Monsoon	Post-monsoon	Winter
Total protein (g/dl)	7.16^{a}±0.22	7.26^{a}±0.20	7.03^{a}±0.18	6.94^{a} ±0.17
Albumin (g/dl)	3.37^{a}±0.05	3.66^{b}±0.06	3.65^{b}±0.07	3.89^{b}±0.07
Globulin (g/dl)	3.78^{a}±0.22	3.59^{a}±0.20	3.37^{a}±0.20	3.04^{a}±0.18
Glucose (mg/dl)	51.52^{a}±0.73	56.12^{b}±0.98	55.55^{b}±0.93	60.95^{c}±0.94
BUN (mg/dl)	16.14^{b}±0.53	20.74^{c}±0.93	14.41^{b}±0.46	11.01^{a}±0.29
Creatinine (mg/dl)	0.78^{c}±0.02	0.75^{c}±0.02	0.67^{b}±0.02	0.59^{a}±0.01
ALT (U/L)	29.47^{b}±1.02	27.04^{b}±0.99	22.23^{a}±1.10	21.18^{a}±0.94
AST (U/L)	87.56^{a}±2.55	92..65^{a}±4.20	93.17^{a}±2.76	88.47^{a}±2.30
Sodium (mmol/L)	131.53^{a}±2.39	134.99^{a}±2.55	142.12^{ab}±3.70	147.00^{b}±1.49
Potassium (mmol/L)	4.76^{a}±0.17	4.92^{a}±0.11	4.96^{a}±0.15	6.04^{b}±0.13
Chloride (mmol/L)	103.68^{a}±1.86	111.61^{b}±1.30	115.28^{b}±2.10	115.80^{b}±2.09
Copper (mg/l)	1.73^{a}±0.16	1.71^{a}±0.15	1.98^{a}±0.23	1.85^{a}±0.29
Zinc (mg/l)	2.13^{a}±0.20	2.47^{ab}±0.12	2.44^{ab}±0.08	2.71^{b}±0.11
Magnesium (mg/dl)	3.02^{b}±0.14	2.81^{a}±0.34	2.64^{a}±0.36	2.14^{a}±0.11
Calcium (mg/dl)	7.80^{a}±0.28	7.87^{a}±0.35	8.17^{a}±0.31	9.28^{b}±0.17
Phosphorus (mg/dl)	5.56^{b}±0.22	5.62^{b}±0.17	6.21^{c}±0.24	4.80^{a}±0.14
T3 (ng/ml)	1.83^{a}±0.15	1.85^{a}±0.09	2.15^{ab}±0.61	2.35^{b}±0.21
T4 (ng/ml)	40.14^{a}±2.22	46.70^{a}±2.70	59.48^{b}±4.08	61.13^{b}±5.36
TSH (µ IU/ml)	2.56^{a}±0.18	2.50^{a}±0.17	3.03^{ab}±0.27	3.29^{b}±0.22
Cortisol (ng/ml)	13.09^{b}±0.87	12.39^{b}±0.42	7.68^{a}±0.84	7.60^{a}±0.54
GSH (µmole/ml)	0.17^{a}±0.06	0.18^{a}±0.09	0.22^{b}±0.07	0.23^{b}±0.01
LPO (nmol/ml)	4.63^{b}±0.26	4.53^{b}±0.22	3.14^{a}±0.27	2.93^{a}±0.21
SOD (U/ml)	90.44^{b}±2.9	90.77^{b}±2.58	62.19^{a}±2.56	59.44^{a}±1.81
Catalase (U/ml)	184.52^{b}±4.38	182.22^{b}±4.89	133.17^{a}±3.72	128.55^{a}±5.38
FRAP (µmol/l)	105.93^{a}±4.71	111.16^{ab}±5.51	135.20^{ab}±4.96	147.36^{b}±5.14

Notes: Data represent the mean ± SE. Means bearing different superscripts (a-b) differ significantly ($p<0.05$).

related physiological adjustments (Rathwa *et al*., 2017). Chloride levels increased significantly in monsoon, post-monsoon and winter compared to summer. Zinc concentration was significantly higher in winter ($P<0.05$), whereas copper did not show significant seasonal variation. These findings align with earlier reports on decreased levels of zinc and copper under stress (Noaman, 2014; Ganger *et al*., 2016; Manimaran *et al*., 2024). The reduction in magnesium levels may result from the shift of ions between cellular compartments under chronic stress (Pickering *et al*., 2020). Calcium levels were significantly higher in winter and phosphorus showed significant seasonal variation, with the highest levels during monsoon. These trends may reflect improved dietary intake and absorption during cooler seasons (Lima *et al*., 2021; Rathwa *et al*., 2017; Ganger *et al*., 2016).

Hormonal and oxidative stress markers. T3, T4 and TSH levels were significantly higher during post-monsoon and winter and lower during summer, which supports the idea that animals suppress metabolic hormones under thermal stress to reduce internal heat production (Todini, 2007; Pragna *et al*., 2018). Cortisol levels were significantly elevated in summer and monsoon, indicating heat-induced stress responses and activation of the hypothalamic-pituitary-adrenal axis (Sejian *et al*., 2008). Elevated cortisol supports energy mobilization during stress and aligns with previous findings (Chergui *et al*., 2017; Shaji *et al*., 2017).

Oxidative stress responses also exhibited seasonal trends. MDA levels, a marker of lipid peroxidation, peaked during summer and monsoon, indicating increased reactive oxygen species (Abdelnour *et al.,* 2019). Correspondingly, SOD and CAT activities were significantly higher in these seasons, suggesting a compensatory antioxidant response (Lakhani *et al*., 2020; Karthik *et al*., 2021). GSH concentrations were also elevated, possibly due to increased activity of glutathione-S-transferase (Bernabucci *et al*., 2002; Dhanasree *et al*., 2020). The total antioxidant capacity (TAC), measured using the FRAP assay, was significantly higher in winter, indicating enhanced endogenous antioxidant activity during cooler periods (Benzie and Devaki, 2018). These results are consistent with other studies demonstrating seasonal regulation of antioxidant defense systems (Gujar *et al*., 2024; Giri *et al*., 2019; Khushboo *et al.,* 2020).

CONCLUSION

Our research highlights the considerable impact of seasonal changes on the physiological and biochemical parameters of goats. The Temperature-Humidity Index (THI) values indicated severe heat stress during the summer and monsoon seasons, moderate stress during the post-monsoon period and comfort during winter. Although goats are naturally adaptable, their metabolic, hormonal and oxidative stress responses are negatively influenced by prolonged exposure to high temperatures. Seasonal variations in serum proteins, enzymes and minerals suggest adaptive responses to environmental stress, with significant changes in albumin, globulin and glucose levels observed during the summer. This study underscores the importance of monitoring thyroid hormones and cortisol as stress indicators, particularly during hot seasons. Oxidative stress markers, such as malondialdehyde (MDA) and superoxide dismutase (SOD), further confirm the harmful effects of high temperatures on goats. These findings highlight the need for targeted management strategies to alleviate the negative effects of seasonal stress on goats, thereby ensuring their well-being and productivity throughout the year.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

The experiment was conducted following the necessary approval from the Institutional Animal Ethics Committee (IAEC) of the Bihar Veterinary College, approval was granted by IAEC vide IAEC/BVC/20/15 dated 24.07.2020.

Conflict of interest

The authors declare that they have no conflict of interest.

REFERENCES

Abdelnour, S.A., Abd El-Hack, M.E., Khafaga, A.F., Arif, M., Taha, A.E. and Noreldin, A.E. (2019). Stress biomarkers and proteomics alteration to thermal stress in ruminants: A review. *Journal of Thermal Biology*. **79:** 120-134.

Aebi, H.E. (1983). Catalase In: Bergmeyer, HU (ed) Method of enzymatic analysis, Verlag Chemie, Weinhem. pp 273-286.

Banerjee, D., Upadhyaym R.C., Chaudhary, U.B., Kumar, R., Singh, S., Ashutosh, Das, T.K. and De, S. (2015). Seasonal variations in physio-biochemical profiles of Indian goats in the paradigm of hot and cold climate. *Biological Rhythm Research*. **46(2):** 221-236.

Benzie, I.F. and Devaki, M. (2018). The Ferric Reducing/Antioxidant Power (FRAP) Assay for Non Enzymatic Antioxidant Capacity: Concepts, Procedures, Limitations and Applications. In: Apak, R, Capanoglu E, Shahidi F (ed) Measurement of Antioxidant Activity and Capacity: Recent Trends and Applications. 77-106.

Benzie, I.F. and Strain, J.J. (1996). The ferric reducing ability of plasma as a measure of antioxidant power: The FRAP assay. *Analytical Biochemistry*. **239(1):** 70-76.

Bernabucci, U., Ronchi, B., Lacetera, N. and Nardone, A. (2002). Markers of oxidative status in plasma and erythrocytes of transition dairy cows during hot season. *Journal of Dairy Science*. **85(9):** 2173-2179.

Bobade, M., Khune, V., Mishra, S., Mukherjee, K., Gendley, M.K. and Soni, A. (2020). Effect of season on biochemical profile of Osmanabadi goat under agro-climatic conditions of Chhattisgarh plains. *Journal of Animal Research.* **10(4):** 593-599.

Chaudhary, S.S., Singh, V.K., Upadhyay, R.C., Puri, G., Odedara, A.B. and Patel, P.A. (2015). Evaluation of physiological and biochemical responses in different seasons in Surti buffaloes. *Veterinary World*. **8(6):** 727-731.

Chergui, N., Mormede, P., Foury, A., Khammar, F. and Amirat, Z. (2017). Seasonal effects on plasma cortisol concentrations in the Bedouin buck: Circadian studies and response to ACTH. *Animal*. **11(3):** 445-451

Chowdhury, S.M.Z.H., Nazir, K.N.H., Hasan, S., Kabir, A., Mahmud, M.M., Robbani, M., Tabassum, T., Afroze, T., Rahman, A, Islam, MR, Hossain, M (2010). whole genome analysis of black bengal goat from savar goat farm, Bangladesh. *BMC Research Notes.* **12:** 687.

Dhanasree, G., Pillai, U.N., Deepa, C., Ambily, V.R., Shynu, M. and Sunanda, C. (2020). Evaluation of oxidative stress in caprine anaplasmosis and effect of vitamin E–selenium in monitoring oxidative stress. *Tropical Animal Health and Production*. **52(5):** 2695-2698.

El-Tarabany M.S., El-Tarabany, A.A. and Atta, M.A. (2017). Physiological and lactation responses of Egyptian dairy Baladi goats to natural thermal stress under subtropical environmental conditions. *International Journal of Biometeorology.* **61(1):** 61-68.

Ganger, R., Garla, R., Mohanty, B.P., Bansal, M.P. and Garg, M.L. (2016). Protective effects of zinc against acute arsenic toxicity by regulating antioxidant defense system and cumulative metallothionein expression. *Biological Trace Element Research.* **169(2):** 218-229.

Giri, A., Bharti, V.K., Kalia, S., Raj, T. and Chaurasia, O. (2019). Evaluation of antioxidant status in serum and milk of Jersey cross-bred in different seasons reared under high-altitude stress condition. *Biological Rhythm Research.* **50(5):** 726-738.

Gujar, G., Kumar, V., Sodhi, M., Vivek, P., Tiwari, M. and Mukesh, M. (2024). Modulations in antioxidant defence system and expression of genes involved in antioxidant and apoptosis pathway helps ward-off heat stress in cows reared in hot-arid ambience of Thar Desert. *The Indian Journal of Animal Sciences.* **94(4):** 333-341.

Gupta, M. and Mondal, T. (2019). Heat stress and thermoregulatory responses of goats: A review. *Biological Rhythm Research.* **52(3):** 407-433.

Hamzaoui, S.A.A.K., Salama, A.A.K., Albanell, E., Such, X. and Caja, G. (2013). Physiological responses and lactational performances of late-lactation dairy goats under heat stress conditions. *Journal of Dairy Science*. **96:** 6355-6365.

Inbaraj, S., Kundu, A., De, A.K., Sunder, J. and Sejian, V. (2018). Seasonal changes in blood biochemical and endocrine responses of different indigenous goat breeds of tropical island agro-ecological environment. *Biological Rhythm Research.* **49(3):** 412-421.

Indu, S., Sejian, V. and Naqvi, S.M.K. (2014). Impact of simulated heat stress on growth, physiological adaptability, blood metabolites and endocrine responses in Malpura ewes under semiarid tropical environment. *Animal Production Science*. **55(6):** 766-776.

Joy, A., Dunshea, F.R., Leury, B.J., Clarke, I.J., DiGiacomo, K. and Chauhan, S.S. (2020). Resilience of small ruminants to climate change and increased environmental temperature: A review. *Animals*. **10(5):** 867.

Karthik, D., Suresh, J., Reddy, Y.R., Sharma, G.R.K., Ramana, J.V., Gangaraju, G., Reddy, P.P.R., Reddy, Y.P.K., Yasaswini, D., Adegbeye, M.J. and Reddy, P.R.K. (2021). Adaptive profiles of Nellore sheep with reference to farming system and season: Physiological, hemato-biochemical, hormonal, oxidative-enzymatic and reproductive standpoint. *Heliyon.* **7(5):** e07091.

Khushboo, Mamta, K., Neha, K. and Arup, G. (2020). Evaluation of physico-chemical and antioxidant properties of dairy cow, goat and buffalo urine in two different seasons in a sub-tropical region of India. *Indian Journal of Animal Research.* **55(1):** 25-30. doi: 10.18805/ijar.B-3916.

Lakhani, P., Kumar, P., Lakhani, N. and Alhussien, M.N. (2020). The influence of tropical thermal stress on the seasonal and diurnal variations in the physiological and oxidative status of Karan Fries heifers. *Biological Rhythm Research*. **51(6):** 837-846.

Leite, J.H.G.M., Façanha, D.A.E., Bermejo, J.V.D., Guilhermino, M.M. and Bermejo, L.A. (2021). Adaptive assessment of small ruminants in arid and semi-arid regions. *Small Ruminant Research*. **203:** 106497.

Lima, A.R.C., Silveira, R.M.F., Castro, M.S.M., De Vecchi, L.B., Fernandes, M.H.M.R. and Resende, K.T. (2022). Relationship between thermal environment, thermoregulatory responses and energy metabolism in goats: A comprehensive review. *Journal of Thermal Biology.* **109:** 103324.

Lima, J.M., Vale, R.G., Sousa, R.D.S., Nunes, T.L., Gameleira, J.D.S., Cavalcante, J.M., Minervino, A.H.H., Ortolani, E.L. and Barreto Junior, R.A. (2021). Seasonality effects on the mineral profile of goats farmed in the semiarid region of Brazil. *Veterinary Sciences*. **8(1):** 8.

Madesh, M. and Balasubramanian, A.K. (1998). Microtiter plate assay for superoxide dismutase using MTT reduction by superoxide. *Indian Journal of Biochemistry and Biophysics.* **35(3):** 184-188.

Manimaran, S., Kekan, P.M., Daware, S.B., Wankar, A.K., Munde, V.K., Khose, K.K. and Bhagade, P.M. (2024). Effect of copper and zinc supplementation on antioxidants and biochemical status of Osmanabadi goats. *Indian Journal of Animal Research*. **58(2):** 293-297. doi: 10.18805/IJAR. B-4926.

Mehaba, N., Coloma-Garcia, W., Such, X., Caja, G. and Salama, A.A. (2021). Heat stress affects some physiological and productive variables and alters metabolism in dairy ewes. *Journal of Dairy Science.* **104(1):** 1099-1110.

Nair, M.R., Sejian, V., Silpa, M.V., Fonsêca, V.F.C., de Melo Costa, C.C., Devaraj, C., Krishnan, G., Bagath, M., Nameer, P.O. and Bhatta, R. (2021). Goat as the ideal climate-resilient animal model in tropical environment: Revisiting advantages over other livestock species. *International Journal of Biometeorology.* **65(12):** 2229-2240.

Noaman, V. (2014). Serum copper, zinc and iron concentrations of Holstein dairy cows in different seasonal and physiological states. *Comparative Clinical Pathology*. **23(4):** 1059-1062.

Nohara, M., Hisaeda, K., Ono, T., Inoue, Y., Ogawa, K., Hata, A., Siban, K., Nagahata, H. and Fujitani, N. (2022). The relationships between environmental parameters in livestock pen and physiological parameters of Holstein dairy cows. *Journal of Veterinary Medical Science*. **84(11):** 1446-1454.

Perveen, S., Kumar Das, P., Ranjan Ghosh, P., Banerjee, D., Mukherjee, J., Naskar, S. and Mondal, M. (2019). Alterations in haemato-biochemical profile and blood metabolites during different periods of prepubertal growth in Black Bengal goat (*Capra hircus*): Effect of sex and season. *Biological Rhythm Research*. **50(4):** 626-636.

Pickering, G., Mazur, A., Trousselard, M., Bienkowski, P., Yaltsewa, N., Amessou, M., Noah, L. and Pouteau, E. (2020). Magnesium status and stress: The vicious circle concept revisited. *Nutrients*. **12(12):** 3672.

Pragna, P., Sejian, V., Soren, N.M., Bagath, M., Krishnan, G., Beena, V., Devi, P.I., Bhatta, R. (2018). Summer season induced rhythmic alterations in metabolic activities to adapt to heat stress in three indigenous (Osmanabadi, Malabari and Salem Black) goat breeds. *Biological Rhythm Research.* **49(4):** 551-565.

Prins, H.K. and Loos, J.A. (1969). In: Glutathione. In: Yunis, J.J. (ed.) Biochemical Methods in Red Cell Genetics. Academic Press, New York, pp. 127-129.

Ramachandran, N. and Sejian, V. (2022). Climate resilience of goat breeds in India: A review. *Small Ruminant Research.* **208:** 106630.

Rathwa, S.D., Vasava, A.A., Pathan, M.M., Madhira, S.P., Patel, Y.G. and Pande, A.M. (2017). Effect of season on physiological, biochemical, hormonal and oxidative stress parameters of indigenous sheep. *Veterinary World.* **10(6):** 650-654.

Roy, S.S. and Balling, R.C. (2005). Analysis of trends in maximum and minimum temperature, diurnal temperature range and cloud cover over India. *Geophysical Research Letters.* **32(12):** L12702.

Scharf, B., Carroll, J.A., Riley, D.G., Chase Jr, C.C., Coleman, S.W., Keisler, D.H., Weaber, R.L. and Spiers, D.E. (2010). Evaluation of physiological and blood serum differences in heat-tolerant (*Romosinuano*) and heat-susceptible (Angus) Bos taurus cattle during controlled heat challenge. *Journal of Animal Science.* **88(7):** 2321-2336.

Sejian, V., Silpa, M.V., Reshma Nair, M.R., Devaraj, C., Krishnan, G., Bagath, M., Chauhan, S.S., Suganthi, R.U., Fonseca, V.F.C., König, S. and Gaughan, J.B. (2021). Heat stress and goat welfare: Adaptation and production considerations. *Animals.* **11:** 1021.

Sejian, V., Srivastava, R.S. and Varshney, V.P. (2008). Pineal-adrenal relationship: Modulating effects of glucocorticoids on pineal function to ameliorate thermal stress in goats. *Asian-Australasian Journal of Animal Sciences.* **21(7):** 988-994.

Shaji, S., Sejian, V., Bagath, M., Manjunathareddy, G.B., Kurien, E.K., Varma, G. and Bhatta, R. (2017). Summer season-related heat and nutritional stresses on the adaptive capability of goats based on blood biochemical response and hepatic HSP70 gene expression. *Biological Rhythm Research.* **48(1):** 65-83.

Silanikove, N. (2000). Effects of heat stress on the welfare of extensively managed domestic ruminants: A review. *Livestock Production Science.* **67:** 1-18.

Soni, P. K., Bhar, R., Vipin and Kumar, K. (2022). *Tinospora cordifolia* stem powder effects on antistress and blood biochemical parameters in heat stressed gaddi goats. Tinospora cordifolia Stem Powder Effects on Antistress and Blood Biochemical Parameters in Heat Stressed Gaddi Goats. *Agricultural Science Digest*. **42(5):** 649-653. doi: 10. 18805/ag.D-5498.

Srivastava, A., Yadav, P., Mahajan, A., Anand, M., Yadav, S., Madan, A.K. and Yadav, B. (2021). Appropriate THI model and its threshold for goats in semi-arid regions of India. *Journal of Thermal Biology.* **96:** 102845.

Stock, T. and Dormandy, T.L. (1971). The auto-oxidation of human red cell lipid induced by hydrogen peroxide. *British Journal of Haematology*. **20(1):** 95-111.

Tesfaye, T., Sithole, B., Ramjugernath, D. (2017). Valorisation of chicken feathers: A review on recycling and recovery route-current status and future prospects. *Clean Technologies Environmental Policy.* **19:** 2363-2378.

Todini, I. (2007). Thyroid hormones in small ruminants: Effects of endogenous, environmental and nutritional factors. *Animal.* **1(7):** 997-1008.

Yadav, B., Yadav. S., Madan, A. K., Anand, M., Swain, D., Pandey, V., Sirohi, R. (2022). Heat stress responses to increasing temperature humidity index (THI) in lactating Murrah buffalo. *Buffalo Bulletin.* **41(1):** 161-170.

Yue, S., Ding, S., Zhou, J., Yang, C., Hu, X., Zhao, X., Wang, Z., Wang, L., Peng, Q., Xue, B. (2020). Metabolomics approach explore diagnostic biomarkers and metabolic changes in heat-stressed dairy cows. *Animals*. **10(10):** 1741.