The Pharma Innovation Journal 2022; SP-11(7): 01-06

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; SP-11(7): 01-06

www.thepharmajournal.com
Received: 01-04-2022
Accepted: 04-05-2022

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A review on adaptive plasticity response under changing climatic conditions in goats

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Abstract
The climate over the earth is ever-changing. The changed environment puts selective and adaptive pressure over the animal species to survive. The animal species that cannot adapt well are eliminated from the ecosystem. To sustain under the climatic stressor animal body is challenged in terms of homeothermy, water, electrolyte, and hormonal balance. The stressor greatly affects the animals productive and reproductive performances as much of the energy is utilized to maintain homeostasis. Amongst the livestock species, goat rearing is assumed to be an integral part of Indian rural economy, as it is the source of high-quality animal protein. The goats can survive in harsh climate, as it has very good adaptive mechanisms against the climatic stressors. The study of goat adaptive mechanism is of considerable interest to understand how this animal respond to different climatic stress, and it would help to make the goat rearing a sustainable venture.

Keywords: Biochemical, goat, hematological, hormone, season

Introduction
Global warming is putting immense pressure on the livestock production. The earth's surface temperature is ever increasing, and it has risen 0.98℃ above the 20th century average (NOAA, 2021) [25]. The increased earth's surface temperature having huge effect over the climate pattern and affecting the pattern and intensity of warm, cold and rainfall (Stagge *et al*., 2017) [45]. Among the climatic stressors, the environmental temperature, humidity and irradiation are important that put the animal under immense environmental stress. To sustain under the climatic stressor animal body is challenged in terms of homeothermy, water, electrolyte, and hormonal balance. At cellular level various genes plays their role to help the animal body to adapt in the changing environment. However, changing in the earth climatic conditions is not a new happening. It has been occurred in past also, and animals were subjected to adaptations. Some species were failed to adapt, but others adapted well under changed climate pressure and flourished. However, they have to cope up the climatic stress which severely impact its production. The animal's production and reproduction capabilities are greatly influenced by the changing environmental conditions, as much of the energy siphoned towards homeostasis maintenance. Though, the animal has the thermoregulatory mechanism but under extreme environmental condition, there may be disturbance in the thermal homeostasis (Lu, 1989).

The Indian subcontinent having the tropical environment and the climatic variation on yearly basis is very high. During summer and winter season animals must face extremes of temperature besides facing a large variation in the day light period in these seasons. The animal species present in this part of the globe are always remain under the ecological and climatic stress. Due to such environmental pressure the animal species develops adaptive mechanisms to overcome the climatic stress. Among the livestock, goats are considered as short-day breeder so they are assumed to be mostly affected and by the sub-continent climatic conditions (Ghosh *et al*., 2013) [11]. To thrive under this sub-continental environment, goats having very good adaptive mechanisms, however their productive capability might be greatly affected during the extreme climatic seasons.

At the verge of climate changes, the mere deviation in the environmental temperature might not be sufficient to evaluate the stress level in the animals. While calculating the environmental stressor the humidity should also be considered along with the temperature, as this affects the animal's wellbeing and productivity. Thermal humidity index (THI) would be a suitable marker to predict the environmental stress, as it based on air temperature and humidity (Lallo *et al*., 2018). To make goat rearing a sustainable venture, the physiological adaptive responses of goat towards the elevated climatic stress remain a major focus for research.

The current knowledge of physiological adaptation responses/mechanism of goats towards the environmental stress is presented.

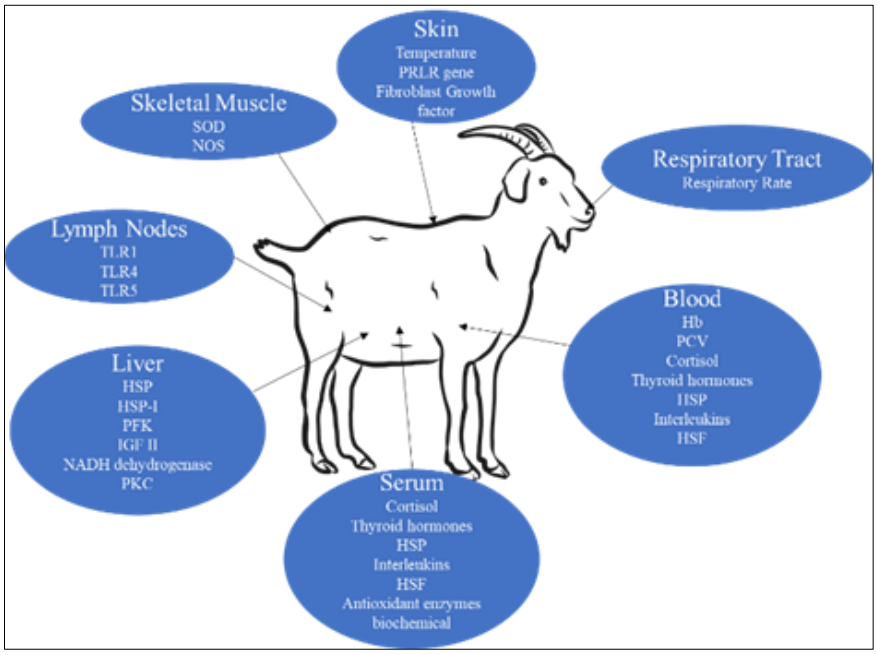

Fig 1: Biological markers for quantifying stress response in goats

Adaptive response of goat in different environmental conditions.

Adaptation may be defined as any change in animal partnering to reduce its physiological stress made by environment. In biological term adaptation is changes in physiological, biochemical, behavioral, morphological, anatomical features in animal to survive in specific environment. The first responses to change in environment in animal is physiological and behavioral changes (Fuller *et al*., 2010; Sejian *et al*., 2018) [9, 38]. Adaptation ability of goat to hot or cold climate involves several physiological systems for example circulatory, respiratory, nervous, excretory, endocrine and enzymatic systems. These changes witnessed between different species, among breeds and also among individual animals inside a breed to harmonization of entire systems for maintenance of production performance under thermal stress (Banerjee *et al*., 2015; Kumar *et al*., 2018) [2, 20]. The breed variations suggest different responses to the different stressors in a precise environmental condition and that rely on adaptation ability in that environmental condition (Jindal, 1980) [18].

In India goats are raised under open grazing system. So, they are more prone to heat stress during summer (Mondal *et al*., 2020) [24]. However, goat has typical capability to flourish well in various environmental situations, due to its great disease resistance ability, dexterous grazing behavior, good feed conversion potential, and ability to tolerate drought condition (Shilja *et al*., 2016) [42]. Indigenous breeds have better adapting capability to their native environments where they have evolved then exotic and crossbred animals (Pragna, *et al*., 2018a) [31] and they are more acquainted with sudden environmental change and disease outbreaks as compare to exotic and crossbred goats (Pragna *et al*., 2018b) [32]. The diversified indigenous breeds have greater adaptive capacities in their appropriate ecological zones, however merely few indigenous breeds have capacity to bloom well in different ecological zones due to their higher genetic merit (Helal *et al*., 2010) [15]. There are numerous exclusive adaptive machineries present in indigenous breeds for survival in precise environment. Variability in metabolic activities is one of the most common adaptive response in the indigenous breeds to cope up with external hot environment (Pragna *et al*., 2018b) [32].

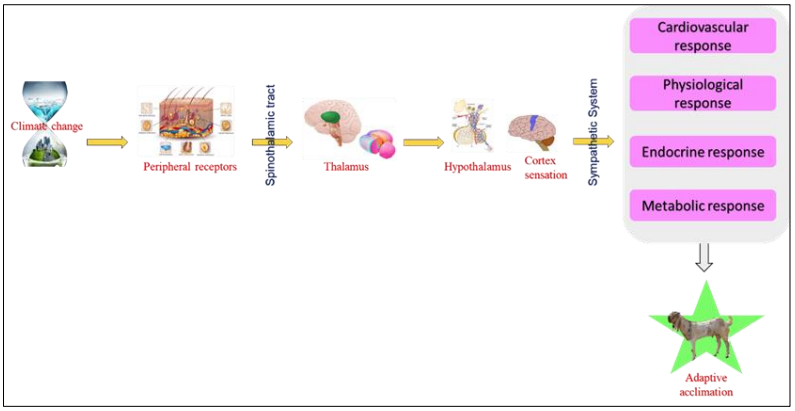

Fig 2: Adaptive response mechanism in goats.

Physiological adaptive response

Seasonal variations exhibited by differences in meteorological circumstances, like temperature of environment and relative humidity, which considerably affect the animals' physiology and may cause heat stress in animal (Habibu *et al*., 2016; Piccione *et al.*, 2012) [14, 30]. Physiological parameters like respiratory rate (RR), rectal temperature (RT), pulse rate (PR) and skin temperature (ST) are most common parameters to assess adaptive capability in goats. Usually season, sex, age, day time, exercise, physiological stage of animal, food intake capacity, water consumption and digestion are accountable for the alteration in cardinal physiological parameters (Ribeiro *et al*., 2018) [35].

Rate of respiration is one of the furthermost sensitive physiological signs to thermal stress, which acts as one of the most valuable animal centric indicator for thermal stress in animals(Fuller *et al*., 2010; Sejian *et al*., 2018) [9, 38], because of variations in RR alter the other cardinal physiological signs for instance RT and PR during thermal stress most of the time (Singh *et al*., 2016) [44]. Small ruminants like sheep and goat survives in stressful environment by activating the respiratory evaporative cooling machinery by increasing RR which is ultimately leads to reduction in additional heat burden from them (Jyotiranjan *et al.*, 2017; Singh *et al.*, 2016) [44, 19]. When animal is exposed to high ambient temperature this evaporative cooling mechanism will not suffice to maintain the body temperature and results in increased RT, however the goats resist this increase.

Besides the evaporative cooling another adaptation mechanism for body heat loss is cutaneous evaporating cooling mechanism. As an adaptation, the peripheral blood flow in goats is increased and thereby increased PR. The PR accompanied by general metabolic status of animal primarily reflects the homeostasis of circulation (Sejian and Srivastava, 2010) [37]. An alteration in metabolism and muscle action in goats also alter the RR and PR (Banerjee *et al.*, 2015) [2]. Increase in heart rate (HR) and PR may also be due to either increase in movement of muscle which control the RR, or due to decreased resistance of peripheral vascular beds as a plasticity response.

Seasonal variation in RT, RR and PR in goats under tropical conditions has been reported by many workers (Inbaraj *et al*., 2018; Perveen *et al.*, 2019; Shinde *et al.*, 2002) [17, 27, 43]. Increased PR in goat in the course of summer and winter has been reported by Banerjee in Sirohi, Barbari and Gaddi breeds of goat (Banerjee *et al.*, 2015) [2]. The increased PR increases the flow rate of blood from core area to surface area that enhance body heat loss in sensible and insensible means. There is significant rise in RT and RR in goat during summer as compared to spring season and fall in winter season in hot (Sirohi and Barbari) and cold (Gaddi and Chegu) environment adopted breeds of goat (Banerjee *et al*., 2015) [2]. Shilja reported Osmanabadi goats showed better adaptive response to heat stress, nutritional stress and combined stress raised in the Indian semi-arid regions by varying their physiological responses (Shilja *et al*., 2016) [42]. A higher value of physiological parameters viz. RT, RR, PR, and ST during summer season was reported than winter season in goats (Rathwa *et al*., 2017) [33].

Haematological adaptive response

Like other tissues of the animal body, the blood could experience sequence of adaptive transformation on exposure to different season's environment. Blood cells are sensitive to temperature variation and acts as key indicator of physiological responses to stressors (Casella *et al*., 2013) [5]. Haematological variables are usually used for monitoring and evaluating the health status of small ruminants (Fazio *et al*., 2016) [8] and are good indicators for the animal response to the changed climatic condition. Pattern of haematological parameters in goat may be influence by several factors, such as species, breed characteristic, sex, age, nutrition status, diseases condition, physiological stage of animal and seasonal variations (Banerjee *et al.*, 2015; Habibu *et al*., 2017; Zumbo *et al*., 2011) [2, 13, 49].

The central nervous system (CNS) modulates hematological variations in livestock due to heat stress and seasonal variation through hypothalamic-pituitary-adrenal (HPA) axis. Erythrocyte attributes modulated by CNS via influencing the respiration rate, circulation, sweating rate and water intake to increased heat loss during summer and conserve heat during winter (Habibu *et al*., 2016) [14]. Usually, hematological profiling of an animal is primary indicator of physiological changes and acts as an animal-based indicator for assessing heat stress (Ribeiro *et al*., 2016; Singh *et al*., 2016) [35, 44]. Individually, each hematological parameter interpretation gives significant idea about animal's response to heat stress; conversely, the combination of many hematological parameters gives maximum understanding (Casella *et al*., 2013) [5].

Hot and humid environment provokes sweating resulting into loss of water leading to hemo-concentration and increase in TEC and thereby PCV value (Piccione *et al.*, 2010) [29]. Study of Ghosh in goat revealed that significant variation in total leucocyte count (TLC) among seasons (Ghosh *et al.*, 2013) [11]. It was also reported that higher eosinophil, neutrophil and lymphocyte count during winter season, while monocyte decreases during monsoon and winter seasons. Results of Habibu showed that elevation in erythrocyte count (TEC) and packed cell volume (PCV) along with low mean corpuscular hemoglobin (MCH) and mean corpuscular hemoglobin concentration (MCHC) during the hot dry season as compared to cold dry and rainy seasons in kids (Habibu *et al*., 2017) [13]. The influence of season on the concentration of haemoglobin (Hb), PCV, TEC and TLC has been reported widely (Banerjee *et al*., 2015; Perveen *et al*., 2019) [2, 27]. They show that Blood Hb, PCV and TEC levels decreased during summer and increased during winter in goats. Banerjee also observed increased neutrophil percentage and decreased lymphocyte percentage during summer (Banerjee *et al.*, 2015) [2]. Ribeiro observed that the PCV and mean corpuscular volume (MCV) was not influenced by seasons, however during spring season an increased TEC was reported during the spring season (Ribeiro *et al*., 2016) [35]. The stimulation of erythropoietin synthesis and secretion is an adaptive mechanism in goats to combat the reduced oxygen tension during the hot climate, results to the higher erythrocytic indices (Jyotiranjan *et al.*, 2017) [19].

Biochemical adaptive response

Biochemical blood attributes access the level of adoptive response in animals to adverts climate change by defining the biochemical profile, the energy metabolism, metabolism disorders, liver function, bone abnormalities (Gupta and Mondal, 2019) [12].The interpretation of biochemical profiles of an animal is complex become of mechanisms controlling the blood level of various metabolites is influenced by several factors such as breed, age, physiological stage, diet, and

management of the animal and the climate (Ribeiro *et al*., 2018) [34].

Blood glucose and cholesterol levels can be altered as an adaptation mechanism to high ambient temperature. Variation in their level shows greater during heat stress condition than in the comfort zone. Stress due to high ambient temperature decreases blood glucose and cholesterol levels in goats (El-Tarabany *et al*., 2017; Hooda and Upadhyay, 2014; Pandey *et al*., 2012) [7, 16, 26]. Several workers observed high blood glucose and cholesterol in winter season and low in summer season (Banerjee *et al*., 2015; Bobade *et al.*, 2020; Perveen *et al.*, 2019; Sejian and Srivastava, 2010) [2, 4, 37, 27], while Ribeiro observed a high glucose and cholesterol levels in spring season (Ribeiro *et al*., 2016) [35]. Decreased feed intake during summer season lower the level of glucose (Banerjee *et al.*, 2015) [2] and decrease in cholesterol level during summer season in response to more demand of cholesterol for cortisol hormone synthesis. The cortisol hormone limits the glucose utilization by increasing metabolism of triglycerides and proteins (Sejian and Srivastava, 2010) [37].

The total plasma protein, albumin and globulin level in serum is higher in summer season due to increase in plasma volume as a result of heat stress in goats (El-Tarabany *et al*., 2017; Helal *et al*., 2010; Inbaraj *et al*., 2018; Shaji *et al*., 2017) [7, 15, 17, 40] and lower in monsoon season followed by lowest in winter season (Bobade *et al*., 2020; Inbaraj *et al*., 2018) [4, 17]. Higher levels of globulin observed in the rainy season which resulting into low albumin/globulin ratio (AL Eissa *et al*., 2012; Mohamed Abdelatif *et al*., 2009). Perveen reported that the total protein concentration in serum did not alter significantly amongst seasons (Perveen *et al*., 2019) [27].

Increased level of blood urea nitrogen (BUN), uric acid and creatinine during summer season in goat due to reduced blood flow toward kidney during heat stress condition (Bobade *et al*., 2020; Ghosh *et al*., 2013; Rathwa *et al*., 2017) [11, 33, 4]. Higher catabolism of protein to maintain the metabolic needs of the body during hot dry and hot humid season increases urea concentration in blood (Bobade *et al*., 2020) [4]. Surge in urea concentration in blood during hot season may also be a signal of dehydration (Ghosh *et al*., 2013) [11]. The creatinine level was significantly lower in summer, most likely due to the increased air temperature, which promotes increased respiratory rate (Piccione *et al*., 2010) [29].

One of the ways to assess the metabolic regulators is estimation of serum enzymes and they act as important determinants of physiological mechanisms during stressed conditions (Gupta and Mondal, 2019) [12]. Stress due to adverse climate decreases the alkaline phosphatase (ALP) and lactic dehydrogenase (LDH) activity (Helal *et al*., 2010; Sevi *et al.*, 2001) [15] and this decrease during summer season may be due to lower level of thyroid hormone (Helal *et al*., 2010; Ribeiro *et al.*, 2018) [15, 34]. In other reports increase in LDH enzyme activity due to heat stress may be due to higher muscular activity, which involve lactic acid synthesis from glucose through pyruvate as a result of anaerobic cellular respiration (Helal *et al*., 2010) [15]. Serum level of aspartate transaminase (AST) and alanine transaminase (ALT) estimation in serum is helpful to assess the animal health during stress condition. During summer season these enzymes activity increases due to their higher adaptive capability (Banerjee *et al*., 2015; Rathwa *et al*., 2017) [2, 33]. Some reports also find non-significant changes in AST and ALT level in goats during summer season (Sharma and Kataria, 2011) [26].

In cellular metabolism, muscle contraction, nerve transmission, and enzyme reactions electrolytes serve as critical element (Piccione *et al*., 2007) [28]. The primary element involved in every metabolic process is sodium, which has the importance from glucose uptake by cell to the nerve transmission. Alteration in sodium concentration effects the chloride concentration in the body fluids, as the concentration of both electrolytes is interrelated (Piccione *et al*., 2007) [28]. Increase in sodium concentration during summer season due to dehydration (Gupta and Mondal, 2019) [12]. The variation in sodium and chloride content observed in different season also affected by the variation in feedstuff and soil mineral content, during spring-summer seasons as they are richer in minerals content than other seasons (Xin *et al*., 2011) [48].

Endocrine adaptive response

The thermoregulatory mechanism efficacy of an animal decided the adverse effects intensity causes due to high environmental temperatures. Animal Well-adapted to local climate respond rapidly to any change in climate by making necessary physiological adjustments Ribeiro *et al*., 2018) [34]. An important role played by thyroid and adrenal glands during adaptation of animals to adverse climatic condition by regulating the thermoregulatory mechanism. Thyroid hormones like triiodothyronine (T4) and thyroxine (T3) act on most of the tissues of the body by increasing their metabolic activity, this increase in metabolic activity increases the rate of heat production and oxygen consumption at cellular level. The metabolic effect of thyroid hormone are an increase in basal metabolic rate (BMR), glucose availably to cells, protein synthesis and lipid metabolism (Todini, 2007) [47]. Temperature variation during different season highly influence the thyroid gland activity (Ribeiro *et al*., 2018) [34], Proper functioning of thyroid gland thyroid hormone activity are requiring maintaining the productive performance in domestic animals (Gattani and Sareen, 2011; Todini, 2007) [47, 10]. The activity of thyroid gland decreases in animal, when exposed to hot condition during summer season, whereas increases when exposed to cold condition during winter season. During summer season animals are exposed to heat stress, which result in to reduced feed ingestion and metabolism metabolic activity due to hypofunction of the thyroid gland (Gupta and Mondal, 2019) [12]. However, during winter season oxygen consumption and heat production by cells to BMR due to hyper function of thyroid gland (Bernabucci *et al.*, 2010) [3]. Seasonal variation in serum level of serum of T_4 and T_3 of goats has been widely reported in the literature (Ribeiro *et al*., 2016; Todini, 2007) [35, 47].

Increase secretion of cortisol hormone during summer stress in small ruminants like sheep and goat is well documented by many workers (Chergui *et al*., 2017; Sejian *et al*., 2008; Sejian *et al*., 2018; Sejian and Srivastava, 2010; Shilja *et al*., 2016; Tajik *et al*., 2016) [36-38, 42]. Further cortisol acts as primary stress hormone an important biological marker for stress in goats (Shaji *et al.*, 2017) [40]. Animal get benefited from high blood cortisol level to cope up with summer stress condition (Shaji *et al.*, 2017) [40]. The main function of cortisol hormone is to increase protein metabolism and gluconeogenesis (Sejian and Srivastava, 2010) [37]. During summer and monsoon seasons hypothalamic-pituitary-adrenal axis is activated which results in more cortisol secretion to maintain homoeostasis in goats (Sejian and Srivastava, 2010) [37].

Conclusion

Goat husbandry is one of the important economic activities for the marginal farmers. This sector is under pressure to cater the ever-increasing demand of animal protein and on the other hand it is badly affected with the environmental stress. The adaptive plasticity of goats has been highlighted in this paper. In the ever-changing climatic conditions, how the goats are meeting the climatic challenges especially in the tropical environment of India was emphasized. To ameliorate the negative impacts of the environment factor, the understanding of animal plasticity towards climatic stress is vital. At a phenotypic and genotypic level, goats express various adaptive features to combat the climatic changes. The high-density genotypic comparison of different native breeds of goats may elucidate the underlying biological mechanism responsible for their plasticity. The functional genomic approach provides new knowledge about the genes that are up/ down regulated during the changed climatic condition. Such cavernous understanding will be helpful to identify the genetically superior animals that have better adaptive mechanism and to devise the small animal breeding program especially for goats that can cope the devastating effects of changing climate.

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