

Review

Climate resilience in livestock species of hot arid climatic regions of India

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ABSTRACT

Climate change poses a significant threat to livestock systems, leading to unstable productivity, crop failures, and emerging diseases. With rising global temperatures and increased frequency of extreme weather events, livestock face new challenges, particularly in drought-prone regions like India. India's hot arid zones, covering 12% of its land, experience erratic rainfall and extreme temperatures, conditions under which livestock must adapt to survive. Resilience in livestock, defined as the ability to withstand and recover from environmental disturbances, is crucial for ensuring sustainable animal production. Indigenous breeds in these regions have evolved to thrive under such harsh conditions through genetic, physiological, and behavioral adaptations. For example, Zebu cattle exhibit heat tolerance, while sheep and goats possess thermo-regulatory traits that enable them to survive in high thermal stress environments. Climate-resilient livestock not only withstand environmental stressors but also support productivity with fewer health issues. Research into the genetic markers and breeding strategies for resilience is essential to address the impacts of climate change on livestock systems. By focusing on climate-smart livestock management and selecting thermotolerant breeds, the livestock sector can mitigate the challenges of global warming, ensuring food security and the sustainability of livestock production in the future.

Key words: Climate resilience, Heat tolerance, Livestock adaptation, Thermotolerant breeds

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Climate change and climate-resilient livestock

Global warming and climate change are not a myth anymore as they have dynamic and irreversible effects on living beings (humans and animals). During recent decades, global climate data display a warming trend in most parts of the globe, resulting in a wide range of climatic impacts. The surface temperature on earth has already increased by ~2°F (1.1°C degree Celsius) since the pre-industrial era. This increase is continuing and is expected to reach or exceed 1.5°C (~3°F) in a few decades (IPCC, 2021). The world indeed has become more drought-prone with higher frequencies of extreme events (IPCC Report, 2007) like changing trends of monsoonal rainfall, especially in tropical countries like India due to climate change (Stefanski and Sivakumar, 2011). In India, 80% of the annual rainfall comes from the southwest monsoon, and is very important for the whole country, especially for the states with low rainfall belts.

Climate change impacts all sectors of the ecosystem, of which areas of major concern are food and nutritional security under animal-agricultural systems. Climate change is thought to be the most important cause of unstable productivity in livestock production systems, crop failures, feed and fodder scarcity, and increased incidence of endemic and emerging animal diseases

(Phand, and Pankaj, 2021). There is a need to expand the research and development work to different bioclimatic zones, for all economically important species of livestock and livestock management systems including backyard poultry. Research work should focus on animal housing, climate-smart livestock village clusters, vulnerability mapping of the whole country, demarcation of bioclimatic zones and identification of livestock species suited to specific bioclimatic zones (Rymbai *et al.*, 2016). The production environment of livestock is changing due to more disturbances (e.g., due to climate change). In these changing environments, it is important that animals can cope with disturbances well, and are therefore easy to manage (Berghof *et al.*, 2019). The ability to be minimally affected by disturbances and to quickly recover if affected is called resilience (Colditz and Hine, 2016). The fluctuation pattern of longitudinal traits is indicative of the resilience of an animal (Scheffer *et al.*, 2018).

The livestock sector has been blamed for contributing more to global climate change than the automobile industry (FAO 2006). Economic growth and urbanization is increasing global demand of livestock products which has created a booming livestock sector and of late being considered a major factor linked to climate change. Livestock play a critical role in the livelihoods of many of the world's poorest people. Livestock systems are

credited with providing environmental services such as promoting soil health, thereby helping to capture atmospheric carbon and mitigate climate change. Therefore, there is an urgent need to identify the resilient breeds of livestock to fulfil the demand of milk and milk products for ever growing human population in changing scenario of climate change/ global warming.

Hot arid climatic regions of India

The Indian arid zone covers around 12% of the country's geographical area occupying 31.8 million hectares of land. It covers parts of the state of Rajasthan (61%), Gujarat (20%), Andhra Pradesh (7%), Punjab (5%), Haryana (4%), and Karnataka (3%). These areas experience an annual rainfall between 100 and 500 mm with a coefficient of variation varying from 40 to 70%. The region is characterized by low and erratic rainfall with extremes of temperature (1–48°C), high wind velocity and sandy soils. Vegetation constitutes the

primary source of life support and animal husbandry is a major occupation of people that depends entirely on natural vegetation. The hot arid climate is distinguished by having high temperature, lesser precipitation, high evaporation, low and erratic rainfall, and extreme variation of diurnal and annual temperatures for the greater part of the year (Bhandari *et al.*, 2014). The soils of arid regions are predominantly light-textured. Low and erratic rainfall and high atmospheric evaporative demand coupled with a poor water holding capacity of soil limits the crop growing period up to 90 days, and therefore millets and short-duration crops (mainly pulses) are largely cultivated in the region. High light intensity decreases cell wall content and increases water-soluble carbohydrates in vegetation and thus influences livestock. The region is home to many livestock breeds of cattle, buffalo, sheep, goat, camel, and poultry etc which have unique adaptive characters (Table 1).

Table 1: Different livestock breeds with unique adaptive features

Breed	Unique features/traits
Cattle breeds	
Sahiwal, Red Sindhi, Gir, Rath	Milch type, heat and drought tolerant
Haryana, Ongole	Dual Purpose, Heat and drought tolerant
Nagori	Excellent drought animal for hot climate
Umblicherry	Excellent for wet ploughing
Buffalo breeds	
Bhadawari	High fat content (10-12%)
Banni	Unique grazing habit at night
Sheep breeds	
Marwari, Jaisalmeri, Deccani and Chokla	Hardy and capable of traveling long distances
Camel breeds	
Kachchhi camel	Well adapted to humid climate and marshy lands
Jaisalmeri Camel	Well known for riding and race potential, long and thin legs
Mewari Camel	Adapted to travel and carry load across hills
Kharai camel	Ecotonal breed (dryland and coastal ecosystem) Can feed on saline trees and shrubs (Mangroves) Can tolerate high TDS (up to 10000 ppm) water

Importance of resilience in livestock

Resilience is a key trait in the context of sustainable livestock farming. However, its application in breeding and management strategies is still limited because no metrics exist that straightforwardly quantify this trait on a large scale. Resilience can be defined as the ability of an animal to 'bounce back' from a disturbance. It is increasingly seen as an important trait that has a key role in sustainable livestock systems: resilient animals respond well to environmental challenges and have a decreased probability of needing assistance to

overcome them. Consequently, there is considerable interest in the livestock industry in implementing genetic selection and genomic management strategies that favor resilience. Resilience is an important homeostatic phenomenon in animals to cope with the variations in the environment and can be defined as an animal's capacity to respond to environmental disturbances through buffering mechanisms of metabolic and behavioural activities (Berghof *et al.*, 2019; Scheffer *et al.*, 2018). It temporarily modulates the available resources to down-prioritize non-vital life

functions and to up-prioritize homeostatic responses in physiology and environmental challenges. The cost of resilience mechanisms in different environments may favor or penalize selection for resilience by an external disturbance, or to quickly return to the normal productive, physiological, behavioural, cognitive and health state (Colditz and Hine, 2016; Strandberg 2009). The selection of climate-resilient animals is necessary to secure the future of sustainable animal production. Positive effects of resilience on profitability are expected through a smaller yield loss upon disturbances (Poppe *et al.*, 2021) and fewer labour costs, due to fewer health problems and fewer cows with alerts generated by automated systems (Berghof *et al.*, 2019). Positive effects are also expected through favourable associations with health, longevity, and fertility. All these traits affect livestock profitability, for example, through decreasing treatment costs with fewer diseases (Huijps *et al.*, 2008; Bruijn *et al.*, 2010), dilution of rearing costs per kilogram of milk with increasing productive life (Rendel and Robertson, 1950; Grandl *et al.*, 2019), and decreasing insemination costs and increasing the number of productive days in peak lactation with improved fertility (Inchaisri *et al.*, 2010).

Long-term consequences of resilience

Multidisciplinary approaches by amalgamation of animal breeding, nutrition, housing, and health are required to reduce the adverse impact of climate change on livestock (Gaughan *et al.*, 2019). Climate change can directly and indirectly reduce livestock production. Negative consequences of direct influences are a decline in growth, milk production, reproduction and meat production while indirect influences are through the emergence of sudden diseases. Resilience mechanisms function in response to a disturbance on a short timescale and are accepted as favorable in the long term (Friggens *et al.*, 2022). However, resilience based on short-term measures will need to be validated against long-term 'accumulated consequence'. Differences in resilience between animals (or genotypes) over time are present which are as follows:

- 1) Better recovery from the effect of environmental disturbance in a more resilient animal than a less resilient animal.
- 2) Availability of a secondary response in subsequent environmental disturbances.
- 3) Longer endurance power to exposure from many challenges than other mate animals.
- 4) Higher survival probability time of the more resilient animal than less resilient animal.

The resilience in dairy cows can be measured based on productive lifespan, number of disease events and ability to re-calve.

Increasing concern for resilience

Pastoralist communities in drylands of North Sub Saharan Africa (Nigeria, Kenya, Ethiopia, South Sudan, and West Africa) have adjusted their livestock composition in response to environmental extremes and changing ecological conditions, mostly by shifts from cattle to small ruminants (mainly goat) and/or camels (Kimani *et al.*, 2014). Browsers (camels and goats) are preferred over grazers (cattle) due to their greater climate resilience, resulting from their higher tolerance to drought and feed scarcity, as well as their capacity to produce milk and meat in all seasons (Teklegiorgis and Yirga, 2021). The shifting preference for browsers (favouring camels and goats over cattle) due to recent climate variability/change, and associated feed and water shortage was confirmed by over 71.5% of households (Borana community) of Northern Kenya (Kagunyu et al. and Wanjohi, 2014).

Livestock species of hot and arid regions of India

Cattle breeds of hot and arid regions of India

India has been blessed with a large repository of indigenous bovine populations with rich bio-diversity. There are 50 well-defined breeds of cattle of which around 20 breeds are native to hot and arid regions of India (Table 2). These breeds have evolved over generations, surviving due to their adaptability to harsh climatic conditions, ability to perform on poor-quality feed and fodder, resistance to diseases etc. Adult males of some native breeds are also known for their draft qualities. Thus these indigenous breeds are well adapted to our existing agro-climatic conditions, are resistant to many tropical diseases and can survive and produce on marginal and poor feed and fodder resources. A lot of genetic variation exists among all breeds, and the selection within a breed is almost as important as the choice of the breed itself. Evolution has favored the survival of the strongest and better-prepared animals to withstand the intense heat, lack of forages, prolonged dry season and many diseases. It is said that there is no ideal breed and that every breed has strong points and none is better for all important economic traits. Genetic conformation and structure related to body frame and body composition are important factors in the balance between heat generation and dissipation. Zebu has a lower relative body weight (density) or higher surface area than taurine cattle. For each kg of metabolically active tissue, Zebu has a larger surface area to dissipate heat than taurus. Zebu also presents a specific mechanism for heat tolerance which is the presence of a transcription factor (HSF1) to the heat stimulus at the cellular level. This through an expression of certain proteins may mediate the metabolic rate and immune system

activation, favoring adaptation to heat stress. The mRNA expression of metabolism-related genes and apoptotic genes was found to be lower in zebu cattle than crossbred and exotic cattle (Maibam *et al.*, 2017). A higher level of antioxidant enzymes (SOD, CAT, GPx) in both skin and plasma of indigenous cattle reflects their ability to thrive in hot summer months. The presence of specifically eumelanin gene intensifies skin pigmentation and thus helps in photoprotection because of its efficiency in blocking ultraviolet rays (UV) and scavenging reactive oxygen species (Choudhary *et al.*, 2017). Few studies however have compared different zebu breeds for these traits and found area-specific variation in their genetic makeup. As compared to European breeds, tissue resistance to heat flow from the body core to the skin is lower for zebu cattle

followed by lower resistance by hair covering. Marked characteristics of the hair coat in zebu cattle (like slick hair coat gene, light colour) enhance conductive and convective heat loss and reduce the absorption of solar radiation. The genetic adaptations that have developed in zebu cattle during their evolution are the acquisition of genes for thermotolerance. Genetic differences in thermotolerance extend to these animals at their cellular level as well, as deleterious effects of elevated temperature on cellular function are less for cells from Brahman cattle than cells from Angus and Holstein (Hernandez-Ceron *et al.*, 2004). At the molecular level, increased expression of stress-related genes and hence their protein products are helping these animals to combat the stress.

Table 2: Cattle breeds of hot and arid regions of India

S. No.	Breed	Breeding tract	Main uses
1.	Amritmahal	Karnataka	Transport and Draught
2.	Belahi	Haryana and Chandigarh	Milk and Draught
3.	Dagri	Gujarat	Draught
4.	Dangi	Maharashtra and Gujarat	Draught
5.	Deoni	Maharashtra and Karnataka	Milk and Draught
6.	Gir	Gujarat	Milk
7.	Hallikar	Karnataka	Draught
8.	Hariana	Haryana,	Milk and Draught
9.	Kankrej	Gujarat and Rajasthan	Milk and Draught
10.	Khillar	Maharashtra and Karnataka	Draught
11.	Krishna Valley	Karnataka and Maharashtra	Draught
12.	MalnadGidda	Karnataka	Draught
3.	Mewati	Rajasthan, Haryana and Uttar Pradesh	Draught
14.	Nagori	Rajasthan	Draught
15.	Nari	Gujarat and Rajasthan	Milk and Draught
16.	Ongole	Andhra Pradesh	Milk and Draught
17.	Punganur	Andhra Pradesh	Milk and Draught
18.	Rathi	Rajasthan	Milk
19.	Sahiwal	Punjab and Rajasthan	Milk
20.	Tharparkar	Gujarat and Rajasthan	Milk and Draught

Climate resilience characteristics of large ruminants

In Ongole/Nellore cattle, 85% of solar radiated heat is sent back to the environment by the animal through its white, reflective coat. The rest 15% of the heat is immediately absorbed by the underlying black skin. When total body skin is black, these cattle reduce heat load through behavioural means and postural adjustments. Long legs of this breed help minimise the absorption of solar-radiated heat. Conductive

and convective heat loads on these cattle transfer between surroundings and direct contact through soil and bedding, drinking water, feeds and fodders. Avoiding lying down, and stretching its body parts also helps. Ongole cattle have characteristics associated with hardiness and thriftiness like the ability to reverse down metabolism during extremes of scarcity. They are efficient foragers. The tight sheaths and small teats avoid injuries to the grazing animals. Sloppy rumps

which are suitable for quick and hard work, have 4 sacral vertebrae. They have more number of bigger, functional, sweat glands per unit area of the skin. The white or light-coloured, short, sleek, dense, reflecting and glistening coat does not attract vectors and dislodges them. Skin is pigmented, black, mellow, loose, and thick and the presence of subcutaneous panniculus carnosus muscle repels vectors by twitching. It has the highest heat tolerant coefficient. The basal metabolic rate is low. They possess nutritional uniqueness, and the ability to convert low protein, high fiber roughage materials into high-grade foodstuffs with the aid of omasal symbionts. The crude protein utilization is highest and performs well even when the pastures are seasonal, scanty, and sparse. These animals spend much time in grazing even during the daytime, and seek shade only 3% of their total grazing time. They are slow to cycle, when under nutritional stress or lactation stress, but response to cycle is immediate when nutrients are plenty. The active and vivid disposition of the Ongole is largely responsible for their unusual thriftiness, hardiness and adaptability to a wide range of feed and climate. The Sahiwal is the heaviest milker of all Zebu breeds and displays a well-developed udder. Sahiwal demonstrates the ability to sire small, fast-growing calves and is noted for their hardiness under unfavourable climatic conditions. Tharparkar cattle are said to be very hardy and resistant to several tropical diseases. Although animals of the breed are excellent foragers and can stand the rigours of climatic and environmental conditions, they have not been used primarily as a source of meat, and breeders have given little attention to meat qualities. Mewati cattle are in general, sturdy, powerful and docile, and are useful for heavy ploughing, carting and drawing water from deep wells. The cows are said to be good milkers. The Kankrej cattle are highly prized as fast, powerful draft cattle. They are also fair producers of milk. These cattle are resistant to tick fever and they show very little incidence of contagious abortion and tuberculosis. The Nagori breed is one of the most famous trotting draft breeds of India and is generally appreciated for fast road work. Rathu cattle are thought to have evolved from intermixing of Sahiwal, Red Sindhi and Tharparkar breeds with a preponderance of Sahiwal blood. The breeding tract of this breed lies in the heart of Thar Desert consisting of Bikaner, Ganganagar and Jaisalmer districts of Rajasthan. The breeding tract is fragile with less fertile, low productive lands with scorching summer (50 °C), chilly winter (2 °C), dry monsoon (less than 200 mm rainfall in a year) and dust storms. Despite all hardships, Rathu cows are efficient and good milkers. The cows on an average produce 1500-1600 kg of milk. The study conducted by Gujar *et al.*, 2022 indicated a well-developed thermotolerance mechanism in Kankrej

and Sahiwal breeds, with Kankrej cows exhibiting better thermotolerance compared to Sahiwal cows. The physiological parameters showed an increasing trend with the incremental THI, with significantly ($p < 0.05$) higher values of rectal temperature (RT), respiration rate (RR), pulse rate (PR), and body surface temperature (BST) at ventral (VT), lateral (LT), dorsal (DT), and frontal (FT) parts, in both breeds during heat stress. The haematological pictures also revealed significant ($p < 0.05$) seasonal perturbations in erythrocytic and leucocytic parameters. Moreover, the molecular response was driven by a significant ($p < 0.05$) upregulation of all the key *HSPs*: *HSP70*, *HSP90*, *HSP60*, and *HSP40*, except *HSP27* during the hotter months of summer and hot-humid seasons. The expression of *HSF1*, an important transcriptional regulator of *HSP70* was also significantly ($p < 0.05$) upregulated during the summer season in both breeds. All the molecular chaperones revealed a significant upregulation during the summer season, followed by a decreasing trend by the hot-humid season.

Dairy exotic breed Holstein Friesian is very compatible and productive in the highland intensive production system while crossbreeding with indigenous zebu dairy cattle has a considerable role in improving behavioural and physiological adaptability to survive in stressful climatic conditions (Fanta, 2017). Indigenous cattle breeds have superior adaptive response mechanisms to cope with adverse environmental conditions as useful indicators of animal welfare in changing climatic conditions. Better adaptive capacity in physiological responses, behavioural patterns, haematological parameters, higher expression of free radicals, antioxidants, molecular genes deregulation and Interleukin-1 β (IL-1 β) in Tharparkar are counter mechanisms for heat stress (Khan *et al.*, 2021; Pandey *et al.*, 2017; Jose *et al.*, 2020). Sahiwal cows are less sensitive and better able to regulate thermoregulatory mechanisms by increasing the magnitude of respiration rate, rectal temperature and heat tolerance coefficient due to their long-term adaptation to tropical climates, low metabolic rate and great sweating capacity (Sailo *et al.*, 2017; Grewal, and Aggarwal, 2018; Prasanna *et al.*, 2021). Candidate genes (*LIF*, *OSM*, *TXNRD2*, and *DGCR8*) loci for complex traits such as milk production and biomarkers such as *HSP70.1*, *ATP1B2*, *HSF1*, *HSPA6*, *HSP90AA1*, *TNF1/4*, *IL2/6*, *EIF2AK4*, *KIF9*, *SELENBP1*, and *XDH* were found to be associated with thermotolerance and production traits in dairy cows (Silpa *et al.*, 2021; Saravanan *et al.*, 2021). Marker-assisted selection programs by incorporation of candidate genes can improve meat, milk and reproductive performance to improve climate resilience capacity of dairy cattle (Mummed, 2019; Madhusoodan *et al.*, 2020). Effective

management practices (misting, wallowing, water sprinkling, airflow, etc.) during hot humid periods alleviate heat stress to avoid performance losses (milk production and reproduction) and animal welfare issues viz. physiological, metabolic, endocrine, homeostatic responses (rectal temperature, respiratory rate, pulse rate, haematological parameters, serum metabolites, electrolytes, enzyme activities, redox status and stress hormones) and milk biomarkers in Murrah buffalo (Yadav *et al.*, 2016; Li *et al.*, 2021; Chaudhari *et al.*, 2013).

Sheep and goat breeds of hot and arid regions of India

India has 34 registered goat breeds out of which 12 breeds have a home tract in arid and semi-arid areas namely Sirohi, Marwari, Jakhrana, Barabari (Rajasthan), Beetal (Punjab), Zalawadi, Mehsana, Gohilwadi, Kutchi, Surti (Gujarat), Bidri and Nandidurga (Karnataka). India has 44 registered sheep breeds out of which 17 breeds have home tracts in arid and semi-arid tropics namely Bellary, Hassan, Kenguri and Mandya (Karnataka), Chokla, Jaisalmeri, Magra, Malpura, Marwari, Nali, Pugal and Sonadi (Rajasthan) Nellore and Deccani (Andhra Pradesh), Patanwadi, Panchali (Gujarat) and Kajali (Punjab).

Climate resilience characteristics of small ruminants

Sheep and goats can minimize adverse effects of high thermal stress by various adaptive characteristics and

biological markers to improve thermo tolerance which has been acquired over years to stressful conditions in arid and semiarid regions. These characteristics include coat characteristics (light hair color, lightly pigmented skin), morphological features (body shape, size and less subcutaneous fat), behavioural mechanisms (feed intake, water intake, shade seeking, and increased frequency of drinking), physiological (respiration rate, rectal temperature, sweating rate), blood constituents, acid-base balance, haematological and biochemical profiles, hormonal (T3, T4 and growth hormone) responses and the response of molecular regulators as heat shock proteins 70 (*HSP70*) and *ENOX2* (Al-Haidary *et al.*, 2021; Joy *et al.*, 2020; Leite *et al.*, 2021) (Table 3). Physiological responses and behavioural responses (water consumption and feed intake) were found better in long-haired, white or light brown goats than short-haired, dark brown or black goats (Acharya *et al.*, 1995). These types of studies help establish breeding and managemental strategies for the selection of climate-resilient productive animals for dairy and meat purposes in the hot tropics during the summer months (Sánchez-Molano *et al.*, 2020). Conclusively, increased physiological mechanisms, reduced metabolic rate, change in endocrine function and genetics of heritable traits favour the survival of populations (Berihulayet *et al.*, 2019).

Table 3: Biological markers for breed differences in small ruminants for thermotolerance (Joy *et al.*, 2020)

Variable	Species	Tolerant Breed	Susceptible Breed	Quantity of Stress	Effect on Tolerant Breed Compared to the Susceptible Breed
Behavioral Adaptation					
Water intake	Goat	Salem Black	Osmanabadi	Summer heat stress THI -86.5	Lower water intake
Feed Intake	Goat	Salem Black Osmanabadi	Malabari	Summer heat stress THI -86.5	No change in feed intake
Physiological Adaptation					
Rectal Temperature	Goat	Salem Black	Malabari Osmanabadi	Summer heat stress THI -86.5	Lower rectal temperature
	Goat	Jamunapari	Barbari	Summer Heat stress Temperature – 47.5°C RH – 21.5%	Lower rectal temperature
Respiration rate	Goat	Jamunapari	Barbari	Summer Heat stress Temperature – 47.5°C RH – 21.5%	Lower respiration rate
	Goat	Salem Black	Malabari, Osmanabadi	Summer heat stress THI -86.5	Lower respiration rate
Endocrine Adaptation					
T3	Sheep	Chokla	Cross-Breed of Chokla	Summer Heat stress Temperature – 38.8°C RH – 16%, YHI-78.9	Lower concentration
Growth hormone	Goats	Salem Black Malabari	Osmanabadi	Summer heat stress THI -86.5	Higher concentration

Cellular and Molecular Adaptation					
Leptin gene	Goat	Jamunapari	Barbari	Summer Heat stress Temperature – 47.5°C RH – 21.5%	Lower expression
HSP 70	Goat	Salem Black	Malabari Osmanabadi	Summer heat stress THI -86.5	Lower expression
	Goat	Barbari	Sirohi Jhakarana	Summer heat stress THI -81.63	Lower expression
HSP 90	Goat	Barbari	Sirohi Jhakarana	Summer heat stress THI -81.63	Lower expression
	Goat	Jamunapari	Barbari	Summer Heat stress Temperature – 47.5°C RH – 21.5%	Higher expression
IGF-1	Goat	Salem Black	Osmanabadi Malabari	Summer heat stress THI -86.5	Higher expression
TLR genes (TLR3, TLR7, TLR8 and TLR9)	Goat	Salem Black	Osmanabadi	Summer heat stress THI -86.5	Higher expression

The existence of genetic resistance to (or tolerance of) disease challenge implies a genotype-environment (G-E) interaction since the resistant genotype could be expected to perform relatively better in a high challenge than in a low-challenge environment. Diseases covered include gastrointestinal nematode infections, diseases due to mycotoxins, bacterial diseases including footrot and mastitis, and ectoparasites such as flies and lice and scrapie. In all cases, there is well-documented evidence for between-animal genetic variation in resistance to the disease and, in the case of some of the infectious diseases, resistance to infection. These heritable differences between animals lead to opportunities to breed animals for enhanced resistance to the disease. For some diseases, including nematode parasite infections, resistance to various forms of mycotoxin poisoning and fly-strike, the feasibility of breeding for resistance has been demonstrated in experimental flocks. Importantly, in other cases, including nematode parasite infections and some forms of mycotoxin poisoning, but also mastitis, foot rot and scrapie, there

are now breeding programmes selecting commercial animals for enhanced resistance. In almost all cases, the evidence for genetic variation and the documented success of breeding for resistance occurs in sheep rather than goats. Breed differences in resistance to nematode infections have been well documented, particularly for tropical or sub-tropical sheep facing the *Haemonchus contortus* challenge (Bishop and Morris, 2007).

The biochemical and molecular variations are involved in climate resilience features in small ruminants. The study of Rutherford and Lindquist (1998) showed that genetic variation in stress resistance or stress susceptibility (buffering capacity) may be due to polymorphisms at loci responsible for the regulation of stress response (e.g. heat shock) genes. The polymorphic loci developed have produced many biochemical and molecular variations in genes and proteins required during stress responses. At the phosphoglucoseisomerase (PGI) locus, the more anodal allozyme/isozyme is favoured under stressful conditions including high temperature, high salinity,

Table 4: Mean and variances for potassium concentration in LK and HK Sheep (Taneja, 1972)

Breed	Number	Means	Variances
Polwarth	25	8.74	1.60
Rambouillet	9	7.61	1.35
Polwarth X Rambouillet	19	8.41	1.08
Malpura	74	33.81	21.65
Marwari	106	24.38	12.44
Nali	42	27.38	15.10
Pugal	19	29.91	8.96
Magra	75	27.53	4.82
Chokla	168	26.78	4.11
Jaisalmeri	18	23.68	7.76

anoxia and desiccation in data covering a wide range of animal and plant taxa. This suggests at least one locus in natural populations of major importance in determining stress resistance (Riddoch, 1993). This particular situation is not surprising, since *in vitro* biochemical studies of PGI allozymes suggest that this enzyme, which catalyzes a metabolic reaction and regulates flux through glycolysis, is a direct target of selection of such stresses (Watt, 1985). The distribution of whole blood potassium concentration in sheep shows marked bimodality varying about two modes one with a higher concentration of potassium and the other with a low concentration. These are designated as high (HK) and low potassium types (LK). Genetically the two types are controlled by a pair of genes (HK is recessive and LK dominant). Taneja (1967) showed a higher proportion of HK animals in Rajasthan deserts (Table 4) which may give them the advantage in adaptation. The HK animals have higher haemoglobin, and WBC count and maintain lower body temperature than LK. This also indicates a relatively inefficient thermal regulation of LK-type animals in tropical conditions of India.

Climate resilient characteristics of camel

Physiological adaptations in camel are effective survival attributes which include water conservation ability, the unique features of blood, thermoregulation, efficient digestion and metabolism. Anatomical features in camel are also very specific in terms of the nature of skin coat, eyes, nostrils and lips, large body size, long height and large foot pads. Along with physiological and anatomical adaptations, behavioural aspects viz. feeding, drinking, thermal and sexual behaviour are also important for the existence and improvement of health care, management and productivity of camels in the desert environment (Gebreyohanes, and Assen, 2017). The integration of different homeostatic mechanisms such as watering regimes have effect on physiological responses and haematological parameters, molecular mechanisms, physiological changes, proteomic and transcriptomic profiles, gene functions (*HSP60*, *HSPA6*, *HSP105*, *HSPA1L*, *HSP70*, *HSP90*, *HSPFB* and *CaHS*) and glycosylation leading to better body adaptation under heat stress in dromedary camel (Sadder *et al.*, 2015; Faraz *et al.*, 2021; Tibary and El Allali 2020). Adaptive heterothermy is a mechanism of selective brain cooling for acclimatization in camels by fluctuation in body temperature between 34 and 42°C, thus minimizing perspiration and avoiding water losses through evaporation (Ouajd and Kamel, 2009). The flexible thermo tolerance and recovery mechanisms from chronic heat stress involve cellular resilience and plasticity for adaptation in camel cells (Saadeldin *et al.*, 2020).

Climate resilient characteristics of poultry

Suitable thermo-tolerant genes, disease-resistant genes, production associated genes and heat shock proteins (*HSP70* and *HSP90*) in birds are involved in resistance to heat stress (Youssef *et al.*, 2014; Felver-Gant *et al.*, 2012). These genes control several traits with corresponding genes such as the naked neck gene (Na), frizzle gene or the (F) gene, dwarf gene or (dw) gene through slow and reduced feathering, curling the feather to improve the heat dissipation and reduce body size to minimize metabolic heat production.

CONCLUSION

Climate change is a reality and is now a part and parcel of the plant-animal and human life cycle. In this scenario, livestock which are more resilient will be preferred. A shift from cattle to camel and goat farming which can sustain milk production with lower inputs and emissions is in progress in north sub-Saharan Africa's drylands. This shift will be visible in all parts of the world. Whereas different livestock species have different climate resilience and tolerances, location-specific data are required to assess where shifts in herd composition from currently cattle-dominated systems are needed to maintain or even increase dairy production in semi-arid and arid systems under climate change. Responding to the challenges of global warming necessitates efficient and suitable managerial practices with the adoption of a particular breed as per the agroclimatic condition. Any livestock breed needs to be adequate in three key areas i.e. survivability, fertility and productivity. The lack of information about a breed's tolerance to heat is already perceived as a major constraint to production. So, it is necessary to build or improve the adaptive capacity of the animal through the implementation of certain adaptation strategies and policies like the identification of agro-ecological zone-specific climate-resilient thermotolerant animals to sustain livestock production.

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