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Physiological and cellular adaptations of zebu cattle to tropical climatic conditions

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Abstract

Climate change is expected to have maximum impact on extensive livestock production systems. Zebu cattle are uniquely suited to hot climates due to their unique characteristics viz. coat, hide, skin and hematological attributes. Body conformation, growth and physiological aspects are unique genetic attributes, which are different from those of *Bos taurus* cattle. Compared with *Bos taurus*, zebu cattle are valuable in crossbreeding from adaptation point of view. In tropical countries, crossbreeding between *Bos indicus* and *Bos taurus* is a common practice not only to increase production and reproduction, but also to maintain thermal balance. In this article various unique traits and characteristics of zebu cattle with reference to adaptation have been discussed.

Key words: adaptation characters – cattle – climate change – cross breeding

Introduction

Globally, climate change or global warming represents a critical challenge to humanity in 21st century. Reports have indicated that developing countries are more vulnerable to the effects of climate change due to their high reliance on natural resources, very limited capacity to adapt institutionally and financially, and high poverty levels (Thornton *et al.*, 2006). According to Drucker *et al.* (2007) the harsh effects of climate change are more likely to be felt in extensive livestock production systems. Thus, urgent intervention steps are needed to minimize the harsh effects of extreme and severe climate to safeguard the livelihoods of livestock. Thus, a clear understanding of traits related to animal adaptation to extreme environments is crucial for the design of breeding strategies for adaptation to climate change. Adaptation is a broad term used to describe the ability of animals to adjust to environmental conditions or to infer genetic modifications that make animals more suitable for existence under specific environmental conditions. Zebu (*Bos indicus*) cattle are widely recognized as adaptable to tropical and subtropical environments that are restrictive to temperate (*Bos Taurus*) cattle. Zebu cattle are uniquely suited to hot climates due to coat, hide, skin and hematological attributes. Form, growth and physiological aspects are unique genetic attributes which are different from those of *Bos taurus* cattle. Howes (1963) reported that hematological comparisons of Brahman and Hereford cattle were related to respiration and adaptation. Brahman cattle were observed to have higher red blood cell counts, total cell volume and hemoglobin values. Venous blood of Brahman cattle had less carbon dioxide than did that of Herefords. These results imply that Brahman cattle are capable of maintaining lower respiration rates during periods of high ambient temperatures. Evans (1963) confirmed these hematological advantages for Zebu cattle as well as the effect of the advantages on adaptation to temperature stress. Therefore, Zebu cattle must have certain traits unique from exotic breeds that make them resilience to tropical climate.

Physiological responses

The relationship between behavioral and physiological indicators can be used to evaluate the adaptive capacity and consequently the "welfare" of animals in relation to different conditions (Broom and Johnson, 1993). Stressors of some systems are detectable as modifications of respiratory or heart rates, which are a valid index of social stress (Guyton, 1995). Sharma (1974) reported positive correlation between temperature, relative humidity and rainfall with that of pulse rate, respiration rate and body temperature in cattle. Finch (1986) reported a notable difference among different breeds of cattle in their ability to regulate rectal temperature: the mean rectal temperature was higher in *Bos taurus* than in *Bos indicus* cattle and, as a result, *Bos taurus* cattle are more sensitive to heat stress than their *Bos indicus* counterparts. This increase in respiration rate may be used as an index of discomfort in large animals (Bhattacharya *et. al*., 1965). Singh and Upadhyay (2009) observed higher respiration rate and rectal temperature in Karan Fries than Sahiwal cattle during heat stress. Low respiratory rate under hot weather identifies animals with lesser discomfort. This fact is evident when comparing respiration rates of *Bos taurus* versus *Bos indicus* under hot summer weather conditions where *Bos indicus* (Zebu) cattle maintain lower respiration rates. Hansen (2004) also stated that cattle from zebu breeds are better able to regulate body temperature in response to heat stress than those of cattle from a variety of *B. taurus* breeds of European origin.

Skin coat

It is a familiar observation that different ecotypes of cattle, whether they are distinguished as species, breeds, or strains, show marked contrasts in coat cover. These differences follow the principle, dignified by Wright (1954) as "Wilson's Rule", of a gradient from thick, woolly coats in cold climates to short coats with bristly hairs lying sleekly against the skin in hot climates. The contrasts between European cattle and Zebus of India clearly represent adaptations to cold and to heat. Individual animals also grow shorter coats when transferred from a cold to a hot environment (Berman and Volcani, 1961). The fact that coat genotype seems to have changed fairly rapidly in breeds introduced to the tropics confirms the importance of this trait to adaptation. Verissimo (2002) reported that the tropical breed cattle had shorter hair length when compared to the crossbred animals. He found that hair length increased as the Holstein fraction increased. Turner and Schleger (1960) measured the degree of variability of coat type within herds, and assessed the proportion of the variation in growth rate that is accounted for by variation in coat type. Coat characteristics are associated with heat tolerance and performance of animals (Collier and Collier 2012). Skin color is also associated with the health condition of the individual (Stephen *et al.* 2011). In animals, hair and skin pigmentation is a highly visible trait. Under tropical condition with high levels of solar radiation, animals with a light colored hair coat and darkly pigmented skin are better adapted. The light cows show lesser alterations in physiological variables than did cows with less white.

The basis of coat color in mammals including cattle is the presence or the absence of melanin pigment (eumelanin and pheomelanin). Eumelanin is responsible for black and brown colours and pheomelanin for reddish brown (Simon and Peles, 2010). Melanocortin 1 receptor (MC1R) gene is responsible for pigmentation differences in mammals (McRobie *et al.*, 2014). Acquisition of a highly stable MC1R allele promotes black pigmentation which helps in protection from UV damage (Greave, 2014). Another gene, premelanosome (PMEL), encodes a transmembrane protein called pre-melanosomal protein. PMEL is a melanocyte protein necessary for eumelanin deposition (McGlinchey, 2009). Therefore, the above mentioned genes (MC1R and PMEL) divert the pathway of melanin synthesis towards eumelanin (true melanin) rather than pheomelanin. The rate limiting enzyme for melanin synthesis is tyrosinase (Zhang *et al.*, 2010). Eumelanin intensifies skin pigmentation and thus helps in photoprotection because of its efficiency in blocking ultraviolet rays (UV) and scavenging reactive oxygen species (Klungland *et al.*, 1995).

The expression of skin color related genes (MC1R and PMEL) in lymphocytes and plasma tyrosinase activity were found to be significantly higher in Tharparkar than Karan Fries cattle. It shows that the ability of Karan Fries cattle to protect themselves from the harmful UV radiation by melanisation was significantly less compared to Tharparkar and it was found to be declined with heat stress (Uttarani *et al.*, 2014a, b).

Heat dissipation and thermo-tolerance

The main differences in skin structure of domestic cattle of different breeds are in their dimensions and its component organs. Cattle indigenous to tropical regions had a relatively thin hair follicle depth and very often a simple sac-like sweat gland (Jenkinson and Nay, 1975). *Bos indicus* cattle have looser and thicker skin, larger ears, a prominent hump and live in the hot and humid climates. *Bos taurus*, on the other hand, lack all of these characteristics (except for the thick hide) and are more adapted to cooler and drier climates.

The ability of cattle to maintain body temperature depends on their capacity of thermoregulation based on the balance of heat gain and heat loss through: conduction, convection, radiation, and evaporation (Kadzere *et al.*, 2002). Evaporative cooling by sweating and panting is the most important mechanism for body heat dissipation under elevated hot climates (Collier, 2008). However, heat loss by panting becomes effective if the excess heat is not dissipated successfully by sweating and its capacity is impacted by the genetic makeup of cattle. McLean and Calvert (1972) found that 84% of heat was lost by evaporation, of which 65% was lost by sweating and 35% was lost by panting. Cattle utilize evaporative cooling in the form of both sweating and panting in an effort to rid themselves of excess body heat when environmental temperatures begin to exceed 35°C and THI of 90 (Collier, 2008). *Bos indicus* cattle, with their higher sweat gland density, tend to also have a higher sweating rate (Allen 1962; Schleger and Turner 1965). The sweat glands of *Bos indicus* are baggy-shaped, higher in volume (Pan, 1963), and closer to the skin surface (Nay and Hayman 1956) than those of *Bos taurus.* Comparative studies found that *Bos indicus* are more dependent upon increased sweating to dissipate excess body heat based on higher sweating rates, lower rectal temperature and lower respiration rate, while *Bos taurus* are more likely to utilize an increase in respiration rates to dissipate heat based on higher respiration rate and higher rectal temperature (Koatdoke, 2008). Sweating rate was found to be increased with increasing THI and was more prominent in Sahiwal than HF and the crossbreds. Sahiwal (*Bos indicus*) and HF-50% responded to the elevated temperature by sweating, whereas 87.5% and 100% HF *(Bos taurus)* employed respiration to dissipate excess body heat.

Heat shock proteins

Cellular tolerance to heat stress is mediated by a family of proteins named heat shock proteins (Hsp). Heat shock proteins are a large protein family consisting of both constitutively expressed and inducible proteins, classified according to their molecular weight (Kregel, 2002). The expression of constitutive HSPs increases in response to stress, whereas inducible HSPs are expressed only after stress. HSPs are representative of stress proteins, and their cellular up-regulation especially that of HSP70, provides resistance to the cell against stressors because the HSPs re-fold or degrade denatured proteins produced by stressors (Morimoto and Santoro, 1998). HSPs function as molecular chaperones in restoring cellular homeostasis and promote cell survival (Collier *et al.*, 2008). Among the heat shock proteins, HSP 70 is the most abundant in both eukaryotes and prokaryotes and it appears as a thermal switch. The HSP 70 acts as an indicator of thermo-tolerance retention. Studies have shown a specific association between the presence of HSP70 and thermo-tolerance mechanisms in various types of cells (Adachi *et al.*, 2009). When vertebrate cells are exposed to high temperatures for a long period of time, the acclimatization properties were observed to increase due to the synthesis of HSPs (Hunter-Lavin *et al.*, 2004).

Mayengbam (2014) also reported an increase in relative HSP72 mRNA expression in Sahiwal and crossbred Karan-Fries cattle after exposure at 40 and 44 °C with 50% RH. Singh *et al.* (2014) found a sharp rise in the HSPs mRNA expression in dermal fibroblasts of Tharparkar and Karan-Fries cattle during heat stress. But, the relative expression of inducible HSP70 genes (HSPA1A and HSPA2) at 40 and 44°C were higher in fibroblast of Karan-Fries than Tharparkar, which may be attributed to superior adaptability of Tharparkar cattle to heat stress. Theodorakis *et al.* (1999) found that thermo tolerant cells expressed less HSPA1A when subjected to heat shock. Kishore *et al.* (2014) reported highest level of expression of HSPs throughout the time period of heat stress in buffaloes, followed by HF and Sahiwal cows. The higher abundance of HSP70 mRNA at each time point after heat stress showed prolonged effect of heat stress in HF PBMCs. The viability data indicated HF PBMCs to be the most affected to the heat shock, whereas Sahiwal PBMCs were least affected, indicating its better survivability during the heat stress condition. This differential expression of HSP70 mRNA in the present study could be attributed to its genetic divergence across the studied species (Sodhi *et al.* 2013).

Oxidative stress and thermal stress

Under heat stress, free radicals are produced in the body and are neutralized by intracellular antioxidant enzymes produced in the different tissues of the body depending upon their metabolic activity. When reactive oxygen is produced faster than they can be safely neutralized by antioxidants, the oxidative stress results (Bernabucci *et al.*, 2002). The increase in ROS reflects increased level of thermal stress. Keller *et al.* (2004) also observed that exposure of animals to elevated temperatures accelerated mitochondrial respiration and increased mitochondrial ROS formation. ROS, being cellular toxicants can be induced through hyperthermia (Flanagan *et al.*, 1998). Excess ROS production by intensively respiring mitochondria induces cellular damage (Abele *et al.*, 2002). ROS formation in fibroblast of cattle decreased at lower temperature (25°C) than control (37 °C), but increased at 40 and 44°C. At 40 and 44 °C, ROS formations were observed to be more in Karan-Fries cattle than Tharparkar (Singh *et al.*, 2014). The breed/species differences observed in the levels of the ROS in Tharparkar and Karan-Fries cattle can be attributed to their difference in adaptability to different environmental conditions. The levels of the ROS are associated with the susceptibility of dermal fibroblasts to different environmental stresses. The higher level of ROS observed at high temperature in crossbred Karan-Fries (crossbred) cattle indicates their higher susceptibility to hot environment than Tharparkar (zebu cattle). The major defense in detoxification of superoxide anion and hydrogen peroxide resulted from oxidative stress, are Super Oxide Dismutase (SOD), Catalase and Glutathione peroxidase (Chance *et al.,* 1979). Erythrocytic SOD and Catalase increased significantly after 3h of exposures in climatic chamber (Lallawmkimi *et al.*, 2012). Kumar (2005) observed a significant positive correlation of THI with the erythrocyte SOD and Catalase activity in Murrah buffalo and KF cattle. The highest increase was registered in KF followed by Murrah.

Stress indicator hormone (cortisol)

Activation of hypothalamo-pituitary adrenal axis and the consequent increase of plasma cortisol level is the most prominent response to stressful conditions. This increase in cortisol level stimulates physiological adjustments that enable the animal to tolerate the stress caused by a thermal stress (Christison and Johnson, 1972). Plasma cortisol rises markedly when cattle are acutely exposed to high environmental temperatures (Habeeb *et al.*, 1992). Chandrabhan *et al.* (2013) reported higher plasma cortisol levels in KF compared to Zebu cattle during different seasons but the peak level of cortisol was observed when animal were exposed to higher temperature. The higher cortisol level in crossbred cattle during heat stress indicates that they are in greater stress on exposure to heat.

Conclusion

There are certain significant differences between Tharparkar and Karan Fries cattle in the parameters related to thermal stress. The ability of Karan Fries cattle to protect themselves from the harmful radiation of sunlight by melanisation was significantly less compared to Tharparkar and it was found to be declined with heat stress. The resistance of dermal fibroblasts to thermal stress differed between Tharparkar and Karan Fries cattle. Dermal fibroblasts of Tharparkar were more heat resistant than crossbred Karan-Fries cows. Sweating rate is significantly higher in zebu than exotic cattle. Inducible HSPs expression, plasma cortisol level and ROS formation on exposure to heat stress were comparatively lower in indigenous than European breed. Therefore, it may be concluded that zebu cattle have certain traits unique from European cattle that contribute to their superior adaptability to tropical climatic condition with high solar radiation. However, many other mechanisms are likely to contribute to the difference in thermo tolerance between the zebu and crossbred cattle. Additional research is necessary to establish the association between unique traits of zebu cattle and thermo tolerance.

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