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Physiological Responses of Cattle to Heat Stress

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Abstract: Pakistan lies in the Warm Climate Zones of the world and is subjected to extended periods of high ambient temperature and relative humidity. The objective of this article is to review the physiologic/adaptive responses of acclimated cattle to heat stress emphasizing its affects on nutrient acquisition and metabolism, acid-base chemistry and hormonal balance of the body. Heat stress invokes a decrease in dry matter intake, enhanced digestibility and reduced blood flow to the forestomach. The energy metabolism decreases while the water and electrolyte metabolism increases. A nycthermal pattern of acid-base balance is manifested by a high respiratory rate leading to respiratory alkalosis in the hot day time hours; and lower urine pH and greater urine ammonia concentrations in the cool night time hours. Hormones involved in thermal adaptations include, prolactin, growth hormone, thyroxine, glucocorticoids, mineralocorticoids, catecholamines and antidiuretic hormone. These are either involved with nutrient partitioning and homeorhesis or for homeostatic regulation, augmented by thermal stressor. All these adaptive physiologic responses are the same in *Bos taurus* and *Bos indicus* but are less pronounced in the later, making it a thermotolerant breed. Cholistani breed of cattle may be utilized as a model to study the physiologic responses augmented by heat stress both on molecular and endocrinological levels.

Key words: Heat Stress · Nutrition · Metabolism · Hormones · Zebu Cattle

INTRODUCTION

Animal Environment is a broad term which includes both physical and biological components [1]. An external factor having a positive or negative impact on growth, lactation, or reproduction is generally included in the term " environment" whereas the factors that make up the components of "animal environment" include photoperiod, sound, altitude, effective ambient temperature (EAT), contaminants,physiological restraint and management systems [2]. Out of all these factors, environmental heat/heat stress is the most detrimental to dairy cattle and results in the hindrance of feed consumption [3], decreased milk production [4] and reproductive performance [5].

Homeotherms have Optimal Temperature Zones (OTZ) / Thermo-neutral Zones (TNZ) for production within which no additional energy above maintenance is expended to heat or cool the body [6]. Heat stress results from a negative balance between the net amount of energy flowing from the animal to its surrounding environment and the amount of heat energy produced by the animal. A highly integrated cascade of behavioral and physiological responses is set in motion in the animal which helps to maintain *homeostasis* and physiological equilibrium [7-9].

Biologic Consequences of Heat Stress: All the reactions evoked in response to moderate climatic changes are directed towards maintaining or restoring thermal balance [10]. The numerous physiologic mechanisms for coping with heat stress have been reported by Blackshaw and Blackshaw [11]. Sweating, high respiration rate, vasodilation with increased blood flow to skin surface, reduced metabolic rate, decreased dry matter (DM) intake and altered water metabolism are the physiologic responses that have negative impact on the production and reproduction of the cows [12]. All these physiologic responses are substantial and prolonged in *Bos taurus* than in *Bos indicus* [13, 14], hence the consequences of exposure to heat stress for production of milk and meat are less pronounced in the later [15].

Nutrient Acquisition and Metabolism: Nutrient acquisition encompasses three major functions: diet consumption having potentially absorbable nutrients,

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digestion of the diet and nutrient absorption from alimentary tract mucosa. All of these three functions are affected by thermal stress [16].

Consumption of Feed and Nutrients: Temperature-Humidity Index (THI), the combined effect of temperature and relative humidity, is not only the vital measure of effects of heat stress but is also correlated with the nutrient intake [17]. Studies have found that there is a significant negative correlation (-0.63) between THI and dry matter intake (DMI) [18]. However, genetic differences exist for heat tolerance of cattle as *Bos indicus* breeds are more heat tolerant than *Bos taurus* because of greater sweating capacity and lower metabolic rates [11]. Holter *et al.,* [19] has reported a reduction in DMI in Jersey cows when minimum THI exceeded 56 and continued until THI reached 72. During heat stress, DMI was reduced to 22% for multiparous and 6% for primiparous cows because of smaller body size and lower metabolic rate in primiparous cows [20]. Reduced DMI and therefore heat generated during ruminal fermentation and body metabolism, aid in maintaining heat balance. Moreover, increased environmental temperature elevates the respiratory rate and water intake [21], reduces the gut motility, rumination, ruminal contractions [22] and depresses appetite [23] by having a direct negative effect on appetite centre of the hypothalamus [24]. Other factors such as variation in managemental practices [25], stage of lactation, breed and age [26] and diet composition [16] also affect the nutrient intake. Grazing animals have been reported to be more affected than intensively managed ruminants.

Digestion: Digestibility is affected by many factors eg., rate of feed consumption, feed quality, nutrient composition, rates of passage of digesta and volumes of ruminal and postruminal digestive organs [27]. All of these factors are influenced by thermal stress. At high temperature, decreased feed intake evokes increased digestion by decreasing the passage of digesta and increasing the ruminal volume [28]. These physiological alterations are more helpful for animals consuming higher forage diets.

Absorption of Nutrients: Peripheral vasodilation and central vasoconstriction cause reduced blood flow to ruminant forestomach [29]. This in turn decreases the portal vein plasma flow hence reducing the nutrient absorption [30]. Data regarding quantification of net portal and hepatic uptake of specific nutrients during thermal stress is lacking.

Thermal stress decreases the energy metabolism (basal metabolic rate) and increases water and electrolyte metabolism [31]. Maximum water intake during the hot period was at least doubled from the control period, from 4.8 to 9.8% in *Bos taurus* and from 3.8 to 9.3% in *Bos indicus* [32]. This is mainly due to lower plasma concentrations of metabolic hormones such as thyroxine [7], growth hormone (GH) [33] and corticoids [34].

Acid-Base Homeostasis: Heat stress is cyclic in nature, with cows generally being at the peak of their stress by mid-afternoon and cooling somewhat in the evening and early morning hours [12]. This cyclic nature induces a nycthermal pattern of acid-base *homeostasis* in cattle which was first proposed by Dale and Brody [35]. Respiratory rate sharply increases during the daytime causing respiratory alkalosis because of the loss of CO_2 via pulmonary ventilation [36]. However during the cooler hours of the night, lower urine pH and greater urinary ammonium concentrations were recorded [37]. These nycthermal changes in acid-base and electrolyte balance are similar, both in *Bos taurus* and *Bos indicus*, with changes in *Bos indicus* being less pronounced [32].

Hormonal Imbalances: The endocrine system involved heavily in coordination of metabolism is substantially altered because of thermal stress [16]. The hormones associated with adaptation to heat stress are prolactin (PRL), growth hormone (GH), thyroid hormones, glucocorticoids, mineralocorticoids, atecholamines and antidiuretic hormone (ADH). Prolactin is vital for mammogenesis [38], lactogenesis [39] and to varying degrees for galactopoiesis [40]. Concentrations of plasma PRL are elevated during thermal stress in dairy cows [41]. However, the function of this elevated PRL is not yet clear. Collier *et al.* [42] proposed that elevated PRL is involved in meeting increased water and electrolyte demands of heat stressed cows.

Growth hormone is a calorigenic hormone produced from the anterior pituitary gland and does not function through a target gland but exerts its effects on almost all tissues of the body. The plasma GH levels declined from 18.2ng/ml at thermo-neutrality to 13.5ng/ml in heat stressed Jersey cows [33]. Igono *et al.* [43] reported that GH content in milk of low, medium and high production groups declined when THI exceeded 70. Plasma GH reductions that occurred with heat stressed cows did not occur in thermoneutral conditions for cows fed restricted intakes that were similar to those consumed during heat stress [30]. The decreased GH leads to less calorigenesis aimed in maintenance of heat in the body [44]. In addition to calorigenesis, GH also enhances heat production by stimulating thyroid activity [45]. Therefore, a reduced secretion of this hormone is all the more necessary for survival of the homeotherm in high ambient temperatures.

The thyroid gland secretes triiodothyronine (T_3) and tetraiodothyronine/ thyroxine (T_4). These hormones are the primary determinants of basal metabolic rate and have a positive correlation to weight gain or tissue production [46]. The response of T_3 and T_4 to heat stress is slow and it takes several days for levels to reach a new steady state [47]. A decline in the plasma concentrations of T_3 from 2.2 to 1.16ng/ml has been reported by Johnson *et al.* [48] whereas a reduced thyroid activity in thermal acclimated cattle has been reported by Gale, [49]. This decline in thyroid hormones along with decreased plasma GH level has a synergistic effect to reduce heat production [50].

Acute and chronic thermal stress shows differing responses on glucocorticoid concentrations, being elevated in former but not in later [42]. Alvarez and Johnson [51] reported an increase in glucocorticoids level from 2.4 to 3.9 µg/100 ml (62%) by the second hour of heat exposure, reached a peak of 5.4 µg/100 ml (120%) at 4 hours, then declined gradually to the normal of 2.4µg/100 ml at 48 hours and stayed at this level inspite of continued heat stimulus. The initial rise in plasma glucocorticoids is due to activation of the adrenocorticotropin (ACTH) releasing mechanism in the hypothalamus by thermoceptors of the skin [52], whereas the later decline to normal, inspite of continuing heat stimulus, indicates a negative glucocorticoid feedback and a decrease in the glucocorticoid binding transortin [53]. The glucocorticoids work as vasodilators to help heat loss and have stimulatory effect on proteolysis and lipolysis, hence, providing energy to the animal to help offset the reduction of intake [54].

In the bovine species, the simultaneous relationship among thermal stress, plasma aldosterone concentration and urine electrolyte excretion has been documented by El-Nouty *et al.* [55]. Plasma aldosterone concentration was the same during the first few hours of heat exposure, however, with prolonged exposure; it was 40% lower and declined rapidly during later hours of exposure. This decline in aldosterone concentration is due to a fall in serum K levels because of its increased excretion in sweat [55] and is explained on the basis of a major difference between ruminants and nonruminants with respect to location of Na and K loss during thermal stress. Nonruminants produce sweat high in Na and low in K concentrations [56]; but this is vice versa for ruminants.

The concentration of catecholamines is elevated during both acute and chronic thermal stress. Alvarez and Johnson [51] have reported an average increase of 45 and 42% in short and 91 and 70% in long heat exposures for epinephrine and norepine-phrene, respectively. Allen and Bligh [57] have reported that catecholamines activate sweat glands of cattle and are involved in regulating sweat gland activity. Data regarding the catecholamines is still lacking.

An increase in plasma osmolality, or a decrease in blood volume, leads to ADH secretion from the pituitary gland; which in turn acts on the kidneys to retain water [54]. Increased water losses in the respiratory tract and at the skin of thermal-stressed animal invokes increased secretion of ADH which is associated with a need to conserve water and increase water intake [55].

CONCLUSION

Acclimation to heat stress is a homeorhetic process which involves changes in nutrient acquisition and metabolism, hormonal signals which affect responsiveness of target tissues to environmental stimuli and imbalances in acid-base chemistry of the animal. These alterations are same in *Bos taurus* and *Bos indicus* breeds of cattle but are less pronounced in *Bos indicus* making it better adaptive to heat stress. Hence the consequences of heat exposure on production of milk and meat are also less for *Bos indicus*.

Pakistan is blessed with a thermotolertant Cholistani breed of zebu cattle which can be utilized as a model to study the adaptive physiologic processes augmented by heat stress. Future research needs: 1) identification of genes associated with heat tolerance and sensitivity and 2) use of endocrine regulations as means of improving thermal tolerance. These diverse tasks require a coordinated collaboration of physiologists, nutritionists, biotechnologists and animal breeders.

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