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DIETARY CATION ANION DIFFERENCE BASED DIET: A STRATEGY TO REDUCE CLIMATIC STRESS

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ABSTRACT

Climatic stress affects various physiological functions in the body and has a negative effect on livestock growth, health and production. Heat stress of high intensity and duration, causes metabolic disruptions, oxidative stress, decrease nutrient intake and immuno-suppression resulting in infections and death. Animals are found to cope up with the adverse effects of stress when the nutritional requirements are not compromised. Challenged by physiological reactions to heat stress, dietary requirements of macro minerals may differ from requirements in thermo-neutral environment. Dietary minerals are an integral part of all biological functions in the animal body The thermal stress imposes some unique metabolic conditions that require elevated dietary cation anion difference, specifically dietary sodium and potassium. Under such circumstances, in order to sustain productivity, suitable nutritional interventions such as dietary cation anion difference (DCAD) should be adopted, with the objective of increasing the dry matter intake (DMI), improve blood buffering, stabilizing ruminal pH and thereby bring about beneficial influence on growth and production.

Keywords: Dietary Cation Anion Difference, Growth, Heat stress, Nutrient intake,

INTRODUCTION

Climatic stress is a phenomenon that can impart physical and economic losses to livestock production. The ability of livestock to breed, grow and lactate to their maximum genetic potential and capacity to maintain health is strongly affected by the thermal environment. Thermally stressed animals undergo a series of metabolic and physiological changes (Rojas-Downing *et al.,* 2017). These changes are necessary for adaptability and survivability of the animal. Climatic stress has strong impact on growth, productive and reproductive processes of the animals. Stress occurs when an animal experiences changes in the environment that stimulate body responses aimed at re-establishing homeostatic conditions (Mumma *et al.,* 2006). Animals are homoeothermic and hence have to maintain their temperature within normal range to maintain homeostasis. Hot and humid environmental conditions stress the animals and reduce intake of nutrients necessary to support milk yield and body maintenance. These conditions evoke a series of drastic changes in biological functions such as depression in feed intake, reduced efficiency of utilisation, disturbances in the metabolism of water as well as other nutrients, minerals balances, enzymatic reactions, hormonal secretions and blood metabolites, resulting in impairment of growth, production and reproduction performances (Suman *et al.,* 2019). Thermal stress is of major concern for growing animals because of the poor growth performance, immuno-suppression and high mortality rate (Nesamvuni *et al.,* 2012). Challenged by physiological reactions to heat stress, dietary requirements of macro minerals may differ from requirements in thermo-neutral environment (Sharif *et al*., 2010). Dietary minerals are integral part of all biological functions in the animal body. They play a key role in the transfer of fluids from cell to cell, tissue to tissue and organ to organ which ultimately help to fulfill the diverse needs of all productive processes of the animals. It has been observed that metabolic or systemic acidosis is aggravated in the hot summer and reduction in the buffering capacity of the blood. There is loss of K through excess saliva, increased urination and increased sweat which increases the requirement of this mineral in the diet of the animals. Thermal stress imposes some unique metabolic conditions that require elevated dietary cation anion difference, specifically dietary Na and K. Recent advances in minerals nutrition suggest that, the difference between cations such as Na^+ and K^+ and anions such as Cl^- and S^- are having a great influence on animal productivity than their individual effects (Rodney *et al*., 2018).

Dietary cation-anion difference (DCAD)

The term dietary cation anion difference is referred to as the difference between threedietary cations and anions (Tucker *et al*., 1992). Shohl (1939) proposed that maintenance of normal acid-base equilibrium required excretion of excess dietary cations and anions. DCAD is a way to balance the electrical charge of the cations and anions in the diet. These electrical charges affect blood buffering capacity and acid-base status. Numerous equations have been cited in the literature for calculating DCAD value of the diet by subtracting the amount of various anions from the cations. The latest equation i.e. (Na + K) − (Cl + 0.6 S) proposed by Goff *et al*. (2004) discounting the acidifying effects of S by 40 per cent compared to the original four-mineral equation (Na + K) − (Cl + S). The equation, [(Na + K) – (Cl + 0.6S)] appears to be the most accurate in predicting blood pH and standard base excess from dietary mineral composition (Goff *et al.,* 2004). Charbonneau *et al*. (2006) conducted a meta-analysis using different DCAD equations and observed that this equation [(Na + K) – (Cl + 0.6S)] is most highly associated with clinical milk fever (R^2=0.44) and urinary pH (R^2=0.85) compared to other equations.

Blood pH is ultimately determined by the number of cation and anion charges absorbed into the blood. Leach (1979) and Mongin (1980) concluded that mineral interrelationships have profound influences to maintain acid-base homeostasis. It was found that net acid intake was related to the difference between dietary cations and anions. Optimal DCAD is dependent on the stage of lactation, production levels and weather conditions. Thermal stress imposes some unique metabolic conditions that require elevated DCAD and dietary Na and K specifically. Serum DCAD increased linearly with increasing DCAD level in the diets and it had a positive association with blood pH thereby improving blood buffering capacity (Hu and Murphy, 2004; Suman *et al*., 2015, and Suman *et al*., 2019). It is also a useful strategy during thermal stress to increase dry matter intake (DMI), stabilising ruminal pH and resultant positive influence on growth.

Effect of DCAD diet on different parameters during climatic stress

Feed intake and rumen health

Hot and humid environmental conditions stress the animals and reduce the intake of nutrients required to support milk yield and body maintenance. Voluntary intake of feed tends to decrease as ambient temperature increases and increases when ambient temperatures decreases. It has been found that when temperature is in the range of 5 to 15 ˚C, the feed intake enhances by 2 to 5 percent whereas the feed intake was reduced by three to ten percent in the temperature range of 25-35 ˚C (Kadzere *et al.,* 2002). There is a marked depression in the feed intake when temperature is above 35^0C with high humidity (NRC, 2001). The increased DMI under prolonged cold exposure conditions has been attributed to increased ruminal rate of passage as a result of enhanced gastrointestinal tract motility (Bernier *et al*., 2012). In hot environmental conditions, cows dissipate heat via panting and due to the hyperventilation plus resultant decrease in blood CO_2; the kidneys secrete HCO_3^- to maintain H^+ to HCO_3^- ratio. This reduces the amount of HCO_3^- that can be used (via saliva) to buffer and maintain a healthy rumen pH (Hill, 1990). In addition, the panting cow drools saliva and drooling reduces the quantity of saliva that would have normally been deposited in the rumen. Increased drooling directly increases the risk of rumen acidosis and indirectly enhances the risk of negative side effects of an unhealthy rumen i.e. laminitis, milk fat depression, etc. (Kadzere *et al*., 2002). Furthermore, due to reduced feed intake, heat-stressed cows ruminate less and therefore generate less saliva. The reduction in the amount of saliva produced and salivary HCO_3^- content and the decreased amount of saliva entering the rumen make the heat stressed animals much more susceptible to sub-clinical and acute ruminal acidosis (Marai and Haeeb, 2010).

Positive DCAD can enhance nutrient intake due to its favorable influence on rumen dynamics and blood chemistry. However, the extent of nutrient intake varies depending on the level of DCAD, diet composition, animal's productive potential and environment. If the dietary DCAD is mainly cationic, ie., more positive, it increases the feed intake as well as nutrient digestibility. Calves fed on diets with positive DCAD, viz., +350 mEq/kg DM consumed 12.55 per cent higher DM CP and ME (Mcal/d) and had a significantly higher ($P<0.05$) N intake, with increase in DCAD concentration (Suman *et al*., 2019). A linear increase in DMI and DMI per 100 kg with greater DCAD has been observed by many researchers (Hu *et al*., 2007; Wildman *et al*., 2007 Apper-Bossard *et al*., 2009 and Suman *et al*., 2018, Suman *et al*.,2019). The increased DMI might be due to effect of higher DCAD diet on ruminal pH, which is a pre-requisite for optimum ruminal microbial activity and also on blood HCO_3- and acid-base balance (Pacheco *et al*., 2018). In the rumen, $NaHCO_3$ is disassociated into Na+ and HCO_3^- with non-buffering and buffering effects, respectively; they also increased ruminal osmotic pressure and liquid dilution rate (Mao *et al*., 2017). Rumen buffering reduces the extent of acidity produced in rumen therefore, improves the systemic acid-base status (Gruenberg *et al*., 2011). Alkaline nature of high DCAD diet or sodium bicarbonate feeding may be used as a nutritional tool to enhance rumen ecology aimed to utilise nutrients more efficiently.

Blood acid base status

Heat stress and the associated perturbations of acid-base physiology, increase the demand for cations by the kidney. With increased respiration, the expiration of CO_2 exceeds the rate of its formation in the body. The partial pressure of CO_2 of blood declines creating a deficit of blood carbonic acid and resulting in respiratory alkalosis (Wildman *et al.,* 2007). The cow compensates for the high blood pH by excreting HCO_3^- ions in the urine (Hu and Murphy, 2007). Alkalemia depresses the rate of renal secretion of H^+, but increases the excretion of filtered HCO_3^-, which subsequently leads to a reduction in blood HCO_3^- concentration. A more normal ratio of HCO_3^- to pCO_2, and H_2CO_3 to HCO_3^- is required to maintain normal blood pH, but in heat stress, acid base status of the animals gets altered due to loss of filtered HCO_3^-, a compensatory response to the respiratory alkalosis (Block, 1994 and Spanghero, 2004). In order to correct the acid-base imbalance, excretion of the HCO_3^- anions in the urine increases (West, 2003). The excretion of HCO_3^- must be accompanied by the excretion of a cation either Na or K; however, excretion of Na is more as compared to K (Kadzere *et al.,* 2002). During heat stress, urinary concentration of K declines because plasma K concentration is decreased, which might reflect a need for K in other processes, such as sweating (Gaughan and Mader, 2009). Nisa *et al.* (1999) noted that, during prolonged heat stress, plasma aldosterone concentration of Holstein cow's declined. This decline was associated with reduced concentrations of Na and K in blood serum and K in urine. However, urinary Na excretion increased, perhaps to aid in the conservation of K. Urinary excretion of Na increased 80 per cent in a hot environment compared with excretion in a cooler environment, but urinary excretion of K increased only by 18 per cent (West *et al*., 1991). The increased demand of Na for renal excretion and of K for sweating was consistent with the idea that dietary requirements of these minerals increase during heat stress (Marai and Haeeb, 2010).

It has been observed in various studies that a positive linear relationship exists between blood acid base status and DCAD level (Chan *et al*., 2006; Shahzad *et al*., 2007 Li *et al*., 2008 and Suman *et al*.,2019). Increased blood bicarbonate concentration has been reported in response to increasing DCAD in the diet of growing beef steers (Ross *et al*., 1994). Similarly, Sarwar *et al*. (2011) also reported that blood pH was the lowest (7.26) in calves fed on zero per cent $NaHCO_3$ diet and highest (7.57) in those fed the 1.6 per cent $NaHCO_3$ diet. An increase in blood HCO_3^- concentration in calves was also recorded with increase in $NaHCO_3$ concentration in the diet. Suman *et al*. (2019) observed that the overall mean pH throughout the experimental period was ($P<0.05$) highest

(7.38) in calves fed +250 mEq per kg DCAD and was minimum (7.33) in the control group.The main reason for increased blood pH and HCO_3^- at high DCAD diet might be due to its higher bicarbonate content or alkaline nature. The increased demand of Na and K during heat stress is also addressed by a high DCAD diet.

Growth

Heat stress negatively affects feed intake and growth performance of animals (NRC, 2001). In heat stress, average daily gain, and efficiency of converting nutrients to tissue was reduced, with body composition and biometric parameters of growing animals also being affected (Lacetera *et al.*, 1994). Exposure of pregnant dairy cows to high ambient temperature affects growth and development of the foetus (Collier *et al.*, 2006). Baccari *et al.* (1983) observed increase in body temperature, reduced feed intake, growth rate, plasma triiodothyronine and growth hormone in heat stressed growing dairy heifers. Young Holstein Friesian calves exposed to heat stress showed significant reduction in body capacity and impairment of growth of anatomical parts (Lacetera *et al.*, 1994). The decline in thyroid hormones in the heat stressed buffaloes may be responsible for the decline in daily body weight gain with elevated temperature (Habeeb *et al.*, 2007). Due to heat stress, acid-base balance of the body is deviated towards acidosis, wherein, most metabolic pathways cannot work optimally and thus they are more involved in homeostatic regulation than growth (Shahzad *et al.*, 2007).

Alkaline diet positively influences blood buffering, and ruminal pH which is quite helpful in homeostatic regulation. Positive DCAD based diet can be a useful strategy in case of thermal stress by influencing the digestibility and increasing nutrient intake and resultant positive influence on growth (Shahzad *et al.* ,2007, Suman *et al.*, 2019). In addition, metabolic activities in growing animals take place at a rapid rate, leading to higher production of CO_2 in the cells which makes the cellular environment acidic (Guyton *et al.*, 2000, Iwaniuk *et al.,* 2015). This slight acidic situation restricts the cells and its organelles to work optimally and consequently reduces cellular activities resulting in poor growth rate (Sarwar *et al.,* 2011). The alkalogenic nature of the positive DCAD diet might have allowed the cells to work to its optimal potential by sustaining the cellular environment slightly alkaline by counteracting the cellular acidity produced by CO_2.

Hormonal changes

Climatic stress leads to alteration in animal body's physiological response and release of various hormones which affect growth and productivity. Activation of the hypothalamic–pituitary–adrenal axis and the consequent increase in plasma glucocorticoid concentrations are perhaps two of the most important responses of the animals to stressful climatic conditions (Beraidinell *et al.,* 1992, Correa-Calderon *et al.,* 2004). Concentration of cortisol is altered by acute and chronic heat exposure (Marai and Haeeb, 2010) and by changes in photoperiod (Leining *et al*., 1980). The thyroid hormones, T_3 and T_4 decline in response to heat stress which is probably an attempt to reduce metabolic heat production in the animal (Marai and Haeeb, 2010; Habeeb *et al*., 2007). Plasma growth hormone concentration and growth hormone secretion rate also declined with hot temperatures (McGuire *et al.,* 1991). During prolonged heat exposure, plasma aldosterone level also declined, with a concurrent and significant fall in serum and urinary K^+ (Marai and Haeeb, 2010). Therefore, it is evident that heat stress affects the release of various hormones ultimately leading to reduced growth, production and reproduction efficiency in animals.

Positive DCAD based diets can be a useful strategy in case of managing thermal stress by regulating blood pH and acid base status, increasing the ruminal buffering capacity and subsequently the digestibility, with consequent enhancement of nutrient intake and thereby reduced stress (Hassan *et al*., 2011; Suman *et al.,* 2015 and 2019). It is known that an alteration in blood pH can affect the production and effectiveness of insulin (Robertson, 1987), growth hormone (Challa *et al*., 1993) and parathyroid hormone (Goff and Horst, 1992). Hence, a positive DCAD diet can also influence the altered endocrine system during climatic stress, which will also help in better regulation of acid-base balance in blood.

CONCLUSION

Thermal stress negatively affects growth, production and reproductive efficiency of animals which ultimately affect the profitability of dairy enterprises. There is need for inclusion of specific nutrients or dietary modifications in thermally stressed animals to maintain homeostasis and to exploit their full genetic potential. Feeding high DCAD diet to animals might be an important nutritional strategy to ameliorate the adverse effects of climatic stress by improving acid base status, nutrient intake and reducing the stress hormone levels, but further studies need to be carried out to ascertain the level as well as the combination of salts in alkaline diet, which will provide maximum benefit to the stressed animals.

CONFLICT OF INTEREST: None

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