MAINTAINING ELECTROLYTE AND WATER BALANCE TO ALLEVIATE HEAT STRESS IN BROILER CHICKENS

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Summary

Under heat stress conditions, maintaining water and electrolyte balances are considered important factors affecting broiler chickens survivability and productivity. When exposed to high temperature, birds increase their respiratory rates (to dissipate heat by evaporation) resulting in higher losses of CO\(_2\), and consequent increased blood pH. The acid-base balance is further disrupted by the increased electrolyte excretion through urine and faeces. Electrolyte supplementation to the diet has been shown to restore the acid-base balance and to improve bird’s performance. Heat distressed broilers lose more water through urine and panting which decrease the heat dissipation capacity by evaporation and increase the osmotic stress on body cells. Organic osmolytes such as betaine have been shown to protect the cells from high osmotic pressure and to control intracellular water, suggesting their use in maintaining water balance under heat stress conditions.

I. INTRODUCTION

As ambient temperature increases, birds start to pant to lose heat by evaporation. Evaporative heat loss through panting is the most important mechanism to control body temperature under heat stress. However, panting is accompanied with increases in respiratory rates. The increased respiratory rate causes higher losses of CO\(_2\) that result in increased blood pH and disruption of acid-base balance (Toyomizu et al., 2005). When this balance is altered towards alkalosis or acidosis, metabolic pathways are diverted to homeostatic regulation rather than used for supporting growth (Mongin, 1981).

Moreover, under heat stress, birds lose more water (through panting and urine) than they do in their thermal comfort zone. A decrease in body water results in a reduced ability to dissipate heat via evaporation and/or through increased peripheral blood flow. As a consequence, birds increase water consumption to compensate for water loss and to increase the heat dissipation capacity. However, water retention is reduced due to the increased electrolyte excretion in urine and faeces (Belay et al., 1992; Belay and Teeter, 1996). Reductions in intracellular water adds further stress to the bird and understanding how this can be minimised will facilitate identification of effective dietary and management treatments.

II. SUPPLEMENTING AND BALANCING ELECTROLYTES

Electrolytes provided in diets are of great importance in maintaining acid-base balance, osmotic pressure and electrical potential of cell membranes; and are also essential for intracellular-extracellular homeostasis (Borges et al., 2003). Among these electrolytes, the monovalent ions (Na, K, and Cl) are the key minerals involved in acid-base balance of the body fluids (Mongin, 1981), because they have a higher permeability and have greater absorption than divalent ions (Ca and Mg) (Borges et al., 2004).

Hyperventilation during heat stress results in increased CO\(_2\) loss and respiratory alkalosis develops (Toyomizu et al., 2005). Under such conditions, the kidney attempts to

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correct the acid-base balance by renal exchange of bicarbonate with Cl (Mongin, 1981). As a consequence Cl concentrations increase in plasma (Belay and Teeter, 1996). Bicarbonates are negatively charged ions that are coupled by positively charged ions such as K and Na and both are excreted in urine (Remus, 2002). During heat stress, Belay et al., (1992) and Belay and Teeter (1996) reported increased K and Na excretion in urine and faeces, but decreased Cl excretion. As Na and K are alkalogenic ions, their loss can lead to body fluid acidification. The changes in systemic pH in response to heat stress are therefore complex involving an initial respiratory response phase which can produce a systemic alkaloidosis and then a compensatory phenomena involving homeostatic mechanisms that can produce systemic acidosis. Predicting the length and duration of these phenomena and how they interact with diet, and management remains problematical. These changes in acid-base balance are responsible (along with decreased feed intake) for growth retardation and poor performance under heat stress (Arad et al., 1983; Teeter et al., 1985).

It was observed, under heat stress, that supplementing diets with 0.3 or 1.0% Ammonium Chloride (NH₄Cl) significantly improved broiler weight gains by 9.5 and 25%, respectively and decreased blood pH. Also, adding 0.5% sodium bicarbonate increased body weight gains by 9%. Moreover, it was observed that both ammonium chloride and sodium bicarbonate had synergetic effect on broiler performance (Teeter et al., 1985). The use of ammonium chloride helps to reduce blood pH, therefore it is recommended to be supplemented in diets when birds experience panting-induced alkalosis. However, care must be taken as if it is supplemented in excess it may cause acidosis. Therefore, it is recommended that sodium bicarbonate be used in combination with ammonium chloride to adjust blood pH and to remove any acidification may develop. Bicarbonate can combine with excess acids to form carbonic acid that converts to carbon dioxide and water by the action of the enzyme carbonic anhydrase, restoring blood pH from acidosis (if developed). Similar results have been reported by (Naseem et al., 2005; Ahmad et al., 2006).

Smith and Teeter (1989) reported that NaCl, K₂SO₄ and KCl were all able to alleviate the adverse effects of heat stress when supplemented in drinking water, but they attributed their effects to increased water consumption which facilitates heat dissipation and reduces body temperature. It is also necessary to keep in mind the concentration and balance of electrolytes included in the diet as well as in the drinking water. Mongin (1981) reported that when dietary electrolyte balance (K + Na - Cl) is higher or lower than 250 m eq/ kg diet, alkalosis or acidosis develops resulting in growth depression. Similarly, Borges et al. (2004) observed that a dietary electrolyte balance of 240 m eq/ kg diet increased N, Na and K retention and water consumption and was more favourable under thermoneutral and heat stress temperatures than diets with dietary electrolyte balance of 140 or 340 m eq/ kg diet. When electrolytes are supplemented in the water, care must be taken as water intake is significantly greater than feed intake, (up to three times as much during high temperatures, Zhou et al., 1999; Tanveer et al., 2005).

III. MAINTAINING WATER BALANCE

To maintain homeostasis, water intake plus that formed by oxidative metabolism should equal water lost by evaporation and through urine and faeces. However, birds exposed to high ambient temperature lose more water in urine (>60%) than those maintained in the thermoneutral zone (Belay and Teeter, 1993). As water deficit develops, extracellular fluid levels decrease causing a fall in circulating blood volume and pressure and an increase in plasma osmolality. A reduced blood volume stimulates the juxtaglomerular cells of the kidney to release renin that in turn stimulates thirst and drinking behaviour. In addition, there is evidence that certain cells in the hypothalamus are sensitive to changes in plasma
osmolality that stimulate the pituitary gland to secret arginine vasopressin (i.e antidiuretic hormone) which acts on nephrons in the kidney for increased water reabsorption and decreased urine output (Reece, 2004). At this point, if the amount of water lost is not completely compensated, dehydration and increased body temperature will occur. To overcome this problem, birds consume markedly more water (Zhou et al., 1999; Tanveer et al., 2005), causing plasma expansion, reduced plasma osmolality and whole blood viscosity (Yahav, 1999; Zhou et al., 1999). Plasma expansion under high temperatures facilitates heat dissipation by peripheral blood and evaporation. However, this expansion leads to a lowering of arginine vasopressin concentrations in blood resulting in a rise in urine flow. Although, birds consume more water to overcome these consequences, water retention is reduced due to increased electrolyte excretion (Belay et al., 1992) and due to continuous loss of water through panting.

Cells must accumulate ions and osmolytes to maintain intracellular water against the extracellular osmotic gradient. The osmotic pressure of intestinal fluid is hypertonic to plasma (650 mOsm in the jejunum versus 300 mOsm in the plasma; Mongin, 1976). To withstand this osmotic pressure, intestinal epithelia controls water and ion transport via ion pumps and water channels (Rao, 2004). However, these ion pumps (i.e., K, Na, Ca and Mg ATPases) use adenosine triphosphate as an energy source to operate (Moeckel et al., 2002), which means energy would be diverted from growth to regulate osmotic pressure. Under hyper tonicity conditions, cells respond quickly by accumulating inorganic ions to prevent water flux. However, these ions can perturb the structure of macromolecules such as proteins and enzymes. Therefore, cells increase synthesis of either organic osmolytes (e.g. betaine, sorbitol, inositol) or transporters for these osmolytes (i.e., betaine aminobutyric acid transporter) and replace the inorganic ions with the organic osmolytes (Alfieri et al., 2002). Organic osmolytes have been shown to inhibit cell membrane ion ATPases activities (Moeckel et al., 2002) and protect the cells from hypertonic conditions (Kettunen et al., 2001; Alfieri et al., 2002). Extreme hypertonicity can induce apoptosis in various types of cells. Alfieri et al. (2002) reported that cultured pig arterial endothelial cells incubated in hypertonic media stopped proliferating and had clear apoptotic morphology. However when betaine was present in the medium, it restored growth and normal morphology.

The mechanism by which betaine exerts its effect as an osmoprotectant is still not clear. However it was suggested that betaine may affect the lipid membrane bilayer that can modify the activity of enzymes responsible for active transport of monovalent ions through ion pumps that indirectly affect water movement. Another suggestion is that betaine accumulation inside the cells may change the surrounding toxicity (Kettunen et al., 2001).

Moreover, betaine supplementation has been shown to be advantageous in controlling and minimising coccidial invasion. Augustine et al. (1997) reported that betaine and/or salinomycin supplementation significantly decreased the number of sporozoites of E. tenella and E. acervulina in broiler chicks. The effect was more pronounced when betaine was used in combination with salinomycin. It is not clear how betaine exerts its effect in limiting parasite invasion, however, it could be due to restoring intestinal epithelial water balance that enhance the resistance against coccidial proliferation (Klasing et al., 2002). Many reports indicate the beneficial effects of supplementing betaine or other organic osmolytes especially under certain conditions such as dehydration, diarrhoea as it reduces water loss in spite of the osmotic pressure.

Few studies have been conducted to investigate the effect of betaine supplementation on maintaining water balance during heat stress challenge, particularly to examine the effect of betaine in combination with electrolytes in diets and/or water. Therefore, we hypothesise that betaine along with electrolyte supplementation could assist broilers during heat stress. Electrolyte supplementation should be considered as a protective management practice during
heat stress as it helps the bird to regulate acid-base balance and stimulates water intake, thereby acting as a water sink to reduce body temperature. Dietary electrolyte balance (K+Na–Cl) should be maintained within the recommended range of 230 to 240 m eq / kg diet to avoid acid-base alteration. The use of betaine would help in maintaining body water balance and reducing the reliance of body cells on ion pumps to regulate their water balance, requiring more energy expenditure.

REFERENCES


