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Role of dietary minerals in heat-stressed poultry: A review

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Abstract
Heat stress is one of the major problems facing the poultry industry in tropics. Various strategies have been put forward to alleviate the adverse effect of heat-stress and to minimize losses of production during this period. Nutritional management is one of the effective methods hence is followed worldwide. In the nutritional management, fulfilling the mineral requirement during heat stress is inevitable for the efficient performance of the poultry. The requirement of most of the minerals are not fulfilled during heat stress conditions due to the restricted feed intake hence supplementation of minerals like calcium, phosphorus, zinc, copper, iron, sodium, potassium, magnesium, selenium, chromium, manganese and iodine is necessary. These minerals help to sustain the production in animals, improve nutrient utilization and at the same time effectively neutralize the oxidant stress and enhance the compromised immune system of heat stressed birds.

Keywords: Antioxidants, heat stress, mineral, poultry, immunity

Introduction
Heat stress is one of the major challenges that poultry industry faces today. It reduces the performance of birds reflecting directly in the economic returns [1]. Birds are said to be heat stressed if the net heat loss from the body is less than the net heat production thus birds have difficulty in achieving the balance between the two. Birds of all types in all age groups can be affected by heat stress. Broiler birds tend to be more susceptible to heat stress than layer birds [2]. Thermo-neutral zone in birds is the range of ambient temperature within which the core temperature of the poultry remains more or less constant. Birds regulate their core body temperature (41 °C/106^{0}F) within a narrow range of ambient temperatures of 16-26 °C [2]. If the upper critical temperature is exceeded, birds resort to panting which is a normal physiological response to the heat stress. As the ambient temperature increases, birds increase their rate of panting to lose more heat. However, if the birds are not able to dispense extra heat produced by the body at the same rate as it is being produced in intensity (acute heat stress) or over a period of time (chronic heat stress), the core temperature may rise above 4^{0}C which birds are unable to bear hence may die [3]. This condition is common in tropics where during most part of the year environmental temperatures remain above the thermo-neutral zone of birds. In an attempt to reduce the production of heat from the body, birds resort to many strategies and one of them is the reduction of the feed intake. The decreased feed intake results in reduced growth rate, poor meat quality, decreased egg production, poor egg quality and reduction in the efficiency of feed utilization [4]. Many feeding practices are in vogue which are used to alleviate the adverse effects of heat stress on poultry performance. Nutritional management of broilers tends to be the main focus of the research than the laying hens. Particle size, moisture content of feed, feed restriction, manipulation of energy and protein requirements, choice feeding, supplementation of herbs, electrolyte, minerals and vitamin, and drinking water management all have beneficial effect in alleviating the heat stress in poultry [2].
Heat stress produces free radicals in the body which tend to disturb the balance between the oxidation and antioxidant systems, causing oxidative damages to lipids, proteins, nucleic acids and other biological molecules [5]. The most common target of free radicals is lipids of cell membrane producing Malondialdehyde (MDA) from polyunsaturated fatty acids. Several studies demonstrated that heat stress increased the free radical production and at the same time reduces the concentrations of antioxidants in the serum [6, 7]. Birds exposed to high ambient temperatures show the reduction in the size of immunological organs like bursa, spleen and

thymus [8, 9]. Heat stress also tends to increase the levels of tumor necrosis factor-alpha (TNF-α) and interleukin-4 (IL-4) and decreased the levels of interferon-gamma (IFN-γ) and IL-2 [10].

Excessive panting during heat stress causes excretion of large amount carbon dioxide which results in the development of respiratory alkalosis. Moreover, loss of electrolytes like Na+, K+ and bicarbonates in urine further shifts the pH towards alkalinity [11]. High ambient temperature conditions decrease the concentration of blood serum electrolytes [12, 13]. Respiratory alkalosis decreases the rate of respiration which affects the dissipation of heat by evaporative cooling further increasing the stress. High environment temperatures result in lower nutrient digestibility in poultry especially that of dry matter, organic matter, crude protein and ether extract due to oxidative damage to small intestine mucosa that restricts absorption and lowers the activity of digestive enzymes like trypsin, chymotrypsin, and amylase [14].

Minerals form an important component of the diet of poultry. Minerals play an important role in maintaining the efficient growth, egg production and reproduction. Heat stress has a negative effect on the mineral metabolism. Heat stress results in the excess loss of minerals from the body which not only reduces the ability of poultry to adapt but may also results in the diseases conditions in chronic cases. Moreover, the reduced appetites during heat stressed results in reduced mineral intake thereby exacerbating the condition of mineral deficiencies [15, 16]. Reduce mineral concentration in the body tissues may impair several enzyme and hormone functioning which may be necessary to combat heat stress, the result of which may even lead to death of the bird.

Calcium (Ca)

Calcium is necessary for the layers for the egg production. Reduced intake of calcium is directly related to the decrease in egg production [11]. Poultry experiencing heat stress often have less than 3.5 g of calcium intake daily. Stress reduces the intestinal expression of calcium-binding protein, calbindin, necessary for the absorption of calcium [17]. Reduced intake and poor absorption of calcium in heat stress result in lower levels of plasma calcium, hence, less calcium is available for the eggshell formation resulting in drop in egg production, smaller eggs or thin-shelled eggs [18]. Addition of a large amount of calcium supplements may not feasible as dry matter intake of poultry is already reduced. Also, the energy level of the feed would be compromised as a calcium supplement would occupy the appreciable bulk of the feed. Calcium supplements may be instead fed either by top dressing them on feed or separately from the feed. A larger particle size of calcium source (limestone or oyster shell) is generally employed to provide a supplemental calcium during heat stress as they are retained in the gizzard for a longer period of time and are released slowly into the duodenum for eventual absorption into the circulation.

Phosphorus (P)

Phosphorus is the second most abundant mineral in the body with immense importance in poultry diets for efficient growth and development. There is a reduction in the available phosphorus requirement in chronic heat stress due to the reduced growth [19]. Reduction in feed intake during heat stress in poultry compromises the nutrient intake hence decreases the phosphorus intake as well. Further, decrease in concentration of plasma phosphorus content has also been reported in heat stressed poultry [20]. Poultry experiencing heat stress should consume 400 mg of available phosphorus as extreme low levels will lead to mortality. Excess of phosphorus intake will cause poor shell quality; however, this is rare in heat stress conditions due to low feed intake [21]. Calcium and phosphorus ratio seem to have some effect on survival time during acute heat-stress. Plasma phosphorus and mortality in chicks have direct relationship with each other [22].

Zinc (Zn)

Zinc being the most essential element is required for normal growth and development of the animals. It is the part of more than 300 enzymes associated with different functioning of the body [23-25]. The NRC [26], recommended 40-75 ppm Zn for poultry. Organic Zn sources tend to have higher bioavailability than the inorganic counterparts [25].

Zinc forms the important part of enzyme carbonic anhydrase which converts carbonic dioxide to bicarbonates and ultimately carbonate is produced for the egg shell formation [27]. Inhibition of carbonic anhydrase can markedly reduce the eggshell weight [28]. Supplementation of 80 or 100 ppm of Zn as Zn-methionine has shown an improved eggshell weight and reduced shell defects in layers reared under high temperatures [29, 30].

Dietary zinc supplementation has a positive effect on the growth and FCR in heat stressed poultry [7, 31]. Zinc supplementation as $ZnSO_4$ (30 ppm) along with Vitamin A have improved weight gain and feed efficiency in heat-stressed broilers [32]. Zinc supplied as $ZnSO_4$ or Zn picolinate (30 or 60 ppm) improved the performance of heat stressed quails [7]. Similarly, Zn (30ppm) and Pyridoxine improved feed conversion and egg production in layers reared under high temperatures [33].

Zinc tends to increase the dry matter, organic matter, crude protein, ether extract digestibility in dose dependent manner in quails reared under heat stressed conditions [34].

Heat stress increases the free radicals in poultry and eats up the antioxidant minerals quickly thereby lowering their concentration in blood [7, 35]. Deficiency of zinc tends to increase the oxidative damage of free radicals. Zinc helps in the quenching of free radicals through being the part of several antioxidant enzyme systems like superoxide dismutase and metallothionein and spares the action of enzymes like catalase, glutathione peroxidase, vitamin A and vitamin C thereby increasing their concentration in the serum, thereby helping the poultry to adapt efficiently to heat stress conditions [36, 37].

Heat stress reduces the antibody production and increases the heterophil-to-lymphocyte ratio in broilers and layers [38, 39]. Zinc plays an important role in maintaining the efficient immune system during heat stress. Zinc supplementation tends to increase the antibody titre (IgM and IgG) and enhance the cell-mediated immunity during heat stress conditions in poultry [6, 40].

Copper (Cu)

Copper is one of the important trace minerals which perform variety of essential functions in the body [41]. Copper is a component of wide array of enzyme systems involved in different body functions including anti-oxidant activity and immunity of birds [42]. Heat stress tends to decrease the copper intake due to reduced feed intake and increased excretion which can lead to marginal copper deficiency. Deficiency of

copper may impair immune system reducing the synthesis of T lymphocytes, decreasing antibodies production and phagocytic index [43]. These phenomena are more aggravated during heat stress conditions which can increase the susceptibility to infections and leading to death [44]. Copper being the part of many antioxidant systems (SOD) may reduce the antioxidant activity in heat stress birds. Supplementation of copper in the heat stress may help birds to cope the stress efficiently. The copper requirement in birds ranges from 5 to 8 ppm of diet [45]. Egg shell contains appreciable amount of copper (8.73 ppm). Any deficiency of copper during heat stress may have direct effect on the quality of egg shell. Higher concentration of copper can also be found in egg shell membranes. Being an essential component of the shell membrane, any deficiency of copper may be reflected in the production of abnormal shell membranes [46].

Iron (Fe)

Iron performs vital functions in the body and is the part of many biochemical reactions like antioxidant system by being the part of the enzymes like catalase and in various oxidation–reduction reactions. Iron plays an important role in the immune response. Birds under heat stress should receive normal dietary iron concentration lest the collapse of immuno-antioxidant system would have a serious repercussion on animal health [47].

Sodium (Na), Potassium (K) and Chloride (Cl)

The monovalent elements sodium, potassium and chloride play an important role in maintaining the acid-base balance, osmolarity and electric potential across membranes [48]. Heat stress alters the acid-base balance of poultry due to excess excretion of carbon dioxide and respiratory alkalosis which has been touted as the main factor responsible for poor performance in heat-stressed poultry [49]. Mineral compounds like ammonium chloride (NH4Cl), sodium bicarbonate (NaHCO3), sodium chloride (NaCl), potassium chloride (KCl) and potassium sulphate (K_2SO_4) can be supplemented to heat stressed poultry to yield better results [49-52]. Supplementation of heat-stressed poultry with Na, K+ and Cl salts alleviate the adverse effect of heat stress by increasing the consumption of water which helps in the efficient dissipation of body heat and maintaining the electrolyte balance [52]. Supplementation of broiler birds with NH_4Cl at 3 and 10 g/kg and $NaHCO_3$ at 5 g/kg feed improved the weight gain by from 9 to 25% and decreased the blood pH countering the alkalosis [49]. However, excess feeding can increase the risk of metabolic acidosis. To compensate for the reduced feed intake under heat stress, dietary allowances for electrolytes may be increased by 1.5% for each 1 °C rise in temperature above 20 °C. Dietary requirement of sodium, potassium and chloride is 0.20-0.25 %, 0.24-0.30% and 0.30 %, respectively [53]. The significant improvement has been seen on the quality and quantity of eggs in heat-stressed poultry supplemented 0.1% HCl in drinking water [51]. In practice, the combined effect of all the three electrolytes is studied and represented either by electrolyte balance (EB) ($Na^+ + K^+ – Cl^-$) or electrolyte ratio (ER) [$(K^+ + Cl^-)/Na^+$]. EB and ER of 230-250 mEq/kg and 3, respectively is recommended in the broiler feed under heat stress [54]. In case of layers under heat stress conditions EB of 250 mEq/kg is recommended [55].

Selenium

Selenium is one of the most important minerals used in the antioxidative defense system in the heat-stressed poultry. It is a part of more than 25 selenoproteins which perform different functions in the body especially being the part of many enzymes [56, 57]. Organic selenium in the form of seleno-methionine and Se–yeast is more bioavailable than the inorganic forms in chicken [58]. Selenium has a positive effect on the nutrient utilization, body weight gain and feed efficiency in normal and heat-stressed birds through its participation in carbohydrate, protein and lipid metabolism [8, 59], though counter reports have also been found [60,61]. Similarly, selenium supplementation during heat stress in layers increased feed intake, feed efficiency, egg production, egg quality, haugh units and egg shell quality [62]. Selenium protects the mucosa of small intestine and pancreas from the oxidative damage during heat-stress in birds [63, 64]. Cu-Zn-superoxide dismutase and glutathione peroxidase activity increases in the poultry fed selenium rich diet while MDA concentrations decrease [65]. Selenium has vitamin E sparing role by enhancing its absorption from the gut and protecting the cell membrane fats from oxidative damage [66]. Selenium supplementation can alleviate the deleterious effect of heat stress on immune systems by increasing the antibody titre (IgG and IgM), interleukin production (TNF-α, INF-γ and IL-2) and phagocytic functions of macrophages [67].

Chromium

Chromium (Cr) is the mineral involved in the metabolism of carbohydrates, proteins, lipids and nucleic acids through its action on insulin [68]. Since glucose is used extensively during heat stress, Cr supplementation would prove useful. Moreover, serum Cr concentration in heat stressed birds is lower than the birds reared under thermoneutral conditions exposing the birds to further stress conditions. Supplementation of Cr tends to restore the Cr reservoir which seems to get exhausted during heat stress [69,70]. It alleviates the oxidative stress, lipid peroxidation and modulates the decreases the expression of hepatic nuclear protein and heat shock proteins in heat stressed layers [71]. Dietary chromium supplementation relieves heat stressed birds from the stress by increasing orexin and GLUTs levels and reducing the NF-κB and HSPs levels bringing their physiology close to the thermoneutral birds [72]. Organic chromium has more bioavailability and lower toxicity than the inorganic forms [73]. Supplementation of Cr increases feed intake, egg production, egg weight, eggshell weight, eggshell strength, haugh unit, however, these results are not consistent [74, 75]. Supplemented Cr tend to increase the insulin, glucose, and cholesterol levels in the heat stressed birds [76].

Manganese

Manganese (Mn) is involved in the metabolism of carbohydrates and lipids by increasing the insulin synthesis from pancreas [77]. Mn supplementation in chronic heat-stressed broilers reduces the fat deposition. Availability of Mn in heat stress conditions is reduced [78]. Organic sources like manganese proteinate have greater bioavailability than inorganic sources, especially in heat stress conditions. Mn supplementation of broilers in heat stress conditions may alleviate some of its detrimental effects. Mn supplementation (240 mg Mn/kg) to broiler chickens resulted in significantly lower insulin concentrations under thermoneutral conditions [79]. There were also reduced serum NEFA concentrations in

response to high Mn supplementation. Maternal dietary manganese supplementation can protect the embryo of birds from the maternal heat stress by enhancing epigenetic-activated antioxidant and anti-apoptotic activities [80]. Manganese acts as cofactors for many enzymes required in the synthesis of egg shell [81]. Any deficiency of the mineral will be reflected in the quality of egg shell especially during heat stress.

Iodine

Heat stress tends to reduce the circulatory concentrations of thyroid hormones which might or might not be related to the decrease in feed intake [82, 83]. The heat stressed layers showed lower T_3, T_4 and TSH concentrations in the serum with the concomitant increase in ACTH concentrations irrespective of genotype [84, 85]. The concentration of T_3 in the plasma is directly related to egg productivity [86]. Metabolic and thermogenic functions are largely regulated by the hormones of thyroid glands in birds [87]. Iodine deficiency at this stage may prove harmful to poultry as iodine content in the diet influences the thyroid gland functioning [88]. Birds, in general, are very sensitive to iodine deficiency causing many metabolic disorders and lowering the laying rates [89]. Iodine content of the diet of layers should be 0.48 mg/kg of feed [26]. However, it shouldn't exceed 1 mg/kg of diet [90]. Excess iodine intake is also harmful producing effects similar to those of low iodine intake [91, 92].

Conclusion

Heat stress puts a lot of pressure on the birds. Trace minerals can be used effectively to alleviate some of the adverse effects of the heat stress. Even though there are other strategies to mitigate the loses during heat stress, supplementation of trace minerals is absolutely necessary for the birds to fully recover and perform efficiently during heat stress.

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