Nutritional Strategies to Enhance Efficiency and Production of Chickens under High Environmental Temperature

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ABSTRACT

Climate model projections indicate that the global surface temperature will probably rise a further 1.1 to 6.4°C during the twenty-first century; therefore, with this rise in global average temperature significant impact on efficiency, production, morbidity and mortality can be expected on birds and animals. Presently, high environmental temperature exposure is of major concern for poultry industry especially in the hot region of the world because of the resulting poor growth performance, immunosuppression and high mortality. Different methods are available for decreasing the heat production using various nutritional strategies to alleviate stress in high temperature-exposed chickens. The nutritional strategies are designed after considering the factors such as type of birds, age of birds, stage of production, duration of heat exposure, intensity of heat exposure and health of the birds. The nutritionists can base their strategy on less heat-production, increased nutrient intake, decreased energy wastage, and reduction in heat-induced oxidative stress and damage in birds to overcome the deleterious effects of high temperatures on metabolism, physiology, feed efficiency, production performance and health. This can be accomplished by traditional nutritional strategies to reduce heat stress by feeding good quality feed with high digestibility and nutrient density, adding fat as an energy source, balancing and provision of additional amino acids, and supplementing with vitamins, minerals and glucose. Recently, there are new concepts for nutritional strategies to focus on redox status of the chickens and to decrease the oxidative stress and damage on exposure to high environmental temperature. None of these strategies are effective alone in terms of growth, feed efficiency, livability, meat quality, stress tolerance or immune response, therefore, a combination of the nutritional strategies may help to alleviate the deleterious effects of heat stress and improve the chicken performance under high environmental temperature.

Key words: heat stress, chicken, nutrition, oxidative stress, oxidative damage, uncoupling protein

REVIEW

During the last century global surface temperature increased 0.74±0.18°C, and climate model projections summarized in the IPCC report indicate that the global surface temperature will probably rise a further 1.1 to 6.4°C during the twenty-first century (IPCC, 2007). There is growing evidence that climate-health relationships pose increasing health risks for humans under future projections of climate change and the warming trend over recent decades has already contributed to increased morbidity and mortality in many regions of the world (See review by Patz *et al*., 2005). Same is true for birds and animals, where significant impact on efficiency, production, morbidity and mortality can be expected with rise in global average temperature.

Presently, high temperature exposure is of major concern for poultry industry especially in the hot region of the world because of the resulting poor growth performance, immunosuppression and high mortality (Bottje and Harrison, 1985; Young, 1990; Mujahid *et al*., 2005, 2009b). The continuous selection for fast growth has been associated with increased susceptibility of broilers to high temperature (Geraert *et al*., 1993; Cahaner *et al*., 1995; Berong and Washburn, 1998). Exposure of chickens to high temperature cause significant changes in physiological responses (Harrison and Biellier, 1969; Altan *et al*., 2003, Toyomizu *et al*., 2005, Mujahid *et al*., 2009b). Thermal stress exerts its deleterious effects on feed intake and body weight gain (Geraert *et al*., 1996) as well as on carcass yield, carcass protein, muscle calorie content and mortality rates (Smith, 1993, Tankson *et al*., 2001).

As ambient temperatures increase within the thermoneutral range, birds initially utilize sensible heat loss mechanisms to control body temperature with little or no loss in growth or production. However, under moderate or severe heat stress birds minimize heat production since the major route of heat loss, evaporation of water from the respiratory tract (panting), requires considerable energy expenditure. Birds respond by reducing their metabolizable energy (ME) and feed intake to reduce thermogenesis. Although ME intake has been shown to decline at an increasing rate with increasing ambient temperature it does so more rapidly than the corresponding decline in metabolic heat production. Therefore, less energy would be available for production processes, as ambient temperature increased.

Many factors influence the response of chickens to change in environmental temperature. Intensity of environmental temperature, humidity, radiant heat, wind velocity, duration of exposure and previous acclimatization of the birds influence the response of chickens to high temperature exposure. Presently, birds are increasingly being subjected to environmental temperatures that are above their comfort zone. Additionally, birds are growing faster and producing more than ever before, and are thus heavier and more productive than previously at any given age with marked change in their metabolic activities. Birds in general, perform well within a relatively wide temperature range, 10-27°C (Milligan and Winn, 1964; de Albuquerque *et al*., 1978; Mardsen and Morris, 1987). Highest growth rate of broiler chickens occur in the range of 10-22°C, while maximum feed efficiency is at 27°C (Kampen, 1984). The ideal optimum temperature range is different for growth and feed efficiency, e.g., feed efficiency in laying hens reduced below 21°C, while egg production and growth rate are reduced at temperature below 10°C. Exposing chickens to high temperature significantly decrease the feed intake, although high environ-mental temperature have significant and direct impact on performance and feed efficiency that are unrelated to feed intake, e.g., exposure of laying hens to 21 and 38°C temperature, 40-50% reduction in egg production and egg weight at 38°C is only due to reduced feed intake, while the reductions in shell thickness and shell strength are mainly due to high temperature (Smith and Oliver, 1972). Similarly, only 63% reduction in broiler chicken growth on exposure to heat stress is due to reduced feed intake (Dale and Fuller, 1979). In addition to the effect of high temperature on feed intake, heat stress-exposure results in increased mitochondrial superoxide production, reduced ATPase activity, and oxidative damage to body proteins and fats, resulting in cellular metabolic changes and growth reduction (Mujahid *et al*., 2005, 2007a-b; Feng *et al*., 2008).

The metabolic and nutritional status affect the tolerance of chickens exposed to high ambient temperature and interrelationship exists between nutritional status and resistance to acute heat stress (McCormick *et al*., 1979; Garlich and McCormick, 1981). Recently, the nutritional strategies are of increasing interest to decrease the heat production and thus alleviate the heat stress in chickens on exposure to high environmental temperature. The nutritional strategies are designed after considering the factors such as type of birds, stage of production, age of birds, duration of heat exposure, intensity of heat exposure and health of the birds. The nutritionists can base their strategy on less heat-production, increased nutrient intake, decreased energy wastage, and reduction in heat-induced oxidative stress and damage in birds to overcome the deleterious effects of high temperatures on metabolism, physiology, feed efficiency and production performance.

Traditional Nutritional Strategies to Reduce Heat Stress

It has been proposed that the adverse effects of high temperature on production performance may be alleviated by following dietary modifications:

Feed Density

Although, ME requirement decreases with increasing temperature above 21°C, mainly due to a reduction in energy requirement for maintenance, the requirement for production is not influenced by environmental temperature (Daghir, 1995). Using high energy rations for chickens have been common in warm regions probably to overcome the negative effects of decreased feed intake and to reduce the heat increment. Under severe heat stress, ME requirements increase due to the need for the bird to dissipate body heat by respiratory heat loss. Adding fat, lysine and methionine has been shown to improve the performance in hot weather (Micklebury *et al*., 1966; McNaughton and Reece, 1984; Jiang *et al*., 2007). The higher fat content of the diet contributes to reduced heat production, since fat has a lower heat increment than either proteins or carbohydrates. High environmental temperature increases food passage time (Wilson *et al*., 1980) while fat has shown to decrease the rate of food passage in GIT (Mateos *et al*., 1982), thus increasing the nutrient utilization. Therefore, the addition of fat to the diet also appears to increase the energy value of the other feed constituents (Mateos and Sell, 1981). Alterations in dietary ME concentration had a limited influence on food and nutrient intake and egg mass output of hens in early lay kept at 10-24, 6-16 or 25-35°C temperatures. Even the highest intakes of ME and protein achieved at hot temperatures failed to increase egg mass output to the values attained on any diet at low temperatures (Scott and Balnave, 1988). Increases in energy and calcium intake helped partially to maintain normal egg production, egg weight, and prevent egg shell deformation on exposure of laying hens to high temperature (Tanor *et al*., 1984). However, when chickens are reared in a warm environment the body weight response to increased dietary energy level will occur only when adequate amino acid levels are supplied (McNaughton and Reece, 1984). Increasing dietary ME at particular amino acid:ME ratios significantly improve growth and food utilization of broilers kept at 18-26 and 25-35°C ambient temperatures during the finishing period. The optimum amino acid:ME ratio varies with dietary ME concentration in the hot, but not in the moderate environment. Relatively greater increases in food intake and growth rate occur in the hot environment when dietary ME increases and the amino acid:ME ratio decreases. Increasing the dietary protein at particular ME concentrations had little or no effect on the food intake and growth rate of birds kept at high temperatures. The rectal temperatures of birds in the hot environment increase with age and, towards the end of the finishing period, when higher energy diets are fed (Sinurat and Balnave, 1985).

Amino Acid

A well-balanced amino acid supply should minimize the energy cost of excreting surplus nitrogen and might therefore help the chicken to cope with heat stress. At high ambient temperatures, there is a decrease in protein synthesis (Geraert *et al*., 1996), probably due to reduced plasma amino acid concentration and to lower energy supply (Temim *et al*., 2000), as observed in broiler chicken muscle tissue. In addition, heat stress decreases plasma T3 concentration and increases plasma corticosterone, both changes known to reduce protein deposition through alterations in protein turnover in birds and other species (Yunianto *et al*., 1997). Under conditions of heat stress, diets in which excess protein had been minimized performed significantly better than conventional diets. An interaction was therefore shown to exist between amino acid balance and environmental temperature. Exposure to high environmental temperature has been shown to influence amino acid digestibility and significantly decrease the uptake of certain amino acids from intestine (Wallis and Balnave, 1984; Balnave and Olivia, 1991; Brake *et al*., 1998). Additionally, high ambient temperatures affect the ideal amino acid balance for broilers (Brake *et al*., 1998; Chamruspollert *et al*., 2004) and increasing the dietary Arg:Lys ratio improves broiler performance at high temperatures (Brake *et al*., 1998). An interaction also exists between dietary NaCl and Arg:Lys ratio and dietary NaCl could affect the apparent ileal digestibility of Arg and Lys at certain Arg:Lys ratios (Brake *et al*., 1998; Balnave and Brake, 2001; Chen *et al*., 2005). In particular, Brake *et al*. (1998) observed that at a low dietary NaCl concentration (1.2 g/kg), the feed conversion ratio and body weight gain of heat-stressed broilers were significantly improved with increasing Arg:Lys ratios, but at a higher dietary NaCl concentration (2.4 g/kg), no such response occurred. Recently, it has been shown that increasing the amino acid levels in the diet of chickens reared under high temperature conditions improve their performance as compared to the birds fed with recommended levels at thermoneutral temperature (Corzo *et al*., 2003; Jiang *et al*., 2007).

Vitamins

Ascorbic acid (Vitamin C) has been shown to improve chicken performance at high temperature and birds experience a less severe stress response after exposure to high temperatures when they are provided dietary ascorbic acid (Mahmoud *et al*., 2004). Optimum responses in growth, feed efficiency and/or liveability in broilers under heat stress were reported to occur with supplements of about 250 mg ascorbic acid / kg (Kutlu and Forbes, 1993). Vitamin A and E in combination (15,000 IU retinol and 250 mg dl-µ- tocopheryl-acetate/kg diet), reduced malondialdehyde concentration (an indicator of lipid peroxidation) more than half in serum and liver of heat stress-exposed broilers, but showed less effect when fed alone (Sahin *et al*., 2002). Ascorbic acid and chromium have similar effects when fed at high temperatures, and a combination of ascorbic acid (250 mg/kg diet) and chromium (400 µg Cr/kg of diet) may offer a potential protective management practice in preventing heat-stress related depression in performance of broiler chickens (Sahin *et al*., 2003). In laying hens, studies have shown that the livability and production of heat-stressed laying hens can be improved by supplementing their diet with ascorbic acid or vitamin E (Njoku and Nwazota, 1989; Cheng *et al*., 1990; Bollengier-Lee *et al*., 1999; Puthpongsiriporn *et al*., 2001). Requirements for thiamine has been shown to be significantly increased for chicks grown at 32.5°C, as compared with chicks raised at 21°C (Mills *et al*., 1947).

Minerals

Dietary modifications in mineral concentration offer a practical way to alleviate the effect of high environmental temperature on chicken performance. Mineral supplementation may reduce the consequences of heat stress in birds and have beneficial effects on production performance and meat quality.

Increased mineral excretion is one of the major consequences of heat stress. Retention rates of phosphorus, potassium, sodium, magnesium, sulfur, manganese, copper, and zinc are lowered in broilers raised at high cycling ambient temperatures (24-35°C) compared with those housed at 24°C (Belay and Teeter, 1996). Egg weight and eggshell strength decline at high environmental temperature. Also, the lower concentrations of plasma calcium and inorganic phosphate in hens exposed to 30°C compared to 18°C (Usayran and Balnave, 1995) may provide some evidence of an increased requirement for these minerals in heat-stressed laying hens. Stress causes secretion of epinephrine and corticosteroids and results in Mg loss (Seelig, 1980, 1981). Mg-aspartate supplementation increases the body weight of chickens during heat stress (Donoghue *et al.*, 1990). Zinc supplementation results in an improved live weight gain, feed efficiency, and carcass traits, as well as a decrease in serum MDA concentrations in chickens reared at high temperature (Kucuk *et al*., 2003).

When broiler chickens are exposed to heat stress (34°C), plasma sodium values reduces after 6 h while no such change occurs after 12 or 18 h of exposure. Potassium levels are lower by 6 or 12 h of heat stress and no differences in blood calcium levels are observed between the control and heat-stressed chickens (Mujahid *et al*., 2009b). Exposure to different durations of heat stress results in significant decreases in the levels of blood HCO_3- and pCO_2 and significant concomitant increase in blood pH which is however, dependent on duration of heat stress exposure (Toyomizu *et al*., 2005, Mujahid *et al*., 2009b).

Panting during heat stress to dissipate body heat may result in an increased loss of carbon dioxide and a consequent depletion of blood bicarbonate (Gorman and Balnave, 1994) which can induce respiratory alkalosis and this may be exacerbated by high RH that makes respiratory heat loss less efficient. Blood alkalosis limits growth rate of chickens reared under high environmental temperature and the induced respiratory alkalosis can be partially alleviated by dietary modifications (Teeter *et al*., 1985). Therefore, it is theoretically possible that heat stress may induce a metabolic requirement for the bicarbonate ion (Teeter *et al*., 1985). One of the means for alleviating the problem of respiratory alkalosis associated with panting has been to supplement the diet with sodium bicarbonate. Metabolizable anions, such as bicarbonate, carbonate and acetate, are all capable of neutralizing acid and raising blood pH. This procedure has the additional merit of improving the shell quality of eggs from heat-stressed laying hens (Balnave and Muheereza, 1997). However, it has been reported that the dietary bicarbonate should be consumed during the period of egg shell formation (Balnave and Muheereza, 1997, 1998). Enhanced body weight gains can be achieved among broilers kept at high temperatures with the addition of either sodium bicarbonate or ammonium chloride, the latter (at 10 g/kg of diet) resulting in a 25 percent increase in growth rate over the controls (Teeter *et al*., 1985). Sodium salts reduces the alkalotic pH and enhanced the blood sodium content, which ultimately improves the blood electrolyte balance and overall performance of heat-stressed chickens. Supplementing chicken diet with sodium salt improves the live performance of heat-stressed chickens and better productive performance observed with NaHCO3 than other sodium supplements (Ahmad *et al*., 2006).

Energy Source

The metabolizable energy (ME) system does not provide a sufficiently accurate description of the feed energy available to the animal, because it does not take account of the efficiency with which different sources of dietary energy are used for different anabolic processes. Emmans (1994) has proposed an effective energy (EE) system that is more accurate in both these aspects. A major advantage of this system of energy evaluation is that it predicts accurately the amount of heat that will be produced by a given animal given a particular feed and housed in a given environment. This information is particularly important when determining how much the animal can lose in that environment. This explains the advantageous effects of providing feeds at high temperature containing highly digestible nutrients, minimal excesses of protein, and a high proportion of the carbohydrate energy replaced with digestible fat energy.

Glucose

Exposure of chickens to elevated environmental temperature markedly reduce food intake and the associated lower growth rate is accompanied by increased plasma glucose levels (McCormick *et al*., 1979) and increased *in vivo* uptake of galactose and methionine when measured on a tissue dry weight basis (Mitchell and Carlisle, 1992). This apparently enhanced absorption capacity was confirmed in *in vitro* studies in which enterocytes from chronically heat-adapted birds showed a 50% increase in galactose accumulation ratio compared with cells from control chickens (Mitchell *et al*., 1995). Heat stress increased microvillous length in chickens, indicating that the surface brush-border membrane is increased even in a metabolic situation characterized by a general reduction in protein synthesis (Geraert *et al*., 1996). This effect on apical surface, together with increased activity of sodium-dependent glucose transporter 1, enhances the capacity to absorb glucose and can, therefore, be interpreted as physiological adaptations of the chicken jejunum to guarantee energy supply (Garriga *et al*., 2006). Thus, supplemental glucose intake by chickens on exposure to high temperature alleviates the influence of heat stress and prolongs the survival time. When chickens are exposed to high temperature, rectal temperature enhances quickly in birds given tap water, while slow increases are found in birds offered glucose water with subsequently higher plasma glucose levels (Iwasaki *et al*., 1998). Oral administration of glucose prevents decrease in feed intake and growth rate, normalizes physiological and immunological responses, and alleviates the influence of heat stress on whole blood viscosity and plasma osmolality in heat-stress-exposed chickens (Zhou *et al*., 1998; Takahashi and Akiba, 2002).

Feed Form and Feeding Time

Offering pelleted feed to broilers can result in a 67% reduction in the energy required for eating. Whereas the ME of the feed is the same whether pelleted or not, the energy sparing effects of pellets is about 6% as a result of the reduced activity (McKinney and Teeter, 2003). Because the physical nature of the pellets allows the birds to consume their feed with less wasted energy, the quality and durability of the pellets is particularly important. A change of 10% in fines may result in a change of 0.01 in feed conversion ratio. At high temperatures there should be an advantage in providing broilers with high quality pellets, with the minimum amount of fines, thereby reducing the proportion of heat expended in acquiring food (see the review Gous and Morris, 2005).

Heat production by broilers can be reduced by withholding feed prior to, and during, a limited period of high temperature stress. Survival is increased if food is withdrawn at least four to six hours before the period of heat stress (Smith and Teeter, 1988; Francis *et al*., 1991; Boulahsen *et al*., 1993; Hiramoto *et al*., 1995). Withdrawing food during day, and replacing it at night once the temperature has declined, would appear to be a sensible approach to deal with uncomfortably high temperatures. The mechanism responsible for this beneficial effect is that the heat increment associated with feeding is reduced during the hottest part of the day. Because food remains in the intestine for up to 6 hours, withdrawal of the food must take place about six hours before the high temperature is experienced if the full impact if this practices to be realized.

New Concepts for Nutritional Strategies to Reducing Oxidative Stress and Damage

Hyperthermia can induce the metabolic changes that are involved in the induction of oxidative stress, and heat stress is responsible for stimulating reactive oxygen species (ROS) production. There is direct evidence of mitochondrial superoxide generation using both electron spin resonance (ESR) spectroscopy, with 5,5-dimethyl-1-pyrroline N-oxide as a spin trap agent, and lucigenin-derived chemilumi-nescence (LDCL) in skeletal muscle of acute heat-stressed birds (Mujahid *et al*., 2005). Additionally, in chickens the liver is more susceptible to oxidative stress than heart during acute heat exposure (Lin *et al*., 2006). Acute heat stress causes oxidative damage to mitochondrial proteins and lipids in skeletal muscle of chickens (Mujahid *et al*., 2007b). Heat stress also causes higher serum malondialdehyde levels (Mujahid *et al*., 2007b) that depends on duration of exposure (Pamok *et al*., 2009). Under heat stress conditions, down-regulation of avian uncoupling protein (avUCP) and mRNA expression are accompanied by increased mitochondrial superoxide production (Mujahid *et al*., 2006), and these effects occur in a time-dependent manner (Mujahid *et al*., 2007a). It is well-known that ROS production can be decreased by mild uncoupling of mitochondrial respiration (Brand *et al*., 2004; Skulachev, 1998). UCPs are specialized members of the mitochondrial transporter family that allow passive proton transport through the mitochondrial inner membrane. This transport activity leads to uncoupling of mitochondrial respiration and to energy waste, which is well documented with UCP1 in brown adipose tissue. The uncoupling activity of more recently discovered UCPs (post-1997), such as UCP2 and UCP3 in mammals or avUCP in birds, is more difficult to characterize. However, recent extensive data support the idea that the newly discovered UCPs are involved in the control of ROS generation rather than thermogenesis (Negre-Salvayre, 1997; Abe *et al*., 2006). This fits with the hypothesis that mild uncoupling caused by the UCPs decrease ROS production. Therefore, it can be assumed that avUCP, expressed appropriately, may play a role in the alleviation of mitochondrial ROS production and an antioxidant role under conditions of acute heat stress.

Up-regulation of avUCP could attenuate oxidative damage caused by acute heat stress. In recent study chickens were fed either a control diet or an olive oil-supplemented diet (6.7%), which has been shown to increase the expression of UCP3 in mammals, for 8 days and then exposed either to heat stress (34°C, 12 h) or kept at a thermoneutral temperature (25°C). Heat stress increased mitochondrial ROS production and malondialdehyde levels, and decreased amount of avUCP in skeletal muscle mitochondria. Feeding chickens an olive oil-supplemented diet increased the expression of avUCP in skeletal muscle mitochondria, and decreased ROS production and oxidative damage. A subsequent study on mitochondrial function showed that heat stress increased oxygen consumption in state 4 and membrane potential in state 3 and state 4, which were abolished by feeding chickens with olive oil supplemented diet (Mujahid *et al*., 2009a). These reports, suggest that feeding olive oil under heat stress reduce mitochondrial ROS production in chickens due to changes in skeletal muscle mitochondrial avUCP contents as well as in mitochondrial respiration and membrane potential thus alleviating the effect of heat stress by changing the redox status and improving production performance.

A variety of ROS react readily with methionine residues in proteins to form methionine sulfoxide, thus scavenging the reactive species. Most cells contain methionine sulfoxide reductases, which catalyze a thioredoxin-dependent reduction of methionine sulfoxide back to methionine. Thus, methionine residues may act as catalytic antioxidants, protecting both the protein where they are located and other macromolecules acting as an endogenous antioxidant in cells (Luo and Levine, 2009). The administration of methionine reduces the process of lipid peroxidation (a decreased in the concentration of MDA) with best antioxidative properties demonstrated by methionine in rat liver (Błaszczyk *et al*., 2009a). Methionine administration also increases the activity of anti- oxidative enzymes in rat kidneys, with significant effect on the activities of glutathione peroxidase, glutathione reductase and glutathione transferase (Błaszczyk *et al*., 2009b). Such antioxidant effect of dietary methionine on lipid peroxidation and increased anti-oxidative enzymes in chickens still need to be confirmed and is the interesting area for future research.

CONCLUSIONS

High environmental temperature exposure is of major concern for poultry industry especially in the hot region of the world. Different nutritional strategies have been used to alleviate stress in high temperature-exposed chickens. The nutritional strategies are designed after considering the factors such as type of birds, age of birds, stage of production, duration and intensity of heat exposure, and health of the birds. The nutritionists can base their strategy on less heat-production, increased nutrient intake, decreased energy wastage, and reduction in heat-induced oxidative stress and damage in birds to overcome the deleterious effects of high temperatures on metabolism, physiology, feed efficiency, production performance and health. This can be accomplished by traditional nutritional strategies to reduce heat stress by feeding good quality feed with high digestibility and nutrient density, adding fat as an energy source, balancing and provision of additional amino acids, and supplementing with vitamins, minerals and glucose. Recently, there are new concepts for nutritional strategies to focus on redox status of the chickens and to decrease the oxidative stress and damage on exposure to high environmental temperature. None of these strategies are effective alone in terms of growth, feed efficiency, livability or meat quality, therefore, a combination of the nutritional strategies may help to alleviate the negative effects of heat stress and improve the chicken performance under high environmental temperature.

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