DOI: 10.1079/WPS200585

Strategies for preventing heat stress in poultry

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Their higher production performance and feed conversion efficiency make today's chickens more susceptible to heat stress than ever before. The increasing proportion of poultry production in tropical and subtropical regions makes it necessary to reconsider the long-term selection strategy of today's commercial breeding programmes. Also, the importance of the potential use of Naked neck and Frizzle genes is accentuated. Nutritional strategies aimed to alleviate the negative effects of heat stress by maintaining feed intake, electrolytic and water balance or by supplementing micronutrients such as Vitamins and minerals to satisfy the special needs during heat stress have been proven advantageous. To enhance the birds' thermotolerance by early heat conditioning or feed restriction seems to be one of the most promising management methods in enhancing the heat resistance of broiler chickens in the short run.

Keywords: heat stress; heat tolerance; naked neck gene; major gene; Vitamin; electrolyte; feeding; environment

Introduction

A hot environment is one of the important stressors in poultry production. The resultant heat stress comes from the interactions among air temperature, humidity, radiant heat and air speed, where the air temperature plays the major role. The optimum temperature for performance is likely to be 19 to 22ºC for laying hens and 18 to 22ºC for growing broilers (reviewed by Charles, 2002). When the thermo requirement of chickens is not satisfied, heat stress may occur, depending on the strain, feathering, nutrition and production system.

In a hot environment, chickens grow and lay by exerting an effort to maintain their body temperature within a normal range, to cope with stress responses and to ensure their visceral organs function under a heavier heat burden. Stress response is mainly associated with the activation of hypothalamo-pituitary-adrenal (HPA) axis and orthosympathic

Received for publication May 21, 2005
Accepted for publication July 8, 2005

nervous system, which aggravates the detrimental effect of high body temperature. The adverse effects of heat stress include high mortality, decreased feed consumption, and poor body weight gain and meat quality in broiler chickens, and poor laying rate and egg weight and shell quality in laying hens (reviewed by Howlider and Rose, 1987; Marsden and Morris, 1987; Shane, 1988; Yahav, 2000a). Many studies have been conducted to help understand the underlying physiological mechanism (Lin *et al.*, 2005c). The present review will focus on the strategies to cope with heat stress.

Genetic strategies

SELECTION FOR HEAT TOLERANCE

Selection for growth rate and feed efficiency (FE) is associated with a number of undesirable consequences and the increased susceptibility to heat stress is one of them. The magnitude of the reduction in body weight (BW) and BW gain at high temperatures (averaging 30ºC) appears to be associated with a high growth rate and breast yield at normal environment (averaging 25ºC) (Deeb and Cahaner, 2001a). As the two traits are emphasized in today's commercial broiler breeding programmes, the modern strain of broiler chickens will suffer more severe effects of stress at high temperatures.

Although most standard breeding stocks are selected in temperate climates, the genotypes may response differentially to high temperature even if they have similar performance in thermoneutral environment. Yalçin *et al.* (1997a) reported that three broiler chicken lines, having similar performance in the fall (average temperature 18ºC), showed significant difference in feed intake, BW gain and FE in summer (average temperature 28ºC). Similarly, the genotypes in commercial broilers that gain more weight in the spring, tend to gain less weight under the hot conditions of summer (Settar *et al.*, 1999). Hence, the broilers' genotype should be taken into account in broiler production in tropical and subtropical regions, especially in view of the increasing proportion of world broiler production in these regions.

Because fast-growing broilers produce more heat and have a higher heat load, the effect of heat stress is more pronounced in commercial broiler stocks and in broilers with high growth potential compared to the slower-growing chickens (Cahaner and Leenstra, 1992; Eberhart and Washburn, 1993; Cahaner *et al.*, 1995; Yunis and Cahaner, 1999). During heat exposure, the slower growing broiler lines have relatively lower mortality and body temperature compared to fast growing lines (Yalçin, *et al.*, 2001). The genetic potential for rapid growth is not achieved under high temperature in fast-growing strains and they show lower heat tolerance, which, in turn, is associated with a more pronounced decrease in feed consumption (Deeb and Cahaner, 2002). The relative lower increase in water consumption in fast- growing broilers under high temperatures, compared to their control counterparts, may be another possible reason for lower feed consumption and BW gain (Deeb and Cahaner, 2002).

Because of the negative correlation between heat tolerance and growth rate (Washburn *et al.*, 1980), no practical commercial genetic selection programme is available. El-Gendy and Washburn (1995) found that the heritability for heat tolerance was very low in fast-growing broiler chickens. Heat adaptation in broilers can be improved by applying selection in a hot environment (Mathur and Horst, 1994). However, such selection may lead to reduced growth potential at normal air temperatures (22ºC) and a reliable association between growing rate and heat tolerance has to be evaluated (Deeb and Cahaner, 2002). On the other hand, the heritability of BW gain is decreased by high temperature, whereas the heritability of feed efficiency is not changed (Beaumont *et al.*, 1998). Therefore, the parameters used in selection should be season-adapted.

Recent research work by Gonet *et al.* (2000) showed that three differentially selected lines of female breeders, with similar growth performance and similar body weight, showed different thermal response when exposed to a hot environment (30ºC and 70% RH) for 2 h. This difference influences the heat tolerance of their offspring. The offspring of one breeder line breeder showed relatively lower body temperature and mild hypocapnia and no significant alteration in pH, while the chickens from the other two lines had a higher body temperature and largest disturbances in blood gas and acid-base balance. This opens possibilities for associating high growth rate with better heat tolerance.

Also, immune parameters may be correlated with changes in heat tolerance and this may be of particular relevance in the long-living laying hens. Heterophil/lymphocyte (H/L) ratio as an indicator of stress has been well recognised (Siegel, 1995; Puvadolpirod and Thaxton, 2000). Al-Murrani *et al.* (1997) reported that H/L ratio could be used as a selection criterion for heat tolerance in laying hens. In their study, H/L ratio was measured at 16 wks of age after exposure to 35ºC for 6 days, The pullets with a ratio less than 0.59 were considered as resistant (R) to heat stress and those over 0.60 as sensitive (S). The R pullets show significantly higher laying performance than that of S birds during heat exposure in the laying period (Al-Murrani *et al.*, 1997).

USE OF MAJOR GENES

Naked neck gene

The naked neck (*Na*) gene reduces feather mass by 20% and 40% (relative to body weight) in the heterozygous (*Na/na*) and homozygous (*Na/Na*) birds respectively, compared with the fully feathered counterparts, having been reviewed comprehensively, especially with regard to high temperature (Mérat, 1986). The advantageous effect of the naked neck gene in hot environment has been recognised since 1980s (Hanzl and Somes, 1983). In broiler chickens the gene results in a relatively higher growth rate and meat yield than their fully feathered counterparts under normal temperature and the effect is more pronounced at high temperature (Cahaner *et al.*, 1993). The naked neck chickens (*Na/Na* or *Na/na*), compared to fully feathered broiler chickens (*na/na*), have higher body weight and feed efficiency but lower body temperature (Patra *et al.*, 2002). Furthermore, the *Na* allele can increase breast meat production especially at high temperatures (Yunis and Cahaner, 1999; Deeb and Cahaner, 1999). The advantageous effect of *Na* genotype is more pronounced in broiler chickens with high growth rate and breast meat yield and increases with broiler size and ambient temperature (Deeb and Cahaner, 2001a). The lower feather mass increases the effective surface of heat dissipation and increases the sensible heat loss from the neck (Yahav *et al.*, 1998). Concurrently, resistance to heat dissipation is decreased because the reduced plumage is associated with lower skin mass due to reduced fat deposition within it (Cahaner *et al.*, 1993; Raju *et al.*, 2004). The high growth rate of the *Na* genotype at high temperature may be related to the relative high T_3 (triiodothyronine) concentration (Decuypere *et al.*, 1993). However, as the fat deposit in breast muscle is also decreased in *Na/na* chickens (Raju *et al.*, 2004), the influence on the flavour of meat needs to be investigated further. In summary, the naked neck gene broiler should be considered for industrial broiler production in hot climates (Yalçin *et al.*, 1997b).

Frizzle gene

Frizzle (*F*) gene may reduce the heat insulation of feather by curling the feathers and reducing their size. The beneficial effect of the *F* gene on broiler growth at high temperature is less than that of *Na* allele, and the effect is only significant in slow growing line. However, there is an additive effect in the double heterozygous (*Na/na F/f*) broilers (Yunis and Cahaner, 1999). The continuous selection for faster growth rate in broilers together with the increasing proportion of broiler production in tropic and subtropical regions may accentuate the importance of the potential use of *Na* and *F* genes.

Dwarf (dw) gene

The *dw* gene results in a reduction of 30-40% of adult body size and leads to speculation about the inherent heat tolerance of dwarf broiler breeders. However, the inherent heat tolerance of *dw* genotype in laying hens seems uncertain (reviewed by Decuypere *et al.*, 1991). In fast-growing broiler chickens the *dw* gene has been proven to have no practical value for improving tolerance to chronic heat stress (Deeb and Cahaner, 2001b).

Nutritional strategies

DIETARY PROTEIN LEVEL AND AMINO ACID COMPOSITION

The protein requirement is decreased because of the suppression in production performance. It has been shown that both protein synthesis and breakdown are affected by chronic heat stress, and protein synthesis is more affected than breakdown, leading to reduced protein deposition. The decreased protein synthesis cannot be restored by high dietary protein level (Temin *et al.*, 2000). Moreover, a high protein diet even has a harmful influence on growing performance. The growth rate and meat yield of commercial fast-growing broiler chickens is suppressed by high dietary protein level at high temperature (Cahaner *et al.*, 1995). As this suppressive effect is not found in stock selected for low abdominal fat or lean type genotype, the effect of dietary protein seems to be genotype specific (Cahaner *et al.*, 1995).

Although protein has a high heat increment, decreasing dietary protein level would enhance the harmful effect of high temperature. The lower level of dietary CP level results in poor FE and BW gain (Alleman and Leclercq, 1997). Compared to the isoenergetic high protein diet, chickens fed with low-protein diet tend to eat more to meet their protein requirement, resulting in high heat production and more fat deposition (Buyse *et al.*, 1992).

The suppression of growth from heat stress reduces the absolute requirement for amino acids. The ideal amino acid balance under high temperature remains unclear, as the altered digestion of protein and absorption of amino acids, and the enhanced protein catabolism and gluconeogenesis in heat-stressed chickens (Reviewed by Lin *et al.*, 2005c). The results from a number of studies are inconsistent and even controversial. For example, increasing lysine levels or arginine:lysine ratios is unable to improve weight gain and breast meat yield, or attenuating the adverse effects of heat exposure in broiler chickens (Mendes *et al.*, 1997) and turkeys (Veldkamp *et al.*, 2000b). The response of growth rate to lysine supplementation is decreased by high temperature in broiler chickens (Rose and Uddin, 1997). Turkeys subjected to high temperature do not response positively to the supplementation of crystalline amino acids (lysine, methionine and threonine) (Veldkamp *et al.*, 2000a). In contrast, the favourable effect of increasing the arginine:lysine ratio on feed conversion and growth performance at high temperature was observed in the study of Brake *et al.* (1998). The increased dietary level of lysine appears necessary to accommodate depressed feed intake and improve feed efficiency (Corzo *et al.*, 2003). The underlying mechanism could in part be ascribed to the changed absorption in heat-stressed birds, as it is observed that the *in vitro* uptake of arginine by intestinal epithelium of heat-stressed broilers is decreased in the presence of an equimolar concentration of lysine

(Brake *et al.*, 1998). On the other hand, the growth response to the supplementation of crystalline amino acids is affected by dietary electrolytes such as sodium chloride (Brake, 1998; Chen *et al.*, 2005) and sodium bicarbonate (Balnave and Brake, 1999). Nevertheless, it is true that, for the diet in a poor balance of amino acids, the supplementation of essential amino acids will be helpful to reduce the heat increment and alleviate the harmful effect of high temperature. Furthermore, the imbalanced diet in amino acids increases the excretion of nitrogenous substances in faeces, which results in the accumulation of aerial ammonia, causing detrimental effects on performance and welfare of chickens (Carlile, 1984; Kristensen and Wathes, 2000; Miles *et al.*, 2004). The emissions of ammonia in poultry house may be augmented by high ambient temperature (Pratt *et al.*, 2004). High levels of atmospheric ammonia can further affect the ability of broiler chickens to control effectively their body temperature (Yahav, 2004). Hence, the ideal amino acids for chickens under hot environments should be given more attention in practice and needs further study in future.

VITAMINS

The decreased nutrient intake at high temperature also has repercussions on the intake of micronutrients such as Vitamin A, E, C, etc., which play important roles in the performance and immune function of poultry. The supplementation of these nutrients might also be helpful for the maintenance of performance and immune function of heat-stressed birds. Vitamin supplementation of drinking water (Vitamin A, D, E and B complex) has been reported to be beneficial for the performance and immune function of heat-stressed broilers (Ferket and Qureshi, 1992).

Vitamin A

The detrimental effect of heat stress on egg production can also be alleviated by dietary supplementation of Vitamin A (8000 IU/kg diet) (Lin *et al.*, 2002). Vitamin A supplementation is favourable for the immunity of heat-stressed hens. Hens suffering heat-stress immediately after NDV vaccination need higher dietary Vitamin A intake to obtain the maximal level of antibody production (Lin *et al.*, 2002). Vitamin A could alleviate the oxidative injuries induced by heat exposure and immune challenge (Wang *et al.*, 2002). In broiler chickens, Vitamin A (15,000IU) supplementation resulted in an improved live weight gain, feed efficiency, and carcass traits, as well as a decrease in serum MDA concentrations (Kucuk *et al.*, 2003).

Vitamin C

Ascorbic acid (AA) can be synthesized by poultry and it is not required to be supplemented in the diet under normal conditions. When birds are challenged with stressors, however, the supplementation of AA might be beneficial for the performance of broilers (Pardue and Thaxton, 1982; Pardue *et al.*, 1984; Mckee and Hurrison, 1995). The improved performance is associated with the suppressed stress responses indicated by the reduction in plasma corticosterone level (Mckee and Hurrison, 1995; Mahmoud *et al.*, 2004), adrenocorticotropic hormone (Sahin *et al.*, 2003) and increased serum insulin, T_3 and T_4 (thyronine) concentrations (Sahin *et al.*, 2002). Ascorbic acid supplementation reduces the respiratory quotient in heat-stressed broiler chickens by emphasizing an increase in fatty acid oxidation over the increase in protein-derived gluconeogenesis (McKee *et al.*, 1997). At high temperature, broiler chicken seems to have a special appetite for AA and tends to consume more diet supplementing of AA (Kutlu and Forbes, 1993). Ascorbic acid supplementation improves carcass quality and produces higher carcass weight and carcass CP content, while reducing carcass crude fat content (Kutlu, 2001). Furthermore, as AA is one of the most important antioxidants in biological system and heat stress could induce oxidative injuries to chickens (Lin *et al.*, 2000), the supplementation of AA is relevant to the maintenance of redox balance in heat-stressed birds.

The beneficial effect of AA supplementation on laying performance, however, seems uncertain. Under normal conditions, dietary AA supplementation is beneficial for egg production and shell quality of broiler breeders (Peebles and Brake, 1985) and force-moulted layers (Zapata and Gernat, 1995), and for the fertility and hatchability of broiler breeders (Peebles and Brake, 1985). For heat challenged laying hens, AA supplementation improves egg weight (Lin *et al.*, 2003) and immune response (Lin *et al.*, 2003; Puthpongsiriporn *et al.* 2001). However, the beneficial effect on laying performance was not observed in a number of other studies (Bell and Marion, 1990; Creel *et al.*, 2001). The effects of supplemental AA on the zootechnical performance and immunity may relate to the management quality, length of supplemental feeding, age of the chickens, endogenous-exogenous balance for AA, the relationship with corticosterone and the level of stress (Niekerk *et al.*, 1989). Dietary level of AA may also take an effect on its supplemental effect. High dose (1000 mg/kg) of AA supplementation may mask the beneficial effect on laying performance of heat-stressed birds (Okan *et al.*, 1996a), while the opposite is true in hens at normal condition (Orban *et al.*, 1993).

Vitamin E

Dietary supplementation of Vitamin E is beneficial to the egg production of hens at high temperatures. This beneficial effect of Vitamin E supplementation is associated with an increase in feed intake and yolk and albumen solids (Kirunda *et al.*, 2001). Vitamin E supplementation increased the plasma concentrations of vitellogenin and very-low-density lipoprotein (Bollengier-Lee *et al.*, 1998), resulting from the enhanced release of vitellogenin from liver, and also protects the hepatocyte cellular membranes from oxidative damage (Whitehead and Mitchell, 1998). The optimum level of Vitamin E depends on the supplemental time. High dietary supplemental level of Vitamin E (250 mg/kg diet) is beneficial to egg production at high temperature (Bollengier-Lee *et al.*, 1998, 1999). Lower supplemental level at 65 IU/kg diet can also enhance the egg production and egg mass of laying hens during chronic heat stress, and meanwhile improves the immune response (Puthpongsiriporn *et al.*, 2001). It is suggested Vitamin E should be added not only before heat stress but also during and after the stress (Bollengier-Lee *et al.*, 1999).

ELECTROLYTIC AND WATER BALANCE

The blood acid/base balance is disturbed by hyperventilation and results in respiratory alkalosis, which suppresses the growth of broiler chicken and impairs eggshell quality of laying hens. The suppression of growth in broilers can be partially alleviated by supplementation of 1% NH_4Cl or 0.5% $NaHCO_3$ (Teeter *et al.*, 1985), and 1.5 to 2.0% K in the form of KCl (Smith and Teeter, 1987). The supplementation effect of electrolyte depends on dietary electrolyte balance (DEB). Moderate dietary DEB values (from 120 to 240 mEq) have a favourable influence on the physiological response of heat-stressed broiler chickens (Borges *et al.*, 2004). On the other hand, the feeding status should be considered in the adjustment of dietary electrolyte balance. At high temperature, feed-restricted broiler chickens have adverse changes in pCO_2 and pH, with a decline in pH and increase in pCO_2, compared to *ad libitum*-fed counterparts (Hocking *et al.*, 1994).

Supplementation of electrolytes in drink water is also favourable to the performance of broiler chickens, for example 0.2% NH_4Cl or 0.15% KCl (Teeter and Smith, 1986), 0.6% KCl (Ait-Boulahsen *et al.*, 1995), 0.2% $NaHCO_3$ (Hayat *et al.*, 1999), and carbonated water (Bottje and Harrison, 1985). Dietary supplementation of sodium bicarbonate for laying hens can improve shell quality as long as hens have access to feed during the period of eggshell formation by using continuous light (Balnave and Muheereza, 1997).

Another beneficial effect of including electrolytes in diet or drinking water is to stimulate water consumption. The supplementation of electrolytes ($NaHCO_3$, NH_4Cl, etc.) in water enhances water consumption (Branton *et al.*, 1986; Balnave and Oliva, 1991) and offers potential to increase tolerance to heat stress and be beneficial to performance. The increased water consumption has no disadvantage effect on the carcass quality of broiler chickens (Whiting *et al.*, 1991; Smith, 1994).

OTHER NUTRIENTS

Heat stress could induce the unfavourable changes in indigenous bacterial microbiota. The supplementation of probiotic Lactobacillus strains may enrich the diversity of Lactobacillus flora in chicken jejunum and caecum, and therefore restoring the microbial balance and maintaining the natural stability of jejunal and caecal microbiota of broiler chicken having suffered heat stress (Lan *et al.*, 2004).

Dietary supplementation of chromium (120 ppb) is favourable to the zootechnical performance of heat-stressed broiler chickens, by increasing feed intake and body weight, improving feed efficiency, and facilitating carcass characteristics (Sahin *et al.*, 2002). Zinc (4.5 mg/kg) supplementation resulted in an improved live weight gain, feed efficiency, and carcass traits (Kucuk *et al.*, 2003). Moreover, there is a combination of zinc and Vitamin A effect in preventing heat-stress-related depression in performance of broiler chickens (Kucuk *et al.*, 2003).

As the above information is mainly derived from studies focusing on one single nutritional factor, it should be practiced with caution when to integrally applying the measures, though a cooperative beneficial influence could be expected. For example, it is noted that there is a significant 3-way interaction between dietary sodium chloride, arginine:lysine ration and methionine source for the digestibility of lysine (Chen *et al.*, 2005). The nutritional measures should be considered as a whole for heat-stressed chickens.

Feeding strategies

Heat production increases with feeding level (Wiernusz and Teeter, 1993; Zhou and Yamamoto, 1997). The level of feed or energy consumption markedly influences the capacity of chicken to exhibit a heat-stress acclimation response (Wiernusz and Teeter, 1996) or heat tolerance (Syke and Salih, 1986).

Temporary feed restriction before heat exposure is an effective way to enhance thermal resistance of broilers. Feed withdrawal reduces heat production, increment speed of body temperature and mortality of broiler chickens (Francis *et al.*, 1991; Yalçin *et al.*, 2001). However, this strategy may result in reduced growth rate, a longer growing period and a delay in marketing age. The dual feeding programme is another strategy used for broilers, which includes a protein diet during the cooler phase and an energy-rich diet during the warmer phase of each day and maintains a nutritional balance by adequate proportion of the two diets. During heat challenge, dual feeding reduces the body temperature and mortality (Basilio *et al.*, 2001). In laying hens, partial feed restriction or controlled-feeding regime alleviates the harmful effect of heat stress on laying performance (MacLeod and Hocking, 1993). Changing the feeding time from twice to one time daily is also favourable to the performance of laying hens and the best time is in the afternoon (18:00) (Samara *et al.*, 1996).

Wet feeding increases the dry matter (DM) intake and, therefore, alleviates partially the effect of heat stress on feed intake and laying performance. Feeding a wet diet containing 50% moisture increased the DM intake of layers at high temperature (Tadtiyanant *et al.*, 1991). Okan *et al.* (1996b) reported that the DM intake, egg production, egg weight were all increased by wet feeding, which was prepared by adding tap water to the diet in the ratio of 1:0.5-1.3. In laying hens, the increased performance by wet feeding is suggested to be the result of elevated DM intake and the feed conversion is not affected on the basis of DM intake (Okan *et al.*, 1996b). In broilers, however, a diet mixed with water in a ratio of 1.5:1 significantly increases BW gain, DM intake, carcass weight and carcass lipid content, but deteriorated DM conversion efficiency (Kutlu, 2001). The increased water intake is speculated as one of the underlying mechanisms of wet feeding.

Normally the layer diet is provided in mash form. During summer, although the feed consumption is not affected by pelleting the ration, egg production, feed efficiency and water intake were significantly increased in laying hens (Almirall *et al.*, 1997). The increased water consumption and improved digestibility of the diet is probably responsible for the advantageous effect of pelleting. Broiler chickens, however, prefer to eat more feed with larger particle size in hot environments. Yo *et al.* (1997) reported that when corn was fed as whole grains, broiler chickens consumed more protein concentrate (43.7% CP) in self-selected diet and shown an improved feed efficiency.

Environmental strategies

INTERMITTENT LIGHT

An intermittent light regime can improve the feed efficiency and thus the broiler production efficiency. The favourable effect is related to the lower heat production during both light and dark period, although fluctuations in heat production are following closely the light-dark alternation (Aerts *et al.*, 2000). Buyse *et al.* (1994) reported that broiler chickens under 1L:3D light schedule produce less heat ($W^{0.75}$kg) during early and later age, except for the compensatory growth period around 35 d of age.

HUMIDITY

Not only heat production but also heat loss could be affected by management. Heat loss by evaporative heat dissipation is related the relative humidity of the surrounding environment. The evaporative heat loss increases along with the temperature and decreases with increasing humidity. The effect of humidity on thermal regulation response of broiler chickens depends on age and air temperature (Lin *et al.*, 2005a, b). Humidity is particularly important for the performance of broiler chickens when exposed to 28ºC and above, and of turkey when exposed to temperatures above 30ºC (Yahav *et al.*, 1995; Yahav, 2000b). Humidity affected the thermoregulation of 1-wk old broiler chickens by redistributing heat within the body at high temperatures, resulting in decreased rectal temperature and increased peripheral temperature (Lin *et al.*, 2005a). However, high humidity above 60% impaired the heat transmission from body core to peripheral at 35ºC but facilitate it at 30ºC in broiler chickens of 4-wk-age (Lin *et al.*, 2005b). Therefore, although it is difficult to control the humidity in the poultry house, more attention should be paid to the varying requirement of chicken to humidity, especially in the hot and humid regions.

EARLY HEAT CONDITIONING

Early heat conditioning (EHC) seems to be one of the most promising methods in enhancing the heat resistance of broiler chickens. Early heat conditioning refers to the practice exposing broiler chicks to high temperature (36ºC) for 24 h at 3 to 5 d of age.

Early heat conditioning induces the heat tolerance of broiler chickens at later growth stage prior to marketing (Arjona *et al.*, 1988, 1990; Yahav and Hurwitz, 1996; Zhou *et al.*, 1997). The EHC chickens have lower body temperature at normal or high temperature (Basilio *et al.*, 2001; 2003), suggesting the changed metabolic status. The suppressed expression of uncoupled protein (avUCP) in skeletal muscles may play an important role in the acquisition of heat tolerance of EHC chickens (Taouis *et al.*, 2002). The acquisition of the long-term heat tolerance seems not to be associated with the induction of heat shock proteins (HSPs) (Yahav *et al.*, 1997).

After the growth retardation caused by the 24-h heat exposure, it is followed immediately by compensatory growth, which results in a higher BW at marketing age compared to the non-conditioned chickens (Yahav and Plavnik, 1999; Yahav and McMurtry, 2001). The favourable effect of EHC is associated with higher feed intake and unchanged feed efficiency. It is suggested that the mechanism is associated with the induction of insulin-like growth factor-I (IGF-I) and its immediate stimulation of satellite cell myogenic processes (Halevy at al., 2001), as well as the enhanced enterocyte proliferation, expression and activity of brush-border membrane enzymes (Uni *et al.*, 2001).

It has also been suggested that a temperature between 36 and 37.5ºC, applied at 3 d of age is optimum for thermal conditioning of broiler chickens (Yahav and McMurtry, 2001).

EARLY FEED RESTRICTION (EFR)

Feed restriction at an early age has been demonstrated to have a beneficial effect on alleviating the subsequent response to heat stress (Zulkifli *et al.*, 1994a,b, 2000). Chicks subjected to 60% feed restriction at 4, 5 and 6 d of age have improved growth and survivability in response to the subsequent heat treatment at marketing age (from 35 to 41 d of age). The negative effects of the heat stress on the immune system of broiler chickens can also be alleviated by feed restriction early in life (Khajavi *et al.*, 2003). The enhanced expression of HSP70 is suggested to be partially responsible for the advantageous effect (Zulkifli *et al.*, 2002). Early feed restriction could work in concert with EHC treatment. Improved heat tolerance and disease resistance are observed in chickens suffering EFR together with EHC (60% feed restriction on D 4, 5 and 6; exposure to 36C for 1 h from D 1 to 21) (Liew *et al.*, 2003).

Besides the early condition, the age of the breeder flock from which the broiler chicks are originating should be taken into account. It was indeed showed by Weytjens *et al.* (1999) that chicks from young breeder flocks, independently from incubating egg weight or growth rate of the posthatch chicks, are more resistant to heat at an older age.

Conclusion

The higher production performance and feed conversion efficiency make today's chickens more susceptible to heat stress than ever before. The increasing proportion of poultry production in tropic and subtropical regions makes it necessary to reconsider the selection strategy of today's commercial breeding programme in the long run, and the importance of the potential use of *Na* and *F* genes is accentuated. Nutritional strategies aimed to alleviate the disadvantage effect of heat stress by maintaining feed intake, electrolytic and water balance or by supplementing micronutrients to satisfy the special need during heat stress, such as Vitamins and minerals, have been proven advantageous. To enhance the thermotolerance by early heat conditioning or feed restriction seems to be one of the most promising management methods in enhancing the heat resistance of broiler chickens in the short run.

Acknowledgement

This work was supported by grants from National Basic Research Programme of China (2004CB117507).

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