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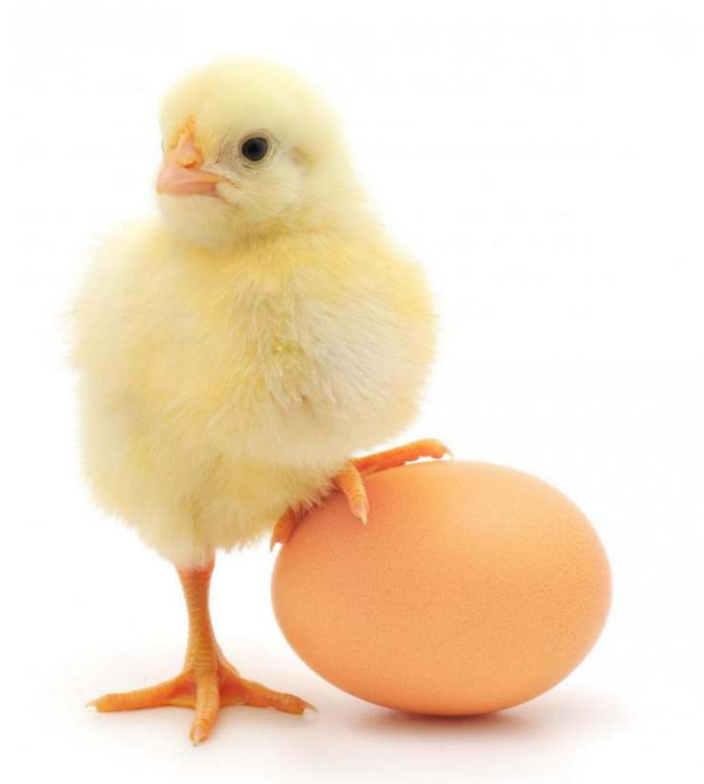

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Protein and Amino Acid Needs of Broilers in Warm Weather[1]: A Review

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Abstract: Broiler production has increased rapidly in tropical and subtropical countries in the past decade and is predicted to sustain strong growth in the future. One of the greatest challenges to efficient production in these areas is the reduction in performance associated with warm and hot weather conditions. Various dietary approaches have been taken to enhance broiler performance under these conditions. Numerous management strategies have been employed to alleviate the adverse effects of heat distress with varying degrees of success. Nutritional means of alleviating heat distress have focused largely on manipulation of energy and protein or amino acid content of the diet. Although the tendency has been to increase protein/amino acid levels to account for reduced intake, research indicates that such an action is not sufficient to overcome adverse effects. Improving overall balance of the diet by amino acid supplementation appears to be more effective than increasing total protein intake. More research is needed to quantify amino acid needs under warm weather conditions.

Key Words: Broilers, environment, warm weather, amino acids

Introduction

Over the last decade, broiler production in tropical and subtropical countries rapidly increased as a result of increasing population and consumers' rising income. Data published by Watt Poultry (2001) show that from 1995 to 1999, chicken meat production in Africa, Asia and South America grew by 13.85, 17.73 and 23.65%, respectively (Table 1). Despite the many challenges faced by broiler industries in these developing nations, including economic crisis, currency devaluation and reliance on imported raw materials, it is predicted that broiler production in these areas will continue to sustain strong growth in the future.

In general however, production performance in these regions remain relatively inferior compared to performance obtained in temperate countries in North America and Western Europe. Although many factors are obviously involved, the combination of high temperature and relative humidity resulting in heat stress remains one of the major challenges to improved production efficiencies in these warm regions. While heat stress is only an occasional challenge during the summer months in temperate countries, it is a constant problem in many tropical countries.

High ambient temperature stress reduces broiler's growth rate, feed consumption, and survival, resulting in a decrease in profitability (Dale and Fuller, 1980; Teeter *et al*., 1985; Deaton *et al*., 1986). Moreover, broilers raised under heat stress have increased abdominal fat (Kubena *et al*., 1972; McNaughton and Reece, 1984) and decreased carcass protein (Geraert *et al*., 1996; Tankson *et al*., 2001).

The heat-related problems associated with growing broilers in warm weather boils down to the sensitivity of the fast-growing commercial broilers to high temperature during the growing-finishing period. The high susceptibility of commercial broilers to heat stress can be attributed in part to the inferior development of their cardiovascular and respiratory system in comparison to their rapid growth potential (Yahav, 2000). In addition, their rapid growth rate is supported by high feed intake; thus, as they grow, metabolic heat production increases but their heat dissipation capacity does not (Teeter, 1994). Optimal broiler production during heat stress requires that an appropriate combination of nutritional and management therapies be applied.

Table 1: World chicken meat production (MT)

Region	1995	1999	% Increase
WORLD	45,786,539	52,991,821	15.74
Africa	2,131,252	2,426,475	13.85
Asia	13,946,341	16,419,035	17.73
Europe	8,728,942	8,851,422	1.40
N C America	14,204,585	16,931,356	19.20
S America	6,200,306	7,666,812	23.65

Source: Watt Poultry CD-ROM, 2001

Heat Stress and Zone of Comfort: During the first few weeks post-hatching, broiler chicks require supplemental heat to maintain body temperature for normal growth and development. However, as the birds grow, their requirement for supplemental heat declines because of development of insulating feathers and higher metabolic heat production. When ambient temperature increases and the bird's capacity to dissipate heat is compromised, heat stress ensues.

"Heat stress" is a term commonly used to describe the bird's response to elevated temperature and humidity where abnormal response to increase heat dissipation such as panting or increased respiratory rate is observed. Respiratory rate may increase from 25 to 150 breaths per minute over a 20-minute period in response to an increase in ambient temperature from 27 to 44 °C (Shane, 1988). The burden of dissipating the excess heat under heat stress conditions results in reduced production efficiency. Thus, in order to maintain optimum production performance and economic return, broilers should be kept in temperatures within their comfort zone.

The "thermoneutral zone" or "zone of comfort" is a particular range of environmental temperature over which birds do not change their behavior or show signs of discomfort and use the minimum amount of metabolic energy to maintain normal body temperature. Within this zone, energetic efficiency is maximized due to minimum energy needed for maintaining body temperature. Heat stress is initiated when ambient temperature rises above the upper critical limit of bird's zone of comfort. Environmental temperature may be temporarily warmer than the bird's comfort zone without compromising the birds' overall well being and survival but will lower productive efficiency in the immediate term. Although studies conducted to established this zone did not indicate relative humidity (RH) level, it should be noted that high temperature coupled with high relative humidity intensify heat stress conditions.

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Table 2: Feed intake, growth rate and feed conversion of broilers raised under varying temperatures[A]

Experiment	Temperature (ºC)	Feed intake ($g.d^{-1}1.kg^{-1}$)	Growth rate ($g.d^{-1}.kg^{-1}$)	Feed conversion (g feed.g^{-1} growth)
3	25	91.93	34.84	2.65
	35	77.31*	30.55*	2.57
4	25	91.87	34.06	2.75
	30-40	78.17*	29.80**	2.65

[A] Adapted from Henken *et al.*, 1983. *P<0.05, **P<0.01.

For various types of poultry, the thermoneutral zone is around 18.3 to 23.9 °C after the first few weeks of life (Keshavarz, 1990). In general, the comfort zone of broilers declines from about 32 °C at hatching, to around 24 °C at three to four weeks of age, and to about 21.1 °C thereafter. Unfortunately, the bird's comfort zone is also influenced by other factors such as breed or strain, gender, and previous exposure of birds to high temperatures (acclimation and thermal conditioning). It is suggested that, depending on earlier acclimation or thermal conditioning, this zone could be between 32 to 40 °C (Farrel and Swain, 1977; May *et al.*, 1987; Sykes and Fataftah, 1986; Teeter *et al.*, 1992; Yahav and Plavnik, 1999; Yahav and McMurtry, 2001).

An interrelationship of the factors that influence the thermoneutral zone of the birds may have contributed to the observed differences in temperatures in which the birds' performance is affected by high ambient temperatures. Yahav *et al.* (1996) reported that the optimal performance of broilers was attained at 18 to 20 °C. At temperatures above 25 °C, a reduction in body weight was observed which coincided with a significant reduction in feed intake. In contrast, Keshavarz (1990) suggested that feed consumption, feed conversion ratio and production performance are affected when ambient temperature was above 27 °C. If house temperature increases only moderately above the point of upper critical temperature (24 to 26.7 °C), feed efficiency may be improved due to reduced energy needed for maintenance.

Effects of Heat Stress in Broilers: Several studies have consistently demonstrated the adverse effects of elevated ambient temperature on growth, livability and carcass quality of broilers. Although the bird's response to increases in ambient temperature could be variable, one of the key indicators of heat stress is a decline in feed intake. Potter (1985) reported that feed consumption decreases about 1% for each 1 °C increase in temperature from the bird's comfort zone. The decline in feed intake could be as much as 30% at an ambient temperature of 32 °C (Polin, 1983).

Henken *et al.* (1983) using constant temperatures of 25 and 35 °C and cycling temperatures of 30 to 40 °C, also observed that feed intake and growth rate were significantly reduced by 15.9% and 12.3% at 35 °C, respectively, and 14.9% and 12.5% at cycling temperatures of 30 to 40 °C, respectively, compared to birds kept constant at 25 °C (Table 2). They calculated that the overall decrease in feed intake per degree increase in temperature was 1.29g/d/kg body weight.

With decreased feed intake, nutrients available to sustain growth performance become limiting. Squibb *et al.* (1959) concluded that the greatest proportion of economic loss associated with heat stress is the result of lowered feed intake. However, efforts to increase feed consumption during heat stress by force-feeding have been shown to decrease survival (Teeter, 1994). Therefore, the general assumption is that productivity decreases primarily as a result of reduced feed intake.

However, in experiments with birds fed equal amount of feed and kept at 20 or 32 °C, Dale and Fuller (1980) reported that only 63% of the growth depression could be attributed to reduced feed intake. The other 37% may be due to factors not directly related to quantity of feed consumed; for example, added energy expenditure in wing lifting and panting. Hai *et al.* (2000) also suggested that passage rate of feed residue and the amount of chyme digesta in the crop and small intestine was decreased by high temperature indicating reduced digestive activity. As suggested by these observations, it is likely that the combined effects of reduced feed consumption, increased energy cost required for heat dissipation, altered metabolic and physiological processes, and perhaps some other factor(s) causes the reduction in weight gain.

Another problem associated with broilers raised under high ambient temperatures is that heat-stressed birds are not only lighter but also fatter (e.g., Kubena *et al.*, 1972; McNaughton and Reece, 1984; Howlider and Rose, 1987) and have lower carcass protein (Geraert *et al.*, 1996; Tankson *et al.*, 2001). For example, El-Husseiny and Creger (1980) found that abdominal fat of broilers housed at 32 °C was 1.54% greater than those grown at 22 ºC. The increase in carcass fat of broilers raised under heat stress is undesirable since the fat content of broiler meat products has become increasingly important to consumer perceptions of the healthfulness of meat. In areas like the United States where the demand for broiler meat is dictated by consumers' preference of white meat, the reduction in breast meat yield of heat-stressed broilers is costly.

Strategies to Alleviate Heat Stress in Broilers: Due to persistent recognition that heat stress is a constant problem for efficient broiler production in warm weather, the objectives of many research trials in recent years has been to develop solutions to alleviate the problem. To date, several management techniques have been tested but only a few were found effective and economical in minimizing the undesirable impact of heat stress on broilers. These solutions include management strategies to make the birds more comfortable such as improving house insulation, providing adequate ventilation, installing roof sprinklers and evaporative cooling system and reducing bird density. Other techniques consist of feed withdrawal or fasting before onset of heat stress and feeding at cooler times of the day, and providing cool drinking water.

Some authors (Yahav, 2000) also suggest that getting young birds accustomed to higher ambient temperature prior to heat stress exposure (acclimation) and exposing the birds at an early age to acute heat stress conditions (thermal conditioning), can improve the birds' resistance to heat stress. A precaution in implementing acclimation or thermal conditioning is that both strategies usually affect performance negatively. Thus, the use of these strategies depends on environmental challenges the birds have to face and to economic restraints.

Similarly, most of the management remedies are usually expensive and not economically feasible in most cases, and can be rather complex to implement since they are difficult to synchronize with the initiation of heat stress. In many tropical areas around the world, the majority of the broiler producers are small-scale growers with simple convection- ventilated housing, and in some cases fans are the only source of ventilation. Insulating the house or installing sophisticated ventilation or

Table 3: Effect of temperature and dietary protein on performance of broilers 3 to 7 week-old [A]

	Body weight gain (g)	Feed conversion[B]	Protein Efficiency Ratio[C]	Energy Efficiency Ratio[D]
Temperature, ºC				
21.0	1969[e]	0.473[c]	2.408[c]	15.02[c]
23.8	1862[d]	0.488[cd]	2.408[cd]	15.49[cd]
26.6	1824[d]	0.503[d]	2.564[d]	15.98[d]
29.4	1461[c]	0.495[cd]	2.531[d]	15.73[d]
32.2	1233[b]	0.419[b]	2.146[b]	13.30[b]
35	545[a]	0.342[a]	1.746[a]	10.84[a]
Dietary CP, %				
16	1478	0.452	2.826[e]	14.36
18	1511	0.454	2.532[d]	14.42
20	1481	0.452	2.259[c]	14.32
22	1503	0.460	2.091[b]	14.59
24	1440	0.449	1.870[a]	14.24
ANOVA P-Values				
Temperature (T)	<0.001	<0.001	<0.001	<0.001
Dietary CP (CP)	0.202	0.854	<0.001	0.867
T x CP	<0.001	0.014	0.011	0.016

[A] Adapted from Cheng *et al.*, 1997a. [B] Feed conversion = weight gain/total feed intake. [C] Protein efficiency ratio = weight gain/total protein intake. [D] Energy efficiency ratio = weight gain x 100/total ME intake. [a-e] Means within each column and within each main effect with different superscripts are significantly different.

evaporative cooling system is obviously not feasible for these growers. In these areas, frequent power shortage is another restriction in using mechanical devices to provide a favorable environment to the birds. Additionally, feed withdrawal could be labor-intensive since feeding equipment is typically manual. In the case of the big commercial growers capable of providing controlled environments, an important consideration is the economic return of using such equipment and strategies.

Dietary modification is another technique recommended to minimize the negative effects of heat stress. In the same way, various nutritional means designed to provide adequate nutrient intake and to lessen the adverse effects of heat stress in broilers have been extensively investigated as well. Earlier work in the 1970's and 1980's suggested that vitamins, minerals, dietary energy, and protein should be increased to compensate for the reduction in feed intake (Teeter and Smith, 1986; Moreng, 1980; Pardue *et al.*, 1985; Dale and Fuller, 1980; Reece *et al.*, 1984; Baghel and Pradhan, 1989). Many of these works have shown potential benefits and could be economical but currently, none of these dietary adjustments can be considered as a perfect solution in itself. It appears that more quantitative data for accurate nutrient adjustment during heat stress conditions is needed.

An area that has shown significant controversy pertains to the protein/amino acid needs of heat-stressed chickens. While it is more generally accepted that increasing the dietary energy content (in the form of added fat) improve productivity of heat-stressed birds, experiments have not shown consistent results from increasing the crude protein/amino acid levels in diets of broilers under heat stress situations. Due to conflicting results of previous studies, protein and/or amino acid requirements of broilers in high temperatures are not currently established.

Protein Needs of Broilers in High Temperatures: Meeting the protein needs of broilers is much more complex than that of other nutrients such as fat or carbohydrates. The protein content and quality of the diet has probably the greatest influence on productivity of broilers than any nutrient. In addition, ingredients that are used primarily to supply dietary protein are among the most expensive ingredients in broiler diets. Most of these ingredients are imported from other areas of the world by many tropical countries. Therefore, providing sufficient amounts of protein to meet the needs for efficient performance is important, but adding more than the requirement is unnecessary. In addition, there is growing evidence that excess protein level is detrimental for broilers raised under high ambient temperatures.

As mentioned earlier, broilers under warm environment decrease their feed consumption. A reduced feed intake implies a reduction in protein intake. Thus, in the past it was usually recommended that the dietary crude protein (CP) level be increased in order to maintain protein intake. Some recent studies still support such practice. For instance, Jaffar *et al.* (1996) observed improved weight gain and feed efficiency with high energy and high CP (25% in starter and 23.5% in finisher) in the diets of broilers grown under acute heat stress of 29 to 42 °C cycling temperature and 45 to 89% RH.

Over the years however, more and more evidence exists to show that protein and/or amino acid requirements of heat-stressed broilers are not necessarily increased. Such increases could rather be more detrimental to the heat-stressed birds due to the higher heat increment associated with protein metabolism. Musharaf and Latshaw (1999) proposed that heat increment for protein is much higher when the birds' ambient temperature is high than when it is low. Dietary protein/amino acids also stimulates protein turnover (Musharaf and Latshaw, 1999) thus resulting in more metabolic heat production.

Cowan and Michie (1978) fed CP levels from 18.3 to 29.3% to broilers raised from 22 to 52 days of age at different temperatures. For each diet, birds at 21 °C grew significantly better than those at 26 and 31 °C. Feed intake was lower with each increase in rearing temperature. However, feeding the diets with increased protein concentrations did not reduced growth rate depression of broilers reared at 26 or 31 °C.

Thorbek and Chwalibog (1984) found that chickens grown in temperatures that were gradually reduced from 28 to 12 °C in 3 weeks time and kept constant at 12 °C for the next 3 weeks had a higher nitrogen intake and a slightly higher nitrogen retention, but not significantly different than the birds kept constantly at 28 °C. In the same way, results of experiments by Kubena *et al.* (1972) demonstrated that even when intake of protein was the same at both temperatures of 18.3 and 29.4 °C, birds at the higher temperature still grew at a markedly reduced rate.

Swick (1989) reported that high CP during heat stress improved early growth but depressed growth later and overall. At 21 d, birds grown under normal (23 °C) and hot (32 °C) temperatures and fed diets with 24% CP had higher weight gain than birds fed 20% CP. During the later part of the growth period, birds fed a high protein diet continued to gain more than birds fed normal protein level under moderate temperatures, but gained less during heat stress. Using a modeling approach, Hruby *et al.* (1995) predicted that broilers at 32 °C had lower protein requirements than those at 21.1 °C. However, based on g amino acid/Mcal of energy in the diet, high temperature did not significantly change the requirement for amino acids. Thus, these researchers do not support increasing protein and amino acid levels in the diets to compensate for lower feed intake at high environmental temperature.

In a later study, Cheng *et al.* (1997a) showed that feeding high CP diets to heat-stressed broilers adversely affected weight gain, carcass composition, and efficiency of feed, protein and energy utilization (Table 3). They suggested that heat-stressed broilers should not be fed increased concentrations of protein to provide the needs for dietary amino acids.

Amino Acid Requirements of Broiler at Warm Environments: Amino acids are the individual units from which proteins are synthesized. To achieve the maximal growth, feed efficiency and carcass quality potential of the commercial broilers, their amino acid needs must be met. Met, Lys and Thr are considered the most-limiting amino acids in corn-soybean meal-based diets for broilers. For many years, diets were formulated by meeting a CP minimum. The accumulation of sufficient data which provided that chickens need certain quantities of essential amino acids and not protein, led to diet formulation based on amino acid requirements. However, the diet should also have a sufficient protein level to ensure an adequate nitrogen supply for synthesis of the indispensable amino acids (NRC, 1994).

The development of amino acid supplements allows for meeting the needs for essential amino acids at a lower protein. In addition, the use of synthetic amino acids to meet the amino acid needs of broilers can reduce feed cost, increase flexibility in raw material selection and can be used to balance amino acids of the diet thus, minimizing excess crude protein and/or amino acids (Bercovici and Fuller, 1995).

Amino acid imbalance has been shown to depress performance of heat-stressed broilers. Amino acid imbalance is a change in the pattern of amino acids in the diet precipitating depressions in food intake and growth, which are completely alleviated by supplementation of the first limiting amino acid (Harper, 1964). D'Mello (1994) classified amino acid imbalance either as one that is precipitated by the addition of a relatively small quantity of an amino acid to low protein diet, or one that is precipitated by an incomplete mixture of amino acids.

Although amino acid imbalance rarely happens in modern broiler diets, this condition can occur where diets are formulated using protein sources with poor amino acid quality to meet the amino acid needs and a CP minimum. This is especially true in countries where feed is sold to the customer and government laws specify that a certain minimum protein level must be met. Again, this condition can likely happen in developing nations where most broiler producers are not vertically integrated and where alternative protein ingredients are widely used. Among the effects of amino acid imbalance is a reduction in appetite and feed intake leading to a reduced intake of the limiting amino acids and therefore growth.

Providing diets with minimum excess amino acids or a better amino acid balance has been suggested to improve tolerance of broilers to heat stress. This concept is supported by the assumption that amino acids in excess of the broiler's requirement are necessarily degraded since the body has no storage pool for amino acids. The carbon skeleton of amino acids is used for energy and the nitrogen from the amine group eliminated in the body as waste products (ammonia). This process is suggested to increases metabolic heat production causing an additional burden for the heat-stressed broilers.

March and Biely (1972) conducted two experiments to evaluate the effect of energy supplied from the diet and from environmental temperature on the response of chicks to different levels of dietary Lys. In both experiments, they observed that the diets that were severely deficient in Lys reduced feed consumption relative to the diets more adequately supplemented with Lys. They believed that this was due to the greater heat production resulting from the amino acid imbalance and that the level of effective protein in the deficient diets limited growth rate and therefore, the amount of energy required for the growth process. In addition, these authors concluded that aggravation of the depressing effect of dietary amino acid imbalance on feed consumption and growth rate occurs with the increased energy supply to the birds either as environmental heat or as dietary metabolizable energy. In contrast, Adams and Rogler (1968) demonstrated that the protein level necessary for maximal weight gain did not differ at 21 or 29 °C when a diet deficient in lysine and with crude protein level from 14 to 20% was fed to broilers. In two experiments where heat production was measured by respiratory calorimetry, methionine deficiency (Baldini, 1961) and methionine-cystine adequacy (Guillame and Summers, 1970) produced an increase in heat production. Under hot weather conditions, Waldroup *et al.* (1976) presented evidence that broilers fed reduced CP diets supplemented with the limiting amino acids to restrict amino acid excesses, improved growth rate and feed efficiency. Likewise, Leeson (1986) emphasized the importance of maintaining optimal amino acid balance under heat stress situations.

However, other researchers have argued that excess amino acids do not necessarily lead to diet-induced increases in heat production since catabolism of surplus amino acids would spare utilization of the other substrates (carbohydrates and fats) for energy production. Macleod (1997) showed that heat production of 14 to 21d male broilers was closely correlated ($P<0.001$) with rate of protein accretion, which in turn was more strongly associated with the intake of the first limiting amino acid, in this case Lys, than with total protein intake. They found that there was no indication of heat production stimulation by excess amino acid. Heat production on an imbalanced, lysine-deficient, amino acid mixture was not greater than those birds fed a balance amino acid source with the same lysine concentration. They suggested that surplus amino acids would spare utilization of some of the substrate for energy production without having a large effect on total metabolic rate.

At almost the same time, Alleman and Leclercq (1997) examined the effects of dietary protein and environmental temperature on growth performance of growing broilers. A group of birds were fed diets formulated with supplemental Lys, Thr, Arg and Val to reduce protein level while providing a better balanced protein than the control diets. They observed that at 32 °C, growth rate was significantly reduced regardless of the crude protein content of the diets and the birds fed the low-protein diet were more affected and had higher FCR than the control group. Likewise, breast yield was reduced and abdominal fat was significantly increased at hot conditions with the influence more pronounced with the low CP diet (Table 4). Thus, these authors concluded that lowering CP content in this experimental conditions while

Table 4: Effect of temperature and dietary protein on performance of broilers 23 to 44 day-old [A]

	Temperature (ºC)			
	22		32	
Crude protein (g/kg)	160	200	160	200
Body weight gain (g)[1]	1783[c]	1779[c]	939[a]	1118[b]
Feed consumed (g) [1]	3256 [c]	3108[b]	2279[a]	2333[a]
Feed conversion ratio[1]	1.81[b]	1.77[a]	2.41[d]	2.19 [c]
Abdominal fat (g) [2]	68.3[b]	53.6[a]	61.3 [a]	57.1 [a]
Breast meat (g) [2]	362.1[c]	373.1[c]	197.6[a]	238.8 [b]

[A] Adapted from Alleman and Leclercq, 1997. [1] Means in the same row not sharing a common superscript are different at P<0.01.
[2] Means in the same row not sharing a common superscript are different at P<0.05.

Table 5: Effect of temperature and amino acid on performance of 8-week-old broilers[A]

Temperature (ºC)	Amino acids % of requirement	56-day body weight (g)	Feed conversion (g feed/g gain)
18.3	110	1794[a]	2.19[a]
	100	1722[a]	2.21[ab]
	90	1719[b]	2.22[ab]
	80	1723[b]	2.26[bc]
29.4	110	1646[c]	2.21[ab]
	100	1620[cd]	2.17[a]
	90	1629[cd]	2.21[ab]
	80	1592[d]	2.29[c]

[A] Adapted from Kubena *et al*., 1972.
[abcd] Means within column with the same superscript do not differ significantly (P<0.05).

supplementing the diet with synthetic amino acid did not seem to be an effective way to help broilers withstand heat stress.

Cheng *et al*. (1997b) also demonstrated that supplementing 16 and 18% CP diets with Met, Lys, Threonine (Thr), Arginine (Arg), and Tryptophan (Trp) to provide a minimum of 100 and 110% NRC (1994) amino acid levels did not improved weight gain of heat-stressed broilers compared to birds fed diets with 90%. These authors nonetheless acknowledged the possible limitation(s) of their results. Alleman and Leclerq (1997) suggested that their conclusion needs further investigation since it could be possible that the levels of essential amino acids used in their experiments were not sufficient for the high temperature conditions. Cheng *et al*. (1997b) postulated that there might be amino acids other than Lys, Met, Thr, Arg, and Trp that limited the results of their experiments.

It is apparent from these studies that before a diet with a better amino acid balance can be produced, requirements for the individual amino acids need to be established. However, current documented amino acid recommendations such as NRC (1994) have been determined using moderate environmental conditions with the least stress possible and no separate requirements have been established for heat-stressed broilers. The limited studies conducted to evaluate absolute requirements for amino acids at elevated temperatures have shown conflicting results.

Results of a study conducted by Kubena *et al*. (1972) with pathogen-free broilers from 5 to 8 weeks of age raised at either 18 or 29.4 ºC showed that increasing amino acid levels at high temperature was not beneficial. Performance of birds raised at 29.4 ºC was poorer but there was little difference in performance of broilers fed 90 to 110% of the recommended levels of Lys and TSAA (Table 5). The quantities of protein and met + cystine required per unit of gain tended to decrease as the dietary amino acid levels decreased.

McNaughton *et al*. (1978) also found that the performance of 4-week-old birds raised at 29.4 ºC and fed adequate levels of Lys was reduced, and that Lys requirement decreased (1.00%) compared to birds housed at 15.6 °C (1.10%). Likewise, Sinurat and Balnave (1985) suggested that one way of improving body weight and feed consumption at high temperature is to induce a slight deficiency in lysine or provide a lower Lys:ME ratio.

In contrast, other researchers have reported that heat-stressed birds respond positively to increased amino acid consumption (e.g., Fuller and Mora, 1973; Dale and Fuller, 1980). Thomas *et al*. (1992) also indicated that broilers raised at 26.7 and 32.2 °C need higher levels of amino acids than birds raised at 21.1 °C.

Other authors have reported that digestibility of protein and amino acids influence the requirements at high temperatures. Zuprizal *et al*. (1993) evaluated the influence of ambient temperature on true digestibility of protein and amino acid of rapeseed and soybean meal in broilers. They reported that total digestible protein and total digestible amino acids were significantly decreased as the ambient temperature rose from 21 to 32 ºC. Wallis and Balnave (1984) reported that digestibility of amino acids appeared to be sex-related and vary between amino acids. Digestibility of Lys was not affected but Met and Thr were significantly reduced at 31 °C compared to 21 °C in female but not in male birds.

Austic (1985) pointed out that linear adjustment in protein/amino acid requirement allows approximation of the nutrient needs of broilers under various environmental conditions, but it is not a precise measure of the dietary requirements at the more extreme high or low environmental temperatures. He suggested that a more accurate estimation in these conditions is a mathematical model proposed by Hurwitz *et al*. (1980). This model calculates the amino acid requirements of growing chickens in the basis of the maintenance requirements and the requirements for growth and production. Based on this model, these authors showed a curvilinear relationship between environmental temperature and the requirements for Arg, Leu and TSAA. Hurwitz *et al*. (1980) determined that the requirement for amino acids declined as the environmental increases above 28 to 30 °C.

It should also be noted that results from different studies can not be directly compared since different authors use different systems to express the amino acid requirements of chicks. Some used percentage of amino acid in the diet, others expressed amino acids in relation to energy level, or grams or milligrams of each amino acid per day. In providing amino acid requirements by a fixed ratio with energy levels, a decrease in energy intake usually results in a corresponding decrease in amino acid intake (Reece and McNaughton, 1982; Hurwitz *et al*., 1980).

Variations in breed or strain, age of birds and environmental conditions (cycling versus constant, temperature range) at which response was evaluated, housing (battery versus floor pen), energy level, and protein and amino acid concentrations employed in these studies also appear to be some of the reasons for the inconclusive results.

Conclusion: Because of lack of consistency in the amino acid requirement data, no amino acid recommendations have been currently established for broilers raised under warm environments. Since adding synthetic amino acids in the diet is expensive and excesses can potentially aggravate performance of heat-stressed broilers as indicated by some studies, it is important to know the minimum levels needed to fortify the diet. Hence, there is an obvious need for further studies in crude protein and/or amino acid nutrition of broilers at warm rearing conditions.

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