Taking nutrition forward in tropical production

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Poultry production is consistently developing in hot climate countries, from Latin and Central America to Asia. However, ambient temperature is a critical determinant of bird performance.

Indeed, managing poultry under hot conditions is thus a challenge that most nutritionists are facing. Even in temperate countries, hot episodes are becoming more frequent and thus concern all poultry managers. Hot conditions may correspond to either chronic heat exposure or acute heat stress.

	22AL	22PF	32AL
Final body weight (g)	2372[a]	1905[b]	1660[c]
Feed conversion ratio (g :g)	2.22[a]	2.11[a]	2.73[b]
Abdominal fat[1]	2.85[a]	1.86[b]	3.28[a]
Subcutaneous fat[2]	5.80[b]	3.94[c]	7.01[a]
Intermuscular fat[2]	2.90[b]	2.59[b]	3.53[a]
Intramuscular fat[3]			
Breast	1.50[ab]	1.32[b]	1.67[a]
Leg	4.04[ab]	3.80[b]	4.50[a]

[1]in g/100g body weight; [2]in g/100g leg weight; [3]in g lipids/100g tissue

[a, b, c]means in a row not followed with the same letter differ significantly at P<0.05

Table 1. Effect of heat exposure (4-7 weeks of age) on lipid deposition in ad libitum heat exposed (32AL), ad libitum control exposed (22AL) and pair fed control exposed (22PF) seven week old male broilers (after Aïn Baziz et al., 1996).

Technical responses to these two different conditions do not evoke the same mechanisms.

While the heat stress might be alleviated through physical means (increased ventilation rate, use of cooling devices) to decrease the peak of temperature, the prolonged exposure might be tolerated through nutritional adjustments.

Elevated air humidity

Furthermore, tropical conditions also mean elevated air humidity reinforcing the heat load for the animals. Hot environmental conditions decrease production parameters including livability, egg production, shell quality, hatchability, growth rate, breast meat yield, feed efficiency and carcase quality.

Birds and mammals are homeotherms, which means they are able to maintain a near constant body temperature.

To achieve a constant body temperature, heat produced by metabolism must equal heat loss. In birds, heat losses are limited by feathering which is an efficient insulation and by the absence of sweat glands.

The main consequence of heat exposure is thus a reduction in feed intake in order to reduce metabolic heat production. In broilers, this reduction is approximately 1.5 to 2.5% per °C increase in ambient temperature above 20°C increasing with age and temperature and in layers reaches 2.5 to 4g per °C.

This reduced feed consumption leads to growth depression and lower egg production. Egg weight is reduced by 0.4% between 23 and 27°C and by 0.8% beyond 27°C. However, the reduction in growth or in egg production is often greater than the reduction in feed intake, resulting in a lower feed efficiency.

Nutrition knowledge gained from the responses of birds under temperate conditions, accumulated over many years has led to the belief that increasing dietary protein concentration by its resulting increase in heat increment would further impair performance under hot conditions, while increasing fat content by its low heat increment would be more efficient.

Whilst such a solution seemed promising, the observed results were insufficient to have spread the uptake of this strategy throughout the world.

Recent research shows that the increased dietary energy concentration was less effective under hot conditions than under temperate conditions in growing turkeys. A statement often made by poultry nutritionists is that temperature does not change requirements for protein.

As in the same manner as under thermoneutral conditions, rebalancing the dietary amino acid profile and thus allowing a decrease in total protein concentration with use of synthetic amino acid has often been proposed to counteract the effect of chronic heat exposure. However, the ideal amino acid balance has to be completely re-examined under hot conditions.

Nutritional strategies defined

The discrepancy between nutritional theory, mainly acquired in thermoneutral conditions, and practical performance results obtained in hot climate countries led to first reconsider the profound modifications induced by heat exposure at the metabolic level to be able to define possible nutritional strategies.

Choice feeding experiments could also give indications about the preferred nutritional solution by the birds. Strategies based on high dietary protein or balanced amino acid supply will then be reviewed. Advantages of genetically leaner birds will be addressed in relation with protein content of the diet.

	Diet 1 (20% CP)			Diet 2 (18.8% CP)		
	2AL	22PF	32AL	22AL	22PF	32AL
N intake (g)	16.7[a]	10.4[b]	9.8[b]	14.8[a]	9.9[b]	9.4[b]
N excreted (g)	8.2[a]	5.0[b]	5.5[b]	7.4[a]	5.0[b]	5.6[b]
N retention (%)	51.1[a]	51.9[a]	43.2[b]	49.9[a]	49.9[a]	40.4[b]

[a, b, c] means in a row, within a diet, not followed with the same letter differ significantly

Table 2. Effect of chronic heat exposure (4-6 weeks of age) on nitrogen (N) ingested, excreted and retained in ad libitum heat exposed (32AL), ad libitum control exposed (22AL) and pair fed control exposed (22PF) seven week old male broilers (After Bonnet et al., 1997).

Minerals and vitamins have often been proposed to alleviate part of the consequences of heat exposure. Supply of electrolytes, especially carbonate (HCO_3^-) and potassium (K^+) through drinking water appeared easy and cheap. Such supplementations have given positive results on performance which could be explained by an enhanced water intake.

Trial results

A recent practical field experiment conducted in France and involving 24 breeding units with two identical houses demonstrated a potential benefit of such a supplementation (0.065% $NaHCO_3$ and 0.035% KCl) when ambient temperature was above 30°C – 75% of the breeding units had greater performance (final bodyweight and feed conversion ratio) and the mortality during the finishing period was reduced by 86%.

Vitamin C is the vitamin most usually associated with beneficial effects in countering heat stress.

In broilers, Jalilvand and Hejazi demonstrated improved growth and carcase characteristics when enhancing from 150 to 400mg ascorbic acid per kg feed.

There are a number of reports indicating that dietary supplementation with vitamin C for hens can minimise the depression in egg production associated with heat stress.

The response to vitamin C may be via more than one mechanism, and it is perhaps relevant that one of the biological roles for vitamin C is the regeneration of vitamin E.

The most important function of vitamin E is its role as an antioxidant in cell and organelle membranes. In this capacity, it prevents oxidation of unsaturated lipid materials by inactivating free radicals generated during stress

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Temperature	22°C		32°C	
Protein (g/kg)	160	200	160	200
Live weight gain (g)	1783^{c}	1779^{c}	939^{a}	1118^{b}
Feed intake (g)	3256^{c}	3108^{b}	2279^{a}	2333^{a}
Feed conversion ration (g:g)	1.811^{b}	1.772^{a}	2.413^{d}	2.194c
Abdominal fat (g/kg)	2.78ab	2.20a	3.77c	3.24b
Breast meat (g/kg)	14.7c	15.4c	12.1a	13.5b

Table 3. Ideal amino acid balance measured at thermoneutrality is no more ideal under hot conditions (after Alleman and Leclercq, 1997).

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conditions. The uniqueness of vitamin E derives from its chain, which allows it to become directly incorporated into the cell membranes where it can be at the site of action.

Affect of hot conditions

Using pair feeding techniques, Geraert et al. demonstrated that about half of the growth reduction effect of chronic heat exposure was not related to feed intake, and thus could have other origins.

Moreover, enhanced fatness has been observed in heat-exposed chickens despite their lower intake. Howlider and Rose found an increase of 0.8 and 1.6% in body lipid content and in abdominal fat proportion respectively per degree rise between 21 and 29°C.

This increased fatness has been further analyzed by Aïn Baziz et al. who found that abdominal, subcutaneous and intermuscular fat deposits were enhanced in hot conditions (32°C) : + 15, 21 and 22% compared to the control group (22°C) and + 58, 64 and 33% compared to the control exposed, pair-fed birds (Table 1).

Metabolism modifications

Moreover, in heat exposed chickens, saturated fatty acid proportions, particularly palmitic acid (C16:0) were increased and conversely, unsaturated fatty acid percentages were decreased especially oleic and linoleic acids.

Consequently, heat exposure significantly decreased the unsaturated to saturated fatty acid ratio in abdominal and subcutaneous fat tissues. These great changes in lipid deposition suggest profound modifications in metabolism.

Increasing energy density has often been proposed to compensate the reduced intake.

However, due the metabolic changes, benefits were not obvious. In turkeys, Veldkamp et al. demonstrated that the benefit of high energy levels (110% of NRC 1994 recommendations) on feed efficiency for instance was more pronounced at 18 than at 28°C until 84 days of age. This observation reinforces the need to reconsider the amino acid supply which might be the limiting factor under hot conditions.

Protein retention also appeared to be reduced in heat exposed broilers (Table 2). Even when taking into account the reduction in feed intake, nitrogen retention is decreased by up to 30%.

Geraert et al. observed that after two weeks at 32°C, protein gain decreased by 54% and protein efficiency by 46%.

In laying hens, ingestion of feed represents about 25% of the maintenance energy costs. Feed form and feed presentation, such as an adequate particle size would reduce energy expenditure while favouring feed intake.

The second step in utilising the feed is its absorption. NSP enzymes might help in improving feed digestibility while reducing variability due to individual sensitivity to heat stress.

However, this effect will depend on both the type of raw materials (wheat, corn, soybean, quality of fats) as well as the enzyme product (range of enzyme activity available).

Using an enzyme containing not only xylanase and β-glucanase but also a wide range of side activities, such as Rovabio Excel, an improved digestibility of corn soybean based diets has been demonstrated in heat exposed growing chickens.

Heat and protein utilisation

In recent years, protein metabolism has received much more attention compared with previously. Reduction in protein deposition depends on the muscle type. Indeed, while most authors have recorded a reduction in the range of 10 to 15% in the pectoral muscle in proportion to body weight, muscle proportion in the legs often appears enhanced, suggesting differential effects according to muscle metabolism and main energy substrate. While the pectoral is mainly glycolytic and use glycogen as the main energy source, the sartorius or gastrocnemius from the thigh and drumsticks are more oxidative with use of fatty acids as the main source of energy.

Using the large dose technique (flooding dose of 3H-Phe), Temim et al. demonstrated that chronic heat exposure reduced protein synthesis and breakdown, thus reducing protein turnover.

This was associated with significant decreases in the capacity for protein synthesis and in the translational efficacy. The reduced protein deposition observed under heat exposure was explained by a greater decrease in protein synthesis compared with protein breakdown.

When placed in a choice feeding situation, broilers selected a greater proportion of a high compared with a low protein diet.

However, irrespective of ambient temperature, chickens consume less protein with increasing age. Recently, MacLeod and Dabutha presented similar results obtained in heat exposed quails having the choice between a 45 and 10% protein diet. Increasing ambient temperature from 20 to 35°C, had no significant effect on food intake by weight but the proportion of the high energy choice decreased and conversely the proportion of the lower energy but high protein choice increased.

These birds consumed 62 and 36% of their total intake as the high protein feed under hot and thermoneutral conditions respectively. However, all previous studies have not shown the same results. This might relate to the degree of imbalance in the dietary amino acids in these specific experiments.

The enhanced intake of the high protein diet might suggest an increased need for protein under hot conditions either associated with the overall decreased food intake or a more specific need in order to maintain protein deposition and thus growth.

Amino acid balance profile

Due to its lower heat increment, fat supplementation has often been proposed as a means of enhancing feed intake at high temperature.

However, the higher net energy content of fat counteracts the benefits in terms of energy intake and also increases fat deposition. Indeed, using a wide range of diet composition, 50 to 150g/kg lipids and 2,800 to 3,300kcal ME/kg, Aïn Baziz et al. could not find any gain in protein deposition under hot conditions but only changes in fat deposition.

Surprisingly, increasing the dietary protein content from 170 to 300g/kg did not result in enhanced heat increment as expressed by the slope of the regression between heat production and ME intake, suggesting different metabolic pathways under hot conditions.

Recently, Padilha showed that enhancing the total protein content of the finisher diet from 15 to 25% resulted in an increased weight gain under constant high temperature (32°C) while under thermoneutral conditions, weight gains of chickens plateau beyond 20%. Similarly, in layers a positive effect of high protein diets has been reported.

Is the positive effect of high protein diets due to increased needs for some amino acids? Dietary supplementation with common amino acids used in poultry nutrition such as methionine, lysine or threonine has not always shown significant improvements.

Rose and Salah Uddin found a significant lysine balance x temperature interaction. The relative changes in growth rate was less affected by lysine to protein ratio at 30°C than at lower tempera-

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Age (days)		**28-33**	**33-38**	**38-43**
Temperature (°C)		**22**	**30**	**22**
Arg :Lys	1.04	1.90	1.97	1.76
	1.19	1.93	1.89	1.76
	1.35	1.88	1.92	1.77
Met	None	1.98[a]	2.16[a]	1.87[a]
	HMB	1.87[b]	1.79[b]	1.71[b]
	DLM	1.85[b]	1.84[b]	1.70[b]

Table 4. Effect of arginine:lysine ratio and methionine source (DLM or HMB) on feed conversion ratio (FCR) in chickens successively exposed to 22 or 30°C (after Chen et al., 2003).

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tures. The effect of temperature on lysine requirement could also depend on sex, being more important for females, as revealed by Han and Baker.

Moreover, Balnave and Oliva reported a lower need for methionine under hot constant or cycling temperatures – 0.22 vs. 0.26g methionine per MJ energy.

Austic and Waldroup reviewing the literature concluded that there was no evidence for an increased need in amino acids above 32°C.

However, blending protein sources in combination with synthetic amino acids addition might help to restore performance under hot conditions.

Protein diets compared

Recently, Alleman and Leclercq compared a standard protein diet (20%) to a low protein diet (16%) but rebalanced with synthetic amino acids.

Lysine, sulphur amino acid and the other essential amino acid contents were added according to the latest requirement figures obtained under thermoneutral conditions.

High temperature reduced growth rate, feed efficiency, as well as breast meat proportion and increased fatness.

Whereas under thermoneutral conditions, both diets gave same performance and breast meat deposition, under hot conditions, low protein fed broilers exhibited lower weight gain and decreased breast meat deposition (Table 3).

Finally, an interesting strategy, based on enhancing the arginine to lysine ratio, was proposed by Brake and Balnave. Arginine supplementation appeared to have a strong effect on viability under acute heat stress. Reviewing a series of five experiments, Brake et al. concluded that increasing the arginine to lysine ratio at high temperature (constant or cycling) produced consistent improvements in feed efficiency without any loss in growth.

Whereas Mendes et al. did not conclude on a positive effect of increasing lysine or arginine: lysine ratio under different environmental conditions, their results showed a consistent improvement of 3-6 week weight gain, feed efficiency and breast meat yield at an arginine:lysine ratio of 1.3. Increasing lysine to 1.3% during that period also enhanced performance parameters.

Metabolic needs for arginine would thus appear to be increased while at the same time its availability is reduced. Using the in vitro methodology with intestine fragments showed that whereas under temperate conditions, arginine and lysine uptakes were similar, under hot conditions arginine uptake by the intestine significantly dropped compared with lysine uptake. Such a discrepancy would create an imbalance under hot climates.

To reconsider the amino acid balance, it might be worthwhile investigating the plasma amino acid profiles of heat exposed and control exposed broilers. Geraert et al. found significant decreases in all plasma amino acids except for aspartic and glutamic acids.

Padilha, demonstrated that supplying a high protein balanced diet could significantly decrease the difference between plasma amino acid profiles at both temperatures and thus greatly improve growth under hot conditions. Thus, ideal amino acid balance differs under different ambient temperatures.

In laying hens, about 75-80% of the ingested protein or amino acids are used for egg production, they are thus highly sensitive to their amino acid intake. The reduced feed consumption has to be counterbalanced by an increased amino acid content in order to sustain performance

Effect of methionine source

It is difficult to find constant and significant difference in bioefficacy between methionine (DLM) and methionine hydroxy analogue (HMB) under hot conditions. Rostagno and Barbosa compared the bioequivalency between DLM and HMB under hot conditions and found similar values compared with those obtained at thermoneutrality.

The only trials showing slightly better performances, feed conversion ratio and nitrogen retention are those from Swick et al.

Balnave and Oliva, Wiernusz and Teeter and Teeter et al. could not demonstrate any difference between sources under hot constant or cyclic conditions.

The scientific basis to account for these differences in efficacy between both sources was first thought to be linked to divergence in absorption or transport mechanisms.

Hot conditions have indeed been demonstrated to affect digestibility and intestinal absorption. However, large discrepancies exist between in vitro methodologies to measure transport mechanisms. The two forms of methionine are not absorbed by the same mechanism.

While DLM is mainly absorbed through a broad specificity energy and Na-dependent neutral amino acid B-type transporter, HMB uses a non-stereo specific H+-dependent intermediate affinity transport system. However, even in this area controversy still exists.

While Dibner et al. and Knight et al. wrote that diffusion was very important for HMB, Maenz and coll. could not demonstrate such a mechanism. Indeed diffusion could be less affected by heat induced changes in physiology than active mechanisms.

As indicated by Dr Maenz, caution must be exercised when trying to extrapolate in vivo consequences from in vitro measurements. Direct measures of in vivo passage rate and clearance in the intestinal lumen have to be performed to further understand if differences might exist between the two forms of methionine.

However, no clear performance evidence exists to show differences between methionine forms.

When considering the difference between methionine source, this should be allied to the knowledge of the dietary arginine:lysine ratio. A recent paper by Chen et al. showed that under heat stress, there was an interesting interaction between arginine: lysine ratio and source of methionine (Table 4).

Vitamin E to alleviate stress

A direct effect of vitamin E in heat stress was first reported by Utomo et al. who showed, in a small-scale experiment, that addition of 500mg vitamin E per kg to the diet of hens subjected to a chronic heat stress at 32°C for one week, markedly alleviated the fall in egg production during the period of heat stress and allowed a faster post stress recovery.

Bollengier et al. demonstrated a positive response in heat stressed laying hens to dietary supplementation with high levels of vitamin E, in terms of increased egg production. Two groups of 300 hens were housed at point of lay in each of two environmentally controlled houses. Diets containing 10, 100 and 500mg vitamin E/kg were each fed to 100 hens in each house. The two houses were maintained initially at a normal temperature of 22°C and the temperature was raised to 32°C for four weeks from week 24 or week 32, and then returned to 22°C.

Prior to heat stress, there were no significant differences in egg production between the different treatment groups, but when the house temperature was raised egg production fell in all groups.

However, the decline was less severe in the groups given the diet containing 50mg vitamin E per kg, and the recovery was more rapid. Mean egg weight, shell thickness and hen live weight were unaffected by the dietary treatments.

	Age of hens (weeks)			
	22-26	26-30	30-34	34-38
Temperature (°C)	22	32	22	22
Dietary vitamin E (mg/kg)				
10	90.1	68.9	62.7	80.4
125	90.4	73.8	67.4	82.1
250	89.8	77.3*	73.0*	86.4*
375	90.6	73.7	73.0*	87.9**
500	90.7	76.3	73.2**	85.0

*Within a column, values followed by different letters differ significantly from control group (10 mg/kg) : *, P<0.05; **, P<0.01.*

Table 5. Egg production (% hen/day) of hens maintained at either 22 or 32°C for different periods and given different dietary concentrations of vitamin E.

Optimum concentration

A further experiment was designed to determine the optimum dietary vitamin E concentration associated with enhancement of egg production during heat stress.

Diets containing 10 (control), 125, 250, 375 and 500mg vitamin E per kg were fed to hens in climate rooms.

The houses were maintained at a normal temperature of 22°C up to 26 weeks of age when a heat stress of 32°C was imposed for a period of four weeks. The results are shown in Table 5.

Egg production was very similar in all groups prior to the onset of heat stress. It was depressed by the heat stress, but the depression was more severe in the control group than in the groups given the higher levels of supplementation ($P<0.05$).

Recovery of egg production after the heat stress was also faster in groups given the higher levels of vitamin E.

Comparison of the responses of the hens to the different levels of supplementation with vitamin E suggests that a dietary concentration of 250mg vitamin E per kg was sufficient to give the optimum response in terms of improvement of egg production during heat stress.

Schiedeler also indicated a significant beneficial effect of supplementary vitamin E during both stresses of transfer to new rearing houses and to high ambient temperature conditions.

With the highest vitamin E supply, egg production was sustained near 80% throughout the heat stress period, compared to drops in egg production of 10% in hens fed 18 or 36mg vitamin E per kg.

A series of basic cellular metabolism studies have contributed to an increased understanding of the mode of action of vitamin E in reducing heat stress in laying hens and also help validate the effect.

Egg formation involves the mutually dependent activities of the uptake of yolk precursors and synthesis of oestrogens by the ovary and oestrogen induced synthesis of yolk precursors in the liver. Neither heat stress nor vitamin E supplementation were found to have any direct effect on either the in vitro uptake by oocytes of vitellogenin, the main yolk precursor protein, or on the circulating concentration of 17 b-oestradiol.

Affect of heat stress

Although in hens given standard levels of vitamin E, heat stress significantly depressed the levels of vitellogenin messenger RNA in hepatocytes and vitellogenin protein in the circulation, the concentration of vitellogenin protein in hepatocytes was greatly increased in these birds (+ 63%) compared with pre-stress values.

The ratio of concentration of vitellogenin in the circulation to the concentration of liver vitellogenin was, therefore, decreased in the control birds which did not receive the high levels of vitamin E.

The magnitude of this decrease was greatest in birds which had the greatest depression in egg production. Depressed egg production appeared to be correlated with high liver and low circulating levels of vitellogenin.

However, in hens supplemented with high levels of vitamin E, this accumulation of vitellogenin protein in hepatocytes did not occur and concentrations of vitellogenin in the circulation were higher than in birds supplemented with the low levels of vitamin E.

These results have been interpreted as indicating that during heat stress, hyper supplementation with vitamin E maintained the export of vitellogenin from the liver into the circulation.

This effect is probably related to the known antioxidant properties of vitamin E and to the consequent protection of the integrity of the cellular membranes of organelles and plasma membranes which is required for efficient export of proteins via the secretary pathway.

Conclusion

Nutrition might thus appear a potential means to alleviate some of the loss of performances under hot conditions. However, a better knowledge of the effects of heat exposure on amino acid metabolism is first necessary to design adequate diets. Indeed, in broilers, the better resistance of lean genotypes suggests that protein metabolism might be the key factor to improve performance under hot conditions.

Dietary protein or amino acid supplementations would be beneficial. However, whereas most of the knowledge in amino acid nutrition has been done under thermoneutral conditions, few studies have looked at the requirements under hot conditions. Ideal amino acid balance thus appears to depend on the ambient temperature.

Finally, feed digestibility particularly protein and amino acid intestinal absorptions which were lowered under hot conditions should also be improved under hot conditions to avoid further imbalances. In that respect, use of in-diet enzyme supplementations might reduce disturbances in feed transit, endogenous enzyme activities and absorption mechanisms.

Finally, vitamin E supplementation would also be able to reduce stress conditions in heat exposed birds, by protecting the cell membranes of metabolically active organs such a sthe liver.

Indeed, in heat stressed laying hens an extra dietary vitamin E supplementation helped to sustain performance by restoring the capacity of the hepatocyte to export the vitellogenin, main precursor of the yolk. ■

References are available from the authors on request.