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The Strategic Application of Electrolyte Balance to Minimize Heat Stress in Broilers

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ABSTRACT

Several physiological and metabolic changes are triggered in broilers submitted to high environmental temperatures, resulting in performance losses. Feed formulation manipulation of the dietary electrolyte balance may be applied to reduce the negative impact of heat stress on broiler performance. This experiment was carried out to evaluate the effect of the manipulations of dietary electrolytes by combining changes in the electrolyte (Na^++K^+–Cl^-) balance (EB) and in the [(K^++Cl^-)/Na^+] ratio (ER) in broiler feeds. In total, 1575 male broilers between 21 and 46 days old were allotted to 15 treatments in a 5x3 factorial arrangement, consisting of five diets with different EB/ER combinations (150/3, 250/2, 250/3, 250/4, and 350/3). Birds were submitted to heat stress at 25 or 35 days old. Live performance, mortality rate, and carcass traits were evaluated. The strategic formulation of diets with different EB and ER improves live performance and minimize the effect of heat stress on broilers. Under thermoneutral conditions, an EB of 250 mEq/kg and an ER of 3 are recommended, whereas under heat stress, and EB of 350 mEq/kg and an ER of 3 should be applied.

INTRODUCTION

Broiler susceptibility to heat stress increase as air relative humidity and environmental temperature values exceed the thermal comfort zone (16-23ºC and 50-70%) (Tinoco, 1998), making it difficult for birds to dissipate heat. Consequently, their body temperature increase, negatively affecting their performance.

The addition of salts to the drinking water or to the feed is frequently employed in broiler production to reduce losses caused by heat stress. The main salts used are potassium chloride (KCl) and sodium bicarbonate ($NaHCO_3$) (Cahaner & Leenstra, 1992; Yalçin *et al*., 2001).

The minerals K^+, Na^+ and Cl^-, in particular, play essential roles in metabolism due to their participation in the osmotic balance, in the acid-base balance, and in the integrity of mechanisms that regulate the transport of substances across the cell membranes. Imbalances among those minerals have a direct effect on acid-base balance, affecting many metabolic functions, and therefore, broiler performance (Judice *et al*., 2002).

The environment and the diet influence the acid-base balance. Maintaining this balance is essential to improve the performance of broilers reared under high temperatures and to overcome the damaging effects of respiratory alkalosis produced by heat stress (Teeter & Belay, 1996).

Previously, only the acid-base balance (K^+, Na^+ and Cl^-) minimum requirements for each rearing phase was previously considered in diet formulation (NRC, 1994), However, according to Mongin (1981), the proportions (difference and ratio) among those minerals should be adjusted to provide better electrolyte balance with the aim of maintaining physiological acid-base homeostasis, and thereby, optimal growth performance (Gezen *et al*., 2005).

Mongin (1981) also emphasizes that diets should contain not only an adequate electrolyte balance, given by the difference (Na^{+}+K^{+}–Cl^{-}), but also adequate electrolyte ratio [(K^{+}+Cl^{-})/Na^{+}]. Therefore, the adequate ratio between K^{+}, Na^{+} and Cl^{-} needs to be considered in addition to the calculation of the difference between the total concentration of anions and cations (Talbolt, 1978).

The present experiment was carried out to experiment was carried out to evaluate the effect of the manipulations of dietary electrolyte balance based on combinations of different electrolyte balances and electrolyte ratios on the performance, mortality, and carcass traits of broilers submitted to heat stress.

MATERIAL AND METHODS

The experiment was carried out at the Animal Science Experimental Sector of the School of Veterinary Medicine of Universidade Estadual Paulista (UNESP), Araçatuba campus, state of São Paulo, Brazil. In total, 1575 male broilers belonging to the same commercial genetic strain, were evaluated between 21 and 46 days of age.

Birds were housed in a masonry broiler house (7.85 x 45.70m) built in the East-West direction, equipped with an adiabatic evaporative cooling system and negative-pressure ventilation, and covered with special tiles made of insulating material (expanded polystyrene) placed under reflecting metal plates. Birds were distributed in floor pens (1.4x3.0m) with wood-shavings litter, and equipped with automatic feeders and drinkers. Each pen was considered as an experimental unit.

At 21 days of age, chicks were weighed and randomly distributed to the pens, which housed 35 birds each. A lighting program of 18 hours of light (12 hours of natural light + six hours of artificial light) was applied. Birds were fed with five diets consistingwith ofdifferent electrolyte balances, inaccording to accordance with the subsequent treatments, and keptmaintained under in thermoneutral conditions.

Treatments consisted of diets containing five different electrolyte balances, derived from the EB/ER combinations of 150/3, 250/2, 250/3, 250/4, and 350/4, shown in Table 1, and thermal environments (thermoneutral conditions or acute heat stress). Acute heat stress was or not applied when birds were 25 or 35 days old, and fed the same diet of other treatments.

Table 1 – Electrolyte balance (EB) and electrolyte ratio (ER) combinations applied in the experimental diets.

ER[1]	EB[2]		
	150	250	350
2:1		X	
3:1	X	X	X
4:1		X	

1 – Electrolyte ratio
2 – Electrolyte balance

Evaluations were carried out when birds were 33 (day 33) and 46 (day 46) days old. On day 33, data were analyzed according to completely randomized experimental design in a 5x2 factorial arrangement (five EB/ER combinations x two environmental temperatures), totaling 10 treatments (Table 2), with six replicates of birds maintained under thermoneutral conditions and three replicates of birds submitted to heat stress on day 25. Each replicate contained 35 birds. On day 46, responses were analyzed according to completely randomized experimental design in a 5x3 factorial arrangement was applied, totaling 15 treatments (Table 2), with three replicates of 35 birds each. The model of the analysis of variance is presented in Table 3.

Table 2 – Treatments according to electrolyte balance and ratio combinations and thermal environment.

Treatment	Diet (EB*/ER**)	Evaluation day 33	Evaluation day 46
1	150/3	No heat stress	No heat stress
2	250/2	No heat stress	No heat stress
3	250/3	No heat stress	No heat stress
4	250/4	No heat stress	No heat stress
5	350/3	No heat stress	No heat stress
6	150/3	Heat stress d 25	Heat stress d 25
7	250/2	Heat stress d 25	Heat stress d 25
8	250/3	Heat stress d 25	Heat stress d 25
9	250/4	Heat stress d 25	Heat stress d 25
10	350/3	Heat stress d 25	Heat stress d 25
11	150/3	---	Heat stress d 35
12	250/2	---	Heat stress d 35
13	250/3	---	Heat stress d 35
14	250/4	---	Heat stress d 35
15	350/3	---	Heat stress d 35

* Electrolyte ratio; ** Electrolyte balance

The experimental diets were based on corn, soybean meal, corn gluten, soybean oil, vitamin and mineral supplement, calcitic limestone, and dicalcium phosphate, and formulated according to the recommendations of Rostagno *et al*.(2005) (Table 4). Salt (NaCl, $NaHCO_3$, K_2SO_4) levels were included to supply minimum K^+, Na^+ and Cl^- requirements and adjusted according to the electrolyte combinations of each experimental diet. Feed was manufactured in the experimental feed mill of the Animal Science Experimental Sector, UNESP.

Table 3 – Model of the analysis of variance of the experiment.

Sources of variation	Degrees of freedom	
	Day 33	Day 46
Total	44	44
Diet (EB*/ER**)	4	4
Heat stress (HS)	1	2
Diet x HS	4	8
Error	35	30

* Electrolyte ratio; ** Electrolyte balance

Table 4 – Ingredients and calculated composition of the diets fed to the broilers during the grower and finisher phases.

		Electrolyte combination (EB/ER)*									
		Grower (21-33 days)					Finisher diet (33-46 days)				
Ingredients		150/3	250/2	250/3	250/4	350/3	150/3	250/2	250/3	250/4	350/3
Corn	%	61.31	56.64	54.16	55.73	52.32	63.65	60.78	58.14	57.62	56.25
Corn gluten meal 60%	%	4.22	0.00	0.00	0.00	0.00	2.21	0.00	0.00	0.00	0.00
Soybean oil	%	3.35	5.26	5.60	5.45	6.23	4.71	5.82	6.27	6.45	6.91
Soybean meal 45%	%	26.86	33.56	36.16	34.23	36.48	25.91	29.64	32.04	32.13	32.36
Dicalcium phosphate	%	1.70	1.69	1.67	1.69	1.68	1.44	1.44	1.43	1.43	1.43
Salt	%	0.51	0.42	0.23	0.48	0.21	0.49	0.15	0.17	0.39	0.17
L-lysine	%	0.33	0.17	0.08	0.15	0.08	0.27	0.18	0.10	0.10	0.10
DL-methionine	%	0.20	0.24	0.22	0.23	0.22	0.19	0.21	0.19	0.19	0.19
L-threonine	%	0.05	0.03	0.00	0.03	0.00	0.04	0.03	0.00	0.00	0.00
Calcitic limestone	%	0.88	0.85	0.84	0.85	0.84	0.79	0.78	0.77	0.77	0.77
Sodium bicarbonate	%	0.00	0.54	0.36	0.00	0.59	0.00	0.69	0.41	0.07	0.62
Potassium sulfate	%	0.00	0.00	0.07	0.58	0.76	0.00	0.00	0.18	0.56	0.90
Supplement - grower**	%	0.60	0.60	0.60	0.60	0.60	0.00	0.00	0.00	0.00	0.00
Supplement - finisher***	%	0.00	0.00	0.00	0.00	0.00	0.30	0.30	0.30	0.30	0.30
Metab. energy	kcal/kg	3150	3150	3150	3150	3150	3250	3250	3250	3250	3250
Crude protein	%	20.25	20.21	21.07	20.41	21.05	18.72	18.76	19.53	19.52	19.51
Calcium	%	0.84	0.84	0.84	0.84	0.84	0.74	0.74	0.74	0.74	0.74
Available P	%	0.42	0.42	0.42	0.42	0.42	0.37	0.37	0.37	0.37	0.37
Potassium	%	0.67	0.77	0.84	1.02	1.13	0.66	0.71	0.82	0.98	1.12
Sodium	%	0.22	0.33	0.21	0.21	0.26	0.21	0.26	0.20	0.19	0.25
Chlorine	%	0.41	0.33	0.20	0.36	0.18	0.39	0.17	0.17	0.30	0.17
Linoleic acid	%	3.16	4.10	4.25	4.19	4.56	3.91	4.45	4.66	4.75	4.97
Dig. Lysine	%	1.10	1.10	1.10	1.10	1.10	1.02	1.02	1.02	1.02	1.02
Dig. methionine	%	0.50	0.52	0.51	0.51	0.51	0.46	0.47	0.46	0.46	0.46
Dig.Methionine + cystine	%	0.79	0.79	0.79	0.79	0.79	0.73	0.73	0.73	0.73	0.73
EB = Na+K-Cl	kcal/kg	150	250	250	250	350	150	250	250	250	350
ER = (K+Cl)/Na		3:1	2:1	3:1	4:1	3:1	3:1	2:1	3:1	4:1	3:1

* EB – electrolyte balance; ER – electrolyte ratio.

** Vitamin and mineral supplement – composition per kg product: Vitamin A, 1.335.000IU; vitamin D3, 300.000IU; vitamin E, 2.000mg; vitamin K3, 335mg; vitamin B1, 167mg; vitamin B2, 670mg; vitamin B6, 170mg; vitamin B12, 1.670mcg; folic acid, 67mg; biotin, 7mg; niacin, 4.670mg; calcium pantothenate, 1.870mg; copper, 1.000mg; cobalt, 17mg; iodine, 170mg; iron, 8.335mg; manganese, 10.835mg; zinc, 7.500mg; selenium, 35mg; choline chloride 50%, 83.340mg; methionine, 235.000mg; coccidiostat, 10.000mg; growth promoter, 10.000mg; antioxidant, 2.000mg. Inclusion of 6kg of the supplement per tonne of feed.

*** Vitamin and mineral supplement – composition per kg product: Vitamin A, 1.670.000IU; vitamin D3, 335.000IU; vitamin E, 2.335mg; vitamin K3, 400mg; vitamin B1, 100mg; vitamin B2, 800mg; vitamin B6, 200mg; vitamin B12, 2.000mcg; folic acid, 67mg; biotin, 7mg; niacin, 5.670mg; calcium pantothenate, 2.000mg; copper, 2.000mg; cobalt, 27mg; iodine, 270mg; iron, 16.670mg; manganese, 17.335mg; zinc, 12.000mg; selenium, 70mg; choline chloride 50%, 100.000mg; methionine, 235.000mg; antioxidant, 2.000mg. Inclusion of 3kg of the supplement per tonne of feed.

Birds were submitted, according to treatment (33 or 46 days of age), to acute heat stress (Gonzalez-Esquerra & Leeson, 2005), mimicking commercial production conditions when there is power outage, and consequently cooling and evaporation systems stop working. Under these conditions, birds suffer from heat stress due to high environmental temperature and air relative humidity, in addition to high ammonia concentrations. Temperature was maintained between 35-38°C for 4h on days 25 and 35by covering the pens corresponding to the heat-stress treatment with a transparent plastic canvas and providing a heat source (porcelain cones with a 600w resistance) controlled by a thermostat. Birds were offered feed and cold water *ad libitum* during the entire experimental period, including the days when heat-stress was applied.

The following performance parameters were evaluated on days 33 and 46: body weight gain (g/bird/period), feed intake (g/bird/period), feed conversion ratio, and mortality rate. Feed conversion ratio was calculating by dividing feed intake by weight gain. All dead birds were weighed and their body weight used to correct feed conversion ratio. During the heat-stress periods, mortality was recorded according to treatment, body weight, and age. Dead birds were disposed in a compost pile located in the experimental facilities.

The following micro-climatic conditions inside the broiler house and at the pens: air temperature (dry-bulb temperature), black globe temperature, air relative humidity, and air velocity. Average micro-climatic parameters inside the house were obtained by an automated weather station placed at the center of the house. Air temperature and relative humidity were detected by a sensor placed inside a weather-resistant shelter with reading ranges of -40 to 60°C for temperature and 0 to 100% for relative humidity. Air velocity was determined with the aid of an ultrasonic anemometer, with 0-60 $m.s^{-1}$ sensitivity and 0.01 $m.s^{-1}$ resolution. All records were managed and stored using a multi-channel data acquisition system (CR10, Campbell Scientific). Temperature and relative humidity were monitored using the Ibutton® in five pens (except for air velocity, which was measured in a single pen) among the birds in treatments not submitted to heat stress. In birds submitted to heat stress, those parameters were measured only on the heat stress days in five pens (one per electrolyte balance treatment).

Five birds per experimental unit (15 birds per treatment), with body weight close to the average of the respective replicate, were selected on day 46 for carcass yield evaluation. These birds were sacrificed, plucked, and eviscerated. The abdominal fat pad (adipose tissue around the bursa, proventriculus, gizzard, and cloaca) was removed and its weight calculated relative to broiler weight at sacrifice. The eviscerated carcass, with no head, feed, and neck, was weighed again to calculate carcass yield relative to live weight. The carcass was then cut up, and the yield of the bone-in parts (whole breast, legs (thighs and drumsticks), and wings) was calculated relative to carcass yield.

The obtained parts and the remaining carcass were ground, and sample was collected and freeze-dried for total lipid composition analysis. The lipid content of the carcass samples was determined by extraction in Soxhlet apparatus, using ethyl ether as solvent.

Data were submitted to analysis of variance to verify the effect of treatments, and then to analysis of regression to evaluate the effects of each supplementation level, according to the PROC GLM of SAS system (SAS Institute, 2000). Means were compared by the Student's t-test.

All parameters described in percentages were normalized for statistical analysis by transformation in arcsine $\sqrt{X/100}$.

RESULTS AND DISCUSSION

Maximum average environmental temperatures were 37.3 and 29.5°C on the first and second heat-stress days, respectively. The remaining of the house was under thermoneutral conditions (19°C – 62%).

Live weight, feed intake, and feed conversion ratio were influenced by heat stress. Birds submitted to heat stress both on day 25 and day 45 presented reduced live weight, increased feed intake, and worse feed conversion ratio (Table 5). These results are consistent with the observations of Plavnik & Yahav (1998), who reported progressive reduction of body weight, weight gain, feed intake, and feed efficiency of broilers submitted to high environmental temperatures. This worse performance may be explained by the fact that, in an attempt to adapt to heat stress, birds reduce their feed intake to try to reduce endogenous heat production (Teeter *et al.*, 1985). Bonnet *et al.*(1997) concluded that broilers submitted to heat stress gained 50% less weight than those maintained in thermoneutral conditions.

Most literature studies agree on the EB figure of 250 mEq/kg for broiler diets (Mongin, 1981; Johnson & Karunajeewa, 1985; Vieites *et al.*, 2004; Borges, 2006). However, only Mongin (1981) mentions electrolyte ratio requirements and recommends a value higher than 1 in broiler diets, but does not provide any precise figure. Therefore, further studies on this subject are needed (Borgatti *et al*., 2004).

In the present experiment, the diets with an EB of 250 mEq/kg resulted in better feed conversion ratio (Table 5). However, the results show that diet formulation should also take into account ER, because the broilers fed the experimental diet with 250 mEq/kg and an ER value of 3 presented better feed conversion ratio relative to those fed the other diets, both on days 33 and 46.

Because linear feed formulation does not allow the use of ratios, because division is unfeasible in the software, it was not possible to apply of the full concept of Mongin (1981), that is, to supply in the diet, simultaneously: 1- minimum Na^+, K^+ e Cl^- requirements, 2- EB of 250 mEq/kg, and 3- ER >1. This has probably limited the research on dietary electrolyte balance for many years. However, the recent publication of the PPFR spreadsheet (Garcia Neto, 2011), which applies a non-linear concept, allows formulation changes such as those applied in the present experiment, and therefore, to check for nutritional imbalances, as reported by Ravindran *et al*. (2008). Unbalanced ratios among K^+, Cl^-, and particularly Na^+, may limit the absorption of amino acids and other nutrients (Ravindran *et al*.,.2008). This problem may be circumvented by the application of the electrolyte combination (both EB and ER) concept, thereby preventing imbalances among electrolytes and their consequences on broiler growth.

The results of the present experiment show that broilers fed diets with adequate electrolyte balance were more tolerant to heat stress. The broilers submitted to acute heat stress at 25 and 35 days of age (±36°C for 4 h) and fed diets with an EB/ER of 350/3:1 dealt more efficiently with this extreme impact, as shown by their lower mortality rate (Table 6).

When broilers are submitted to acute heat stress, in addition to high temperature and high humidity, they are also exposed to high ammonia levels. The association of these three factors may have been the cause of the high mortality observed in this experiment, as it is difficult to separate their individual effects on bird survival. However, the mortality rate of the broilers fed a diet with the combination of an electrolyte balance of 350 mEq/kg and an electrolyte ratio of 3:1 was clearly lower, demonstrating that these birds were capable of maintaining their better acid-base homeostasis and suffered less changes caused by acute stress, including respiratory alkalosis.

The importance of supplying optimal Na+, K+ e Cl- levels in broiler diets is that, during heat stress, the competition between H+ e K+ in the renal tubules is reduced. During alkalosis, extracellular K+ enters the cell, consequently increasing the secretion of this ion in the renal tubule lumen. Under these conditions, H+ is exchanged by K+ in the renal tubule. The increasing K+ secretion reduces its blood concentration, which causes circulation disorders in broilers, leading to death.

Table 5 – Effects of different combination of electrolyte balance ($Na^++K^+–Cl^-$) and electrolyte ratio [$(K^++Cl^-)/Na^+$] in the diet of broilers submitted to acute heat stress with 25 or 35 days old on their weight gain (WG), feed intake (FI), and feed conversion ratio (FCR) between 1 and 46 days of age.

Factors**	FI	WG	FCR	FI	WG	FCR
Diet (EB/ER)		33 days			46 days	
150/3	3027.4	1937.4	1.62b	5230.7b	3491.7	1.76ab
250/2	3062.6	2015.8	1.58ab	5326.0ab	3553.2	1.82b
250/3	3044.9	2024.4	1.55a	5447.4ab	3546.1	1.76a
250/4	3032.3	2001.7	1.57a	5351.7ab	3423.0	1.78ab
350/3	3079.8	2012.1	1.58ab	5560.8a	3537.3	1.78ab
Heat stress						
No	2026.0a	3093.5a	1.57	3660.7a	5784.5a	1.78ab
25 days	1942.9b	2961.1b	1.60	3464.7b	5272.6b	1.76b
35 days	------	-----	----	3394.9b	5092.8b	1.81a
Feed (F)	...	...	...	...	...	...
Heat stress (S)	...	...	...	...	...	...
F*S	...	...	...	...	...	...
CV (%)	....	...	...	...	...	...

*EB = electrolyte balance (mEq/kg); ER = electrolyte ratio.

** Non-significant interaction among factors (electrolyte combination x heat stress).

a-c Means followed by the same letter in the same column, within each factor, are not different by the Student's t-test at 5% probability level.

Table 6 – Effects of the combination of electrolyte balance (Na++K+-Cl-) with electrolyte ratio [(K++Cl-)/Na+] in the diet of broilers submitted to acute heat stress with 25 or 35 days old on the daily intake (g) of potassium (K), sodium (Na), and chorine (Cl), and on the mortality rate of 1- to 46-d-old male broilers.

	K	Na	Cl	K	Na*		Cl*		K	Na	Cl	Mortality due to acute heat stress			
	1-21 days of age			1-33 days of age					1-46 days of age			On day 25		On day 36	
Diet (EB/ER)					Without	With	Without	With				Without	With	Without	With
150/3	0.614e	0.213c	0.435a	0.999e	0.342c	0.301C	0.637a	0.561a	1.118d	0.356b	0.661a	0.00d	58.42a	0.54c	66.38ab
250/2	0.713d	0.339a	0.391b	1.171d	0.521a	0.464A	0.521c	0.464B	1.236d	0.453a	0.296c	0.00d	25.55b	0.00c	75.353a
250/3	0.754c	0.193d	0.202d	1.288c	0.327d	0.313C	0.311d	0.298C	1.515c	0.370b	0.314c	0.00d	8.33bc	0.00c	70.65a
250/4	0.905b	0.191d	0.348c	1.554b	0.324d	0.312C	0.556b	0.535a	1.748b	0.339b	0.535b	0.00d	8.65b	0.52c	71.55a
350/3	0.992a	0.228b	0.167e	1.736a	0.403b	0.392B	0.279e	0.271C	2.138a	0.477a	0.324c	0.00d	1.04cd	0.00c	53.53b
heat stress															
Without				1.378a					1.770a	0.456a	0.493a				
25 days				1.294b					1.549b	0.396b	0.412b				
36 days				_					1.335c	0.345c	0.374b				
	Probability > F														
Feed (F)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001		<0.0001		<0.0001	<0.0001	<0.0001	0.0004		0.2076	
Heat stress (S)				<0.0001	<0.0001		<0.0001		<0.0001	<0.0001	0.0002	<0.0001		<0.0001	
F*HS				0.1615	0.0025		0.0025		0.2410	0.4803	0.1519	0.0004		0.2172	
CV (%)	4.60	5.77	6.54	3.19	3.49		4.16		10.86	13.09	16.22	203.25		44.37	

a-e Means followed by the same letter in the same column, within each factor, are not different by the Student's t-test at 5% probability level.* = interaction between dietary electrolyte combination (EB/ER) and acute heat stress.

Therefore, during heat stress, that ion is essential for broiler survival (Macari *et al.*, 2002), as shown by the lower mortality rate of broilers fed the diet with higher K+ levels.

Broilers exposed to heat stress usually present higher carcass yield because of the slower viscera and feather development (Ain Baziz *et al.*, 1996). However, this higher carcass yield does not compensate for the lower weight gain of broilers reared in hot environments. The results of the present experiment are consistent with literature reports of higher leg yield and lower breast yield of broilers exposed to heat stress (Temim *et al.*,

Table 7 – Effects of the combination of electrolyte balance (Na++K+-Cl-) with electrolyte ratio [(K++Cl-)/Na+] in the diet of broilers submitted to acute heat stress with 25 or 35 days old on slaughter weight and carcass and parts (breast, leg, wing, abdominal fat) of 46-d-old male broilers.

Factors	Average slaughter weight (g)						Parts yield (carcass %)									
Diet (EB/ER)	Live weight	N	Carcass**	N	Carcass yield (%) n	N	Breast	N	Leg	N	Wing	N	Abdominal fat	N	Total fat***	N
150/3	3406.67 C	45	2451.09 B	45	71.84 AB	45	36.51 A	45	29.70 A	45	10.42 A	45	2.36 A	45	31.67 B	38
250/2	3530.00 ABC	45	2517.24 BA	45	71.31 B	45	36.89 A	45	29.49 A	45	10.25 AB	45	2.20 AB	45	31.61 B	33
250/3	3602.22 A	45	2601.33 A	45	72.21 A	45	37.40 A	45	29.71 A	45	9.99 B	45	1.98 B	45	34.71 AB	41
250/4	3434.13 BC	46	2464.55B	46	71.73 AB	46	36.78 A	46	30.05 A	46	10.05 B	46	2.14 AB	46	35.12 A	37
350/3	3580.67 AB	45	2581.51 A	45	72.07 AB	45	36.75 A	45	29.82 A	45	10.14 B	45	2.18 AB	45	33.13 AB	39
Heat stress																
No	3629.33 A	75	2623.84 A	75	72.29 A	75	37.21 A	75	29.65 A	75	10.08 B	75	2.17 A	75	31.91 B	64
25 days	3449.20 B	75	2479.11 B	75	71.85 BA	75	36.37 B	75	29.68 A	75	10.37 A	75	2.20 A	75	30.84 B	62
36 days	3453.42 B	76	2466.46 B	76	71.36 B	76	37.02 BA	76	29.94 A	76	10.06 B	76	2.15 A	76	37.21 A	62
Probabilidade > F																
Feed (F)	0.0430		0.0388		0.3078		0.4832		0.5050		0.0524		0.1427		0.1669	
Heat stress (S)	0.0034		0.0009		0.0279		0.0731		0.4380		0.0195		0.9111		<0.0001	
F*HS	0.4443		0.5102		0.3594		0.1006		0.6381		0.4380		0.6042		0.1323	
CV (%)	10.43		11.10		2.96		6.38		5.07		7.29		32.01		21.86	

† **EB** (electrolyte balance, mEq/kg)=(Na/22.99 + K/39.10 - Cl/35.45)*1000 e ER= [(K/39.10 + Cl/35.45)/(Na/22.99)]; †† No head, feet, and neck; ††† On dry-matter basis; A-C e Means followed by the same letter in the same column, within each factor, are not different by the Student's t-test at 5% probability level; n= number of samples.

1999; Temim *et al*., 2000b; Faria Filho, 2003) These findings are associated with the different metabolism of each specific tissue: the breast present glycolytic metabolism, whereas the leg muscles present oxidative metabolism (Ain Baziz *et al*., 1996).

The broilers exposed to heat stress on day 36 presented higher carcass fat content between 22 and 46 days of age compared with the broilers submitted to heat stress on day 25 and with those not exposed to heat stress. The higher fat content and lower crude protein content of the broilers submitted to heat stress (Cheng *et al*., 1997a,b) results from their lower basal metabolism and physical activity (Ain Baziz *et al*., 1996).

The findings of the present experiment indicate that ER may potentially improve broiler performance and carcass quality, provided EB is concurrently adjusted, particularly under heat stress conditions (Table 7). The birds fed the diet with an EB of 250 mEq/kg and an ER of 3 were heavier at slaughter and presented heavier carcasses and lower abdominal fat content compared with those submitted to the other treatments. This is an important factor to be considered because consumers value heavy and lean chicken carcasses.

Considering that broilers exposed to high temperatures tend to habituate to these conditions, and that those temperatures negatively affect their productivity (Yahav & McMurtry, 2001), it is essential to supply them a nutritionally adequate diet that provides support to prevent disorders caused by heat stress. For instance, there may be reduced weight gain, which may be subsequently compensated (Yahav & McMurtry, 2001), and directed for body fat deposition and visceral growth or for protein accretion (Zhan *et al*., 2007; Rutz, 2011).

CONCLUSIONS

The strategic formulation considering the precise electrolyte balance, including EB and ER, improves broiler performance and may prevent the negative effects of heat stress.

Under thermoneutral conditions, an EB of 250 mEq/kg and an ER of 3 are recommended, whereas under heat stress, an EB of 350 mEq/kg and an ER of 3 to obtain better performance and livability.

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