Dietary Electrolyte Balance for Broiler Chickens Under Moderately High Ambient Temperatures and Relative Humidities[1]

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ABSTRACT Cobb male broiler chicks (1,000) on new litter were used to evaluate effects of dietary electrolyte balance [DEB; Na+K–Cl, milliequivalents (mEq) per kilogram] under tropical summer conditions. Corn-soybean meal-based mash diets had salt (NaCl) alone or in combination with one or more supplements: sodium bicarbonate ($NaHCO_3$), ammonium chloride (NH_4Cl), or potassium bicarbonate ($KHCO_3$). A completely randomized design, with five starter and grower feed treatments (control: 145, then 130 mEq/kg; or 0, 120, 240, or 360 mEq/kg throughout) and four replicate pens (1.5 × 3.2 m) per treatment (50 chicks per pen), was used. Diets were analyzed for Na, K, and Cl for confirmation. There were no significant ($P < 0.05$) effects of treatments on mortality or processing parameters. Water intake increased linearly with increasing DEB, giving higher litter moistures and lower rectal temperatures. Blood HCO_3 and pH increased with the highest DEB (360 mEq/kg) causing respiratory alkalosis. The DEB of 240 mEg/kg gave best weight gain and feed conversion ratio, and ideal DEB predicted by regression analyses were 186 and 197 mEq/kg from 0 to 21 d of age and 236 and 207 mEq/kg of feed from 0 to 42 d, respectively. These DEB corresponded to estimated (interpolated) values in predicted optimal 186 to 197 mEq/kg starter of Na 0.38 to 0.40% and Cl 0.405 to 0.39% (K = 0.52%), in 207 to 236 mEq/kg starter, Na 0.409 to 0.445% and Cl 0.326 to 0.372% Cl (K = 0.52%), and in grower Na 0.41 to 0.445%, Cl 0.315 to 0.267% (K = 0.47%).

(*Key words*: broiler, chloride, dietary electrolyte balance, heat stress, sodium)

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INTRODUCTION

The addition of electrolyte salts to broiler chicken diets has been recommended as a way to minimize the deleterious effects of heat stress (Borges, 1997). Intestinal and renal homeostatic regulation attempt to maintain normal body content of electrolytes, and this is generally affected by higher intestinal absorption of monovalent ions than divalent ions within the electrolyte supplements (Teeter, 1997). The "strong ions" Na^+, K^+, and Cl^- have the greatest impact on acid-base balance or pH of blood and tissues. However, it is important to have the proper dietary ranges and ratios of these monovalent minerals (cations or + charged ions, and anions or − charged ions), without deficiency or toxicity, to meet poultry nutritional demands and achieve the best performance. Acids produced by metabolism ($_{endogenous}H^+$) also contribute to the acid-base balance.

The following equation describes situations when the bird has a constant acid-base balance, without either acid or base excess or deficiency:

$$_{ingested}(\text{anions} - \text{cations}) + {}_{endogenous}H^+ = {}_{excreted}(\text{anions} - \text{cations}).$$

According to Mongin (1981) the physiological acid-base altering effect of dietary $Na^+ + K^+ - Cl^-$ (mEq/kg) is equal to the difference in excreted anions and cations ($_{excreted}$anions − cations) plus the production of endogenous acid (endogenous H^+), plus base concentration in extracellular fluids (BE_{ecf}), sometimes referred to as base excess or alkaline reserves (with the "ecf" referring to "extra cellular fluid"). The optimal dietary electrolyte intake in terms of physiological acid-base balance can minimize the value of BE_{ecf} to zero or near zero. This concept may be written as follows:

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Abbreviation Key: DEB = dietary electrolyte balance; mEq = milliequivalents.

$$_{\text{ingested}}(\text{anions} - \text{cations}) = {}_{\text{excreted}}(\text{anions} - \text{cations}) + {}_{\text{endogenous}}H^+ + BE_{\text{ecf}}.$$

The strong ions Na, K, and Cl are important monvalent minerals in broiler chicken feed formulation, with birds requiring an optimal DEB of around 250 mEq ($Na^+ + K^+ - Cl^-$)/kg of feed. Assuming that the intake of other minerals is constant, then:

$$_{\text{ingested}}(Na^+ + K^+ - Cl^-) \simeq {}_{\text{excreted}}(\text{anions} - \text{cations}) + {}_{\text{endogenous}}H^+ + BE_{\text{ecf}}.$$

Based upon the above mentioned assumptions, a trial was carried out to evaluate the effects of various DEB in broiler diets on live performance, water intake, litter mositure, rectal temperature, and blood gases during summer conditions.

MATERIALS AND METHODS

A total of 1,000 male Cobb chicks were distributed in pens (1.5 m × 3.2 m) with clean wood shavings in a brick house with management and vaccination schedule similar to those used in commercial poultry operations. The chicks were given corn-soybean meal-based mash diets ad libitum (Table 1). Nutrient requirements met or exceeded those suggested by the National Research Council (1994) for broiler chickens except for protein, metabolizable energy, methionine, and methionine plus cystine, which were lower.

In order to isolate the effect of electrolyte balance, four feeds (0, 120, 240, 360 DEB mEq/kg) were formulated in such a way as to have the same percentages of corn, soybean meal, oil, phosphate, limestone, vitamins, trace minerals, monensin, and bacitracin-md, with electrolyte salts being added by substitution for builders' sand according to experimental design. Monensin is an ionophore coccidiostat involved in sodium and potassium transport across cell walls, including those of coccidia. This is mentioned because the requirement for dietary electrolytes could conceivably be affected by the presence or absence of the ionophore although that specific question was not addressed in this research. The regular control diets (145 starter and 130 grower DEB mEq/kg), having only salt as the electrolyte supplement, contained no builders' sand and served as the standard. The ingredients and feeds were analyzed for their protein, calcium, phosphorus, and monovalent mineral (Na, K, and Cl) values to use in feed formulation (ingredients) and to validate that analyzed and calculated values were similar (complete feeds). Water samples were also analyzed for their monovalent mineral contents. The Na and K were determined by flame spectrophotometry (AOAC, 1990), and Cl was analyzed by titration with $AgNO_3$ (Lacroix et al., 1970) and by the Labtest (1996) procedure.

Weight gain, feed and water intake, feed conversion ratio, water intake:feed intake ratio, mortality, and litter moisture were evaluated during 0 to 21 d and 0 to 42 d of age. Weight gain was determined by differences in weight between inital and 21 d, 21 and 42 d, and initial and 42 d of age, respectively. Feed intake was calculated from the difference between supplied feed and feed left in each pen. Feed weighing was performed on the same dates the birds were weighed. Feed conversion was calculated from the ratio between total feed intake and weight gain in the period in each pen and was adjusted for mortality (that is, weight gain and feed intake of birds that died were included).

Bell waterers were individually equipped with an independent water supply system made up of a hose and a 5-L container as described by Borges (1997), with water temperature and pH data being collected twice daily between 0600 and 0700 and 1300 and 1400, corresponding to the times of the day when ambient temperatures were the coolest and the warmest, respectively. Maximum and minimum average ambient temperature and relative humidity were monitored on a daily basis.

Water intake per bird was calculated on a weekly basis from the difference between the amount of water supplied and the water that was left by the end of the week, multiplied by the evaporation rate factor, and divided by the number of birds. To measure evaporation, four empty pens were equipped with waterers connected to containers as described above. Evaporation was calculated from the difference in volume between the beginning and end of the period. The water intake:feed intake ratio was calculated by dividing total water intake per bird by total feed intake per bird.

Litter moisture was evaluated weekly. For each replicate pen, three samples of around 500 g of litter were collected at random locations following equal distances with later homogeinization to make a single sample (100 to 200 g) per pen. Dry matter analysis was performed by oven drying using the forced ventilation method at 55 ± 5 C for 72 h and evaluation by weight difference.

Rectal temperature was monitored on a daily basis starting when the birds were 12 d of age. Two birds were identified per pen for temperature measurement through rectal probe in the morning (0600 to 0730) and in the afternoon (1300 to 1400), corresponding to the coolest and warmest times of the day, respectively.

Mortality percent was calculated by dividing the number of birds that died in the period by the initial number of birds in the pen and multiplying by 100. On slaughter day, birds fasted were for 6 h. Then two birds per pen were weighed live, slaughtered by jugular vein slit (exsanquination), defeathered, eviscerated, weighed dressed, and the carcasses were cut for an evaluation of carcass and parts yield and abdominal fat.

Venous blood samples (1 mL/bird) were collected by brachial vein puncture using sterilized needle in two birds per pen. Whole-blood gas analyses were performed immediately after blood collection using the i-STAT Portable Clinical Analyzer[4] and sensors. The trial design was com-

[4]i-STAT Corporation, 104 Windsor Center Drive, East Windsor, NJ.

TABLE 1. Composition and calculated analyses of experimental diets for the starter and grower phases

	Starter diets (0 to 21 d)					Grower diets (21 to 42 d)				
Ingredients	145[1]	0	120	240	360	130[1]	0	120	240	360
	(Na + K − Cl, mEq/kg)					(Na + K − Cl, mEq/kg)				
Corn (maize), %	59.27	54.81	54.81	54.81	54.81	64.22	59.51	59.51	59.51	59.51
Soybean meal, %	36.09	36.92	36.92	36.92	36.92	29.68	30.56	30.56	30.56	30.56
Soybean oil, %	0.58	2.10	2.10	2.10	2.10	2.60	4.20	4.20	4.20	4.20
Dicalcium phosphate, %	1.95	1.96	1.96	1.96	1.96	1.40	1.42	1.42	1.42	1.42
Calcitic limestone, %	1.13	1.11	1.11	1.11	1.11	1.25	1.24	1.24	1.24	1.24
DL-Methionine, %	0.07	0.07	0.07	0.07	0.07	0.05	0.05	0.05	0.05	0.05
NaCl, %	0.39	0.23	0.24	0.02	0.15	0.28	0.25	0.48	0.04	0.07
$NaHCO_3$, %	—	0.08	0.62	1.49	1.86	—	0.05	0.27	1.46	1.99
$KHCO_3$, %	—	0.00	0.00	0.00	0.32	—	0.00	0.00	0.00	0.30
NH_4Cl, %	—	0.80	0.50	0.40	0.16	—	0.70	0.20	0.30	0.15
Vitamin and mineral premixes,[2] %	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
BHT,[3] %	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Builders' sand, %	—	1.40	1.15	0.60	0.02	—	1.50	1.55	0.70	0.00
Total, %	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis										
AME, kcal/kg	2,900	2,900	2,900	2,900	2,900	3,100	3,100	3,100	3,100	3,100
Crude protein, %	21.50	21.50	21.50	21.50	21.50	19.00	19.00	19.00	19.00	19.00
Calcium, %	1.00	1.00	1.00	1.00	1.00	0.90	0.90	0.90	0.90	0.90
Available phosphorus, %	0.45	0.45	0.45	0.45	0.45	0.35	0.35	0.35	0.35	0.35
Methionine, %	0.49	0.49	0.49	0.49	0.49	0.43	0.43	0.43	0.43	0.43
Methionine + cystine, %	0.69	0.69	0.69	0.69	0.69	0.62	0.67	0.67	0.67	0.67
Lysine, %	1.17	1.19	1.19	1.19	1.19	1.00	1.01	1.01	1.01	1.01
Sodium, %	0.20	0.15	0.30	0.45	0.60	0.15	0.30	0.15	0.45	0.60
Chloride, %	0.28	0.71	0.51	0.32	0.24	0.21	0.46	0.65	0.26	0.18
Bicarbonate, %	—	0.06	0.45	1.07	1.53	—	0.04	0.19	1.05	1.61
Potassium, %	0.53	0.52	0.52	0.52	0.64	0.48	0.47	0.47	0.47	0.58

[1]Control treatment; National Research Council (1994) Na and Cl minimums (regular diets containing salt).

[2]Vitamin supplements contributed per tonne (1,000 kg) of complete feed: starter, vitamin A, 2,650,000 IU; vitamin D_3, 500,000 IU; vitamin E, 2,400 mg; menadione, 400 mg; thiamine, 200 mg; riboflavin, 2,000 mg; vitamin B_{12}, 3,500 mcg; pantothenic acid, 2,200 mg; nicotinic acid, 8,500 mg; pyridoxine, 400 mg; folic acid, 200 mg; biotin, 20 mg; choline, 150 g; monensin, 110 g; bacitracin-md, 40 g; DL-Methionine, 300 g; antioxidant, 20 g; carrier, 1,000 g. Grower feed: vitamin A, 2,300,000 IU; vitamin D_3, 400,000 IU; vitamin E, 1,800 mg; menadione, 300 mg; thiamine, 150 mg; riboflavin, 1,400 mg; vitamin B_{12}, 3,500 mcg; pantothenic acid, 2,000 mg; nicotinic acid, 7,000 mg; pyridoxine, 250 mg; folic acid, 150 mg; biotin, 20 mg; choline, 125 g; monensin, 125 g; bacitracin-md, 30 g; ethoxyquin, 20 g; DL-Methionine, 275 g; carrier, 1,000 g. Trace mineral supplement provided per tonne of complete feed: iron, 35,000 mg; copper, 50,000 mg; manganese, 35,000 mg; zinc, 30,000 mg; iodine, 600 mg; selenium, 90 mg; diluent, 1,000 g.

[3]BHT = butylated hydroxytoluene, an antioxidant.

pletely randomized with five treatments and four replicate pens per treatment (control: 145, then 130 mEq/kg feed; or 0, 120, 240, or 360 mEq/kg throughout) with 50 birds per experimental unit. The desired target "Mongin number" or DEB was obtained by adding NaCl alone or in combination with one or more supplements ($NaHCO_3$, $KHCO_3$, NH_4Cl) to the feed, varying Na and Cl in order to achieve the desired DEBs between 0 and 240 and Na, K, and Cl to reach 360 mEq/kg. The National Research Council (1994) specifications for Na and Cl were used in the DEB 145 and 130 control diets. The results were subjected to regression analysis and to Tukey's HSD Test with 5% probability, using the mathematical model proposed by Banzatto and Kronka (1992).

RESULTS AND DISCUSSION

Air Temperature, Relative Humidity, and Water Temperature

The minimum and maximum average ambient temperatures and relative humidities were 23 and 31 C and 75.5%, respectively, with a peak of 34 C and a minimum of 19 C, thus, proving the exposure of the birds to heat stress. Water temperature and water intake have been shown to be important factors in body temperature regulation in birds, particularly in acute heat challenges. Water temperature varied between 22.5 and 26.9 C and pH from 7.78 to 7.97. The figures found for water temperature (Beker and Teeter, 1994; Macari, 1996; Borges, 1997) and pH (Macari, 1996; Borges, 1997) are very close to those suggested as optimal levels for the maximum performance in birds and probably did not influence the results. The chemical analysis of drinking water showed Na, K, and Cl "traces."

Starter Phase (0 to 21 d)

Weight gain, feed and water intake, feed conversion, water intake:feed intake ratio, and 0 to 21 d mortality data are shown in Table 2. A quadratic effect ($P < 0.01$) was found for the weight gain and feed conversion variables during the 0- to 21-d period, and predicted optimal DEB were 186 and 197 mEq/kg, respectively (Figure 1). These results disagree with those of Mongin (1981), Maiorka et al. (1998), and Rondón (1999), who found optimal DEB of 250, 140, and 256 to 314 mEq/kg, respectively. In comparing treatments, a negative impact on weight gain, feed

TABLE 2. Performance of broilers fed diets with different dietary electrolyte balances (DEB; Na + K − Cl, mEq/kg) from 0 to 21 d of age under moderately high ambient temperatures

DEB (mEq/kg)	Weight gain/ bird (g)	Feed intake/ bird (g)	Feed/ gain (g/g)	Water intake (mL/bird per d)	Water/feed (L/kg)	Mortality[3] (%)
145[1]	761[abc]	1,118[b]	1.470[ab]	99[d]	1.858[d]	3.00
0	751[c]	1,119[b]	1.490[a]	108[c]	2.028[c]	0.50
120	793[ab]	1,135[ab]	1.432[b]	110[c]	2.033[c]	2.00
240	796[a]	1,153[a]	1.449[ab]	122[b]	2.220[b]	1.00
360	757[bc]	1,109[b]	1.466[ab]	146[a]	2.756[a]	1.00
CV, %[2]	2.3	1.3	1.6	2.2	1.9	42.4

[a–d]Means within a column and having superscripts but lacking a common superscript differ ($P < 0.05$).

[1]Control starter diet with salt (NaCl) based on National Research Council (1994) Na and Cl minimums. Other four treatments developed from a common basal feed with NaCl, $NaHCO_3$, NH_4Cl, and at highest DEB also $KHCO_3$.

[2]Coefficient of variation of means, CV%. There were four observations per mean.

[3]Data converted to arcsin SQRT (X + 1) for analysis.

intake, and feed conversion was found for those treatments with extreme DEB of 0 and 360 mEq/kg of feed, explaining the quadratic effect found for these parameters across treatments. It should be remembered that the DEB 120 and 240 treatments were not significantly different in 0 to 21 d weight gain so there may actually be a range of optimal DEB levels rather than a single point. In the starter phase, no effect of DEB treatment was found on mortality rates.

Although not shown in Figure 1, feed intake from 0 to 21 d gave a quadratic response ($YI_{FEED} = 1{,}115.54 + 0.36X - 0.0010X^2$, $R^2 = 0.81$) with maximum inflection point at 176 mEq/kg of diet, estimated (interpolated from Table 1 calculated nutrient values) to correspond with about 0.37% Na, 0.42% Cl, and 0.52% K. From 0 to 21 d, the 120 and 240 DEB levels did not differ in feed intake indicating a possible range of optimal values (Table 2).

Water intake increased linearly with increasing DEB in the diet ($YI_{H2O} = 102.7 + 0.104X$; $R^2 = 0.87$), probably to quench the thirst caused by increased Na and K intake because blood osmotic pressure in birds is a thirst-regulating factor. On the other hand, diets with high Cl content did not stimulate water intake. Possibly because of the progressive increase in water intake by the broilers and

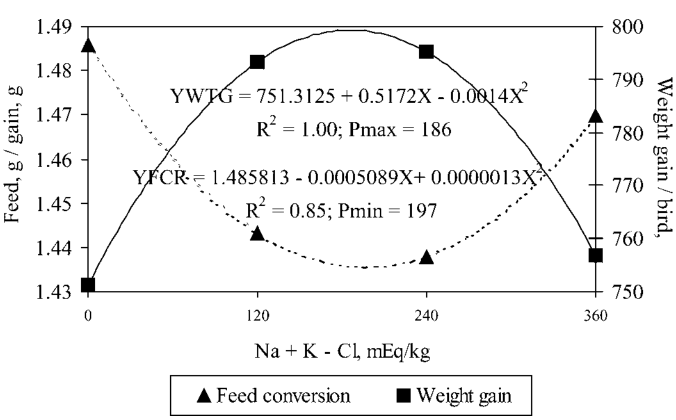

FIGURE 1. Effect of dietary electrolyte balance (Na + K − Cl, mEq/kg) on predicted weight gain (YWTG) and feed conversion ratio (YFCR) of broiler chickens from 0 to 21 d of age.

in order to maintain proper plasma osmotic balance, there was necessarily a reduction in dry matter intake capability with the DEB 360 mEq/kg level. This was shown by the relationship between water intake and feed intake, which was linear. That is, as the electrolyte balance in the diet increased, so did the water intake:feed intake ratio. This had a direct impact on weight gain in these broilers. However, the maximum inflection point in the feed intake curve (176 mEq/kg) may be a direct response to Na presence, an indirect response of the greatly increased water intake or both. It is hypothesized, based on these results, that there may be a saturation limit for the cation Na, which cannot exceed 0.37% of the diet (with estimated 0.42% Cl and 0.52% K) for maximum feed intake.

A linear effect of treatments on litter moisture ($YL_{H2O\%} = 19.935 + 0.04124X$, $R^2 = 0.73$) was a consequence of the linear response found for water intake. Beginning with the first week of production, the birds fed diets with 360 mEq/kg had higher litter moisture (Table 5).

Grower Phase (21 to 42 d) and Overall (0 to 42 d)

In the grower period (21 to 42 d), the birds fed diets with DEB 240 showed higher weight gain than DEB 0 or 130 control, and higher feed intake than DEB 0 treatment (Table 3). The mortality adjusted feed conversion value was lower for DEB 240 than DEB 120 or 130 control treatments. Water intake was affected by the electrolyte balance in the diet. Water intake by the birds fed DEB 0 and 120 mEq/kg was essentially the same as that of the control group. Water intake by those birds fed diets containing DEB 360 mEq/kg was greater than that of the other groups. The same response pattern was found in relation to the water intake:feed intake ratio (Table 3).

The results for weight gain, feed and water intake, feed conversion, water intake:feed intake ratio and mortality for the 0- to 42-d period are shown in Table 4. The 240 DEB treatment gave significantly higher weight gain, feed intake, water intake, and water:feed ratio and lower feed conversion ratio than the 145 and 130 DEB control and 0 DEB treatments. The 360 DEB treatment significantly

TABLE 3. Performance of broilers fed diets with different dietary electrolyte balances (DEB; Na + K − Cl, mEq/kg) from 21 to 42 d of age under moderately high ambient temperatures

DEB (mEq/kg)	Weight gain/ bird (g)	Feed intake/ bird (g)	Feed/gain (g/g)	Water intake (mL/bird per d)	Water/feed (L/kg)	Mortality[3] (%)
130[1]	1,505[b]	2,922[ab]	1.942[a]	315[c]	2.256[c]	1.00
0	1,510[b]	2,850[b]	1.887[ab]	313[c]	2.310[bc]	1.00
120	1,566[ab]	2,985[ab]	1.907[a]	325[c]	2.286[bc]	3.00
240	1,676[a]	3,061[a]	1.827[b]	354[b]	2.433[b]	6.00
360	1,618[ab]	3,046[a]	1.883[ab]	398[a]	2.745[a]	3.00
CV, %[2]	3.7	2.5	1.7	2.8	3.1	73.2

[a–c]Means within a column and having superscripts but lacking a common superscript differ ($P < 0.05$).

[1]Control grower diet with salt (NaCl) based on National Research Council (1994) Na and Cl minimums. The other four treatments were developed from a common basal feed plus NaCl, $NaHCO_3$, NH_4Cl, and at highest DEB also $KHCO_3$.

[2]Coefficient of variation of means, CV%. There were four observations per mean.

[3]Data converted to Arcsin SQRT (X + 1) for analysis.

increased feed conversion ratio, water intake, and water:feed ratio compared to the 240 DEB treatment results. No differences in mortality were found between treatments.

Quadratic responses were found for 0- to 42-d weight gain, feed conversion (Figure 2), and although not shown, feed intake ($YI_{FEED} = 3{,}964 + 1.85X - 0.004X^2$; $R^2 = 0.99$), with inflection points at 236, 207, and 255 mEq/kg, respectively. These results are close to those observed by Mongin (1981) and Johnson and Karunajeewa (1985), who found 250 mEq/kg and 180 to 300 mEq/kg, respectively, to be optimum. From 0 to 42 d, there were no significant differences between 120, 240, and 360 DEB levels for weight gain or feed intake, but DEB 240 and 360 did differ in feed/gain (Table 4). This indicates that there may actually be an optimal DEB range rather than a single point for 0- to 42-d weight gain and feed intake.

The discrepancy between feed conversion (207 mEq/kg) and feed intake (255 mEq/kg) optimal DEB points may be due to additional Cl having a feed intake depressing effect, which is beneficial to feed conversion ratio. Sodium bicarbonate added to raise the DEB to the central range of 120 to 240 mEq/kg may have forced some Cl from the birds via the kidneys (because blood Cl would be used to excrete excess Na and would be partially replaced by HCO_3 from the diet), thus, partially releasing the inhibition of Cl on feed intake. This relationship deserves further investigation.

Imbalances in electrolyte supplementation can cause inappetence with weight gain reduction and death when compensatory mechanisms are not enough to maintain the acid-base homeostasis (Mongin, 1981). The blood HCO_3 levels increased with the highest DEB in the feed (360 mEq), resulting in higher blood pH (Table 6), and, as a consequence, respiratory alkalosis occurred because HCO_3, Na, and K had alkalogenic effects on body fluids (Ruiz-Lopez and Austic, 1993). This explains the low performance in these animals. Therefore, special care should be given to feed formulation in order not to use Na levels below 0.15% and above 0.45% or Cl levels above 0.71%. On the other hand, diets with DEB that are very low (for example, close to 0 mEq/kg) may result in metabolic acidosis because the Cl^- anion is readily absorbed by the gut and is acidogenic.

No significant effects of DEB were found on mortality (Table 4), carcass yield, breast, thigh plus leg, back, wing, feet plus head, or abdominal fat (results not shown) in broilers grown to 42 d of age. Carcass moisture was not evaluated.

Water intake depends on several factors, among which are bird age (body weight), ambient temperature, and the amount of electrolyte salts, especially Na or K salts, added

TABLE 4. Performance of broilers fed diets with different dietary electrolyte balances (DEB; Na + K − Cl, mEq/kg) from 0 to 42 d under moderately high ambient temperatures

DEB (mEq/kg)	Weight gain/ bird (g)	Feed intake/ bird (g)	Feed/gain (g/g)	Water intake (mL/bird per d)	Water/feed (L/kg)	Mortality[3] (%)
145, 130[1]	2,266[b]	4,040[bc]	1.783[a]	207[c]	2.151[c]	4.00
0	2,261[b]	3,969[c]	1.755[a]	211[c]	2.230[c]	1.50
120	2,358[ab]	4,120[abc]	1.747[ab]	217[c]	2.216[c]	5.00
240	2,472[a]	4,214[a]	1.705[b]	238[b]	2.375[b]	7.00
360	2,375[ab]	4,155[ab]	1.750[a]	272[a]	2.748[a]	4.00
CV, %[1]	2.6	1.9	1.1	2.4	2.6	32.7

[a–c]Means within a column and having superscripts but lacking a common superscript differ ($P < 0.05$).

[1]Control with salt (NaCl) based on National Research Council (1994) Na and Cl minimums and DEB in starter 145 mEq/kg (0 to 21 d) and grower 130 mEq/kg (21 to 42 d). The other four treatments were developed from a common basal feed plus NaCl, $NaHCO_3$, NH_4Cl, and at highest DEB also $KHCO_3$.

[2]Coefficient of variation of means, CV%. There were four observations per mean.

[3]Data converted into Arcsin SQRT (X + 1) for analysis.

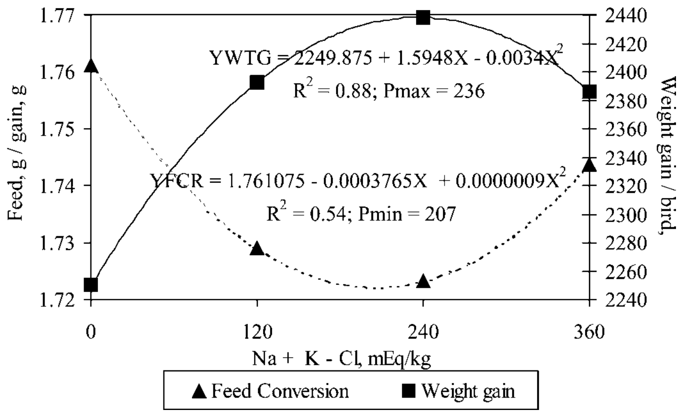

FIGURE 2. Effect of dietary electrolyte balance (Na + K – Cl, mEq/kg) on predicted weight gain (YWTG) and feed conversion ratio (YFCR) of broiler chickens from 0 to 42 d of age.

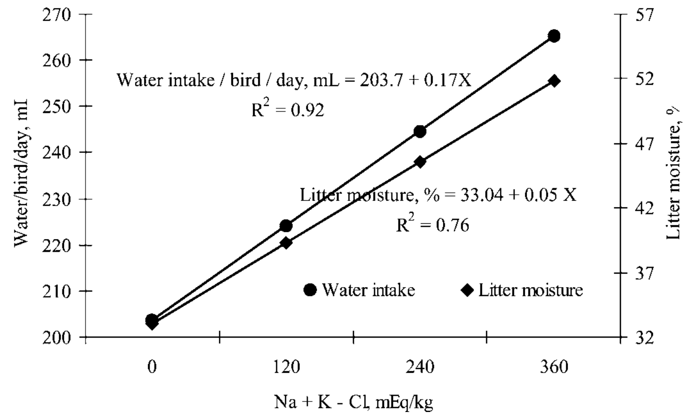

FIGURE 3. Effects of different dietary electrolyte balances (Na + K – Cl, mEq/kg) on predicted average daily water intake and weekly litter moisture of broiler chickens from 0 to 42 d of age.

to the feed (Borges, 1997). In this trial, increasing the DEB caused a linear increase in water intake and in the water intake:feed intake ratio (Table 4; Figure 3). The progressive increase in water intake was reflected in increased litter moisture (Table 5; Figure 3). At 1 wk of age, birds that were fed diets with 360 mEq/kg had higher litter moisture, and by the fourth week, litter moisture became more marked, rendering management difficult, and this may have had an adverse effect on performance. The birds fed 240 mEq/kg diets had high litter moisture after the fourth week, but they also had the best weight gain and feed conversion ratio. Water intake increased with age and with DEB level. However, water turnover increased with increasing DEB but decreased with increasing bird age (data not shown).

The stimulus to higher levels of water intake, as well as a higher rate of water exchange in the bird's body at high temperatures can be beneficial because the increase in water intake cools the birds and reduces mortality in broilers exposed to heat stress (Branton et al., 1986). On the other hand, the higher the level of water intake, the higher its excretion, resulting in litter with higher moisture. Achieving the optimal point in the triad of dietary electrolyte balance, water intake, and litter moisture for commercial broilers seems to be the challenge.

The rectal temperatures of broilers were influenced by the DEB in the diets ($P < 0.01$) and by the collection time, morning vs. afternoon ($P < 0.01$). In the afternoon, bird temperatures increased regardless of treatments. However, the internal temperatures of the broilers decreased linearly as the DEB increased, and birds that were fed diets with 240 and 360 mEq/kg had the lowest temperatures and smallest body heat variation from morning to afternoon (Figure 4). This may have been a direct result of greater water intake by these birds, supporting the hypothesis that the stimulus to increase water intake is a crucial factor in maintaining livability in the hot months of the year. Presumably, heat dissipation and the efficiency in evaporative heat loss also increased with increased water intake although these effects were not measured. Thus, diets formulated by taking into account the concept of DEB balance can help enable broiler chickens better maintain their acid-base homeostasis and body temperature.

In conclusion, of the five DEB (Na+K–Cl, mEq/kg) levels evaluated in summer using male Cobb broiler chickens 0 to 42 d, started on clean litter, 240 mEq/kg

TABLE 5. Litter moisture of broilers fed diets with different electrolyte balances (DEB; Na + K − Cl, mEq/kg) from 0 to 42 d under moderately high ambient temperatures

DEB (mEq/kg)	Litter moisture (%) by week of age					
	1 wk	2 wk	3 wk	4 wk	5 wk	6 wk
145, 130[1]	12.20[b]	16.82[b]	19.43[b]	31.67[c]	25.35[c]	32.22[c]
0	15.82[ab]	21.65[ab]	22.92[b]	29.85[c]	29.89[bc]	37.18[bc]
120	17.17[ab]	21.70[ab]	22.57[b]	30.93[c]	28.63[c]	34.67[c]
240	18.07[ab]	21.57[ab]	25.51[b]	38.82[b]	35.14[b]	42.41[b]
360	21.40[a]	28.13[a]	38.43[a]	51.39[a]	49.40[a]	55.45[a]
CV, %[2]	9.6	7.9	7.7	8.7	8.2	6.6

[a–c]Means in a column without a common superscript letter differ significantly ($P < 0.05$).

[1]Control with salt (NaCl) as industry standard: starter 145 mEq/kg (0 to 21 d) and grower 130 mEq/kg (21 to 42 d). The other four treatments were developed from a common basal feed plus NaCl, $NaHCO_3$, NH_4Cl, and at highest DEB also $KHCO_3$.

[2]Coefficient of variation of means, CV%. There were four observations per mean.

TABLE 6. Effects of different dietary electrolyte balances (DEB; Na + K − Cl, mEq/kg) on blood partial pressure of CO_2 (pCO_2), bicarbonate (HCO_3), and pH of broilers at 42 d of age under moderately high ambient temperatures

DEB (mEq/kg)[1]	Blood pCO2 (mmHg)	Blood HCO3 (mmol/L)	Blood pH
0	40.75	21.00[c]	7.32[b]
120	44.42	23.75[bc]	7.34[b]
240	46.42	25.25[b]	7.33[b]
360	42.92	29.00[a]	7.43[a]
CV, %[2]	27.8	7.1	0.57

[a–c]Means in a column and without a common superscript letter differ significantly ($P < 0.05$).

[1]These four DEB treatments were developed using a common basal feed plus NaCl, $NaHCO_3$, NH_4Cl, and at highest DEB also $KHCO_3$.

[2]Coefficient of variation of means, CV%. There were four observations per mean.

gave the best BW gain and feed conversion ratio ($P < 0.05$; vs. 0 mEq/kg or 145/130 mEq/kg control, other treatments intermediate). Potassium levels in the diets (0.52% K in starter; 0.47% K in grower) were lower than expected based on U.S. table values because the Brazilian soybean meals were lower in K. Supplementation with sodium bicarbonate ($NaHCO_3$) and ammonium chloride (NH_4Cl), along with salt (NaCl), was used to obtain 240 mEq/kg. Mortality was not affected by DEB treatment.

The predicted optimum DEB levels, based on regression analyses for weight gain and feed conversion ratio, were 186 and 197 mEq/kg from 0 to 21 d and 236 and 207 mEq/kg from 0 to 42 d, respectively. Corresponding optimum dietary Na and Cl ranges were 0 to 21 d, Na 0.38 to 0.40%, Cl 0.405 to 0.39% (K = 0.52%); 0 to 42 d, in starter, Na 0.409 to 0.445%, Cl 0.268 to 0.314% (K = 0.52%); and grower, Na 0.409 to 0.445%, Cl 0.267 to 0.315% (K = 0.47%). Estimates are based on diets supplemented with Na, Cl, and HCO_3 (plus NH_4). These monovalent mineral levels are higher than those conventionally used in the broiler industry during summer months. The optimal starter feed DEB (0 to 21 d) combined with the optimal grower feed DEB from the 0 to 42 d data analysis would warrant further testing. Regression analyses for the grower period gave inconsistent results.

Water intake increased with bird age and higher DEB, resulting in increased litter moisture and reduced rectal temperature of market age broilers under heat stress. However, there was a limit to electrolyte addition because the high DEB diet with 360 mEq/kg (containing +0.11 to

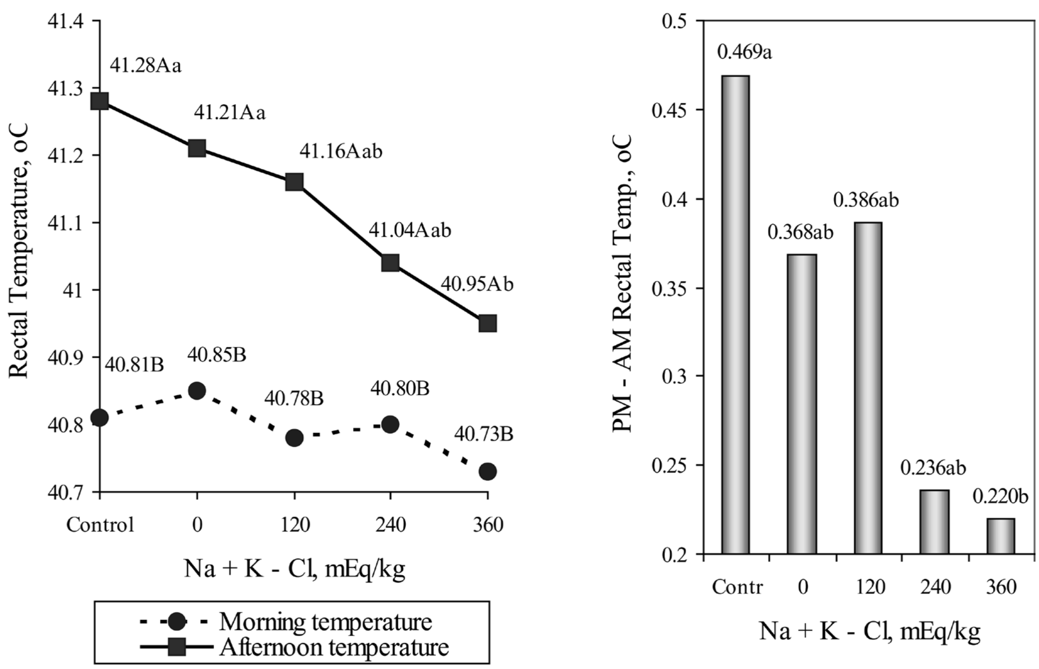

FIGURE 4. Left panel: Morning (AM) and afternoon (PM) rectal temperature (C) of broiler chickens from 12 to 42 d of age when fed diets with different electrolyte balances (Na + K – Cl, Eq/kg) in summer. [A,B]Significant differences between AM and PM ($P < 0.01$); [a,b]Significant differences between treatments ($P < 0.01$). Right panel: Change in rectal temperature (C) from morning (AM) to afternoon (PM) by treatments. [a,b]Significant differences between treatments ($P < 0.01$).

+0.12% K from $KHCO_3$, as well as increased Na from $NaHCO_3$), resulted in poor live performance, higher litter moisture, and respiratory alkalosis, as shown by higher blood pH and HCO_3 compared to control birds.

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