International Journal of Poultry Science 3 (10): 623-628, 2004

Electrolyte Balance in Broiler Growing Diets

Sebastião Aparecido Borges*[1], Ana Vitória Fischer da Silva[1], Ana Silvia Alves Meira Tavares Moura[2], Alex Maiorka[1] and André Ostrensky[3]
[1]Departmento de Zootecnia, FCAV/UNESP, Rodovia Carlos Tonanni, km 05, Jaboticabal, CEP 14870-000, SP, Brazil
[2]Departamento de Produção e Exploração Animal, FMVZ/UNESP, 18618-000, Botucatu, SP, Brazil
[3]Pontifícia Universidade Católica do Paraná, Rod. BR 376, km 14, 83010-500, São José dos Pinhais, PR, Brazil
E-mail: borgessa@terra.com.br

Abstract: Two experiments were carried out using 1,120 chicks to evaluate the electrolyte balance (EB = Na+K-Cl) in growing (21-42 days) broiler diets. The feed, based on corn and soybean meal with 20.0% CP and 3,200 kcal ME/kg, was offered *ad libitum*. In experiment I, K level was fixed, but Na and Cl levels varied among the four treatments, which included five replications of 40 birds each. In experiment II, increasing levels of Na and K were used, with a total of four treatments and four replications of 20 birds. In both experiments, the EB treatments were 40; 140; 240 and 340 mEq/kg of feed. EB showed a quadratic effect on weight gain and feed to gain ratio when the electrolyte ratio was increased only by the supplementation of Na. Feed intake was maximum for 264 mEq/kg, when Na level was increased in the diet, and 213 mEq/kg, when K and Na levels were concurrently increased in the diet, indicating that there is a limit over which feed intake is depressed as a function of excessive Na and/or K. The ideal EB, obtained by the manipulation of Na and Cl levels, was between 202 and 235 mEq/kg.

Key words: Chlorine, electrolyte, broilers, potassium, sodium

Introduction

The acid-base balance is influenced by the environment, diet and metabolism. Under thermoneutrality, birds theoretically show an optimal electrolyte balance that enables maximum growth and feed use, in which the water to electrolyte balance in the body is kept within narrow limits.

An electrolyte may be defined as a chemical that breaks down into its ionic components. Under this concept Na^+, K^+ and Cl^- are included. K^+, the most abundant intracellular cation is important, not only to minimize the arginine-lysine antagonism, but also as an essential element in the synthesis of tissue proteins, maintenance of intracellular homeostasis, maintenance of the electric potential of cell membranes, enzymatic reactions, osmotic pressure and the acid-base balance. Na^+ and Cl^- play important roles in the extracellular space, as well as in the acid-base balance. Therefore, the effects of the ionic balance of the diet on the performance of broilers may be related to variations in the acid-base balance. Osmoregulation is achieved by the homeostasis of these ions at the intra- and extracellular levels.

The nutritional requirements of broilers vary with age. Therefore, recommendations for K^+ may vary from 0.21 to 0.73% (Robbins *et al.*, 1982; Teeter and Smith, 1986; NRC, 1994) and for Na and Cl from 0.41 to 0.12% and from 0.53 to 0.12%, respectively (Edwards, 1984; NRC, 1994; Rondón, 1999). K^+ is present in abundance in most feed ingredients, unlike Na^+, which is present in nutritionally inadequate levels in the feedstuffs used for animals. However, electrolyte availability may be influenced by the intestinal and renal homeostatic regulation as a result of greater absorption of monovalent ions (Teeter, 1997).

Although birds have minimum established electrolyte requirements, it is also important to keep the proper ratios among them. The three electrolytes should be in the proper ratios in order for the acid-base homeostasis to be maintained and for birds to achieve maximum performance. The sum of the acid power of the ingestion of $Na^+ + K^+ - Cl^-$ equals the difference of excreted cations and anions plus endogenous acid production (endogenous H^+) plus excess bases (BEecf) or alkaline reserves. The optimal electrolyte intake, in terms of acid-base balance, can minimize the presence of BE, tending to zero. Birds have an optimal electrolyte balance requirement in terms of mEq ($Na^+ + K^+ - Cl^-$) around 250 mEq/kg of feed. According to this equation, Na^+, K^+ and Cl^- are important for the acid-base balance, without taking into account the way they are ingested. According to Mongin (1981), the sequence could be described as follows:

$_{ingested}$(Anions - Cations) + $_{endogenous}$ H^+ = $_{excreted}$ (Anions - Cations)

$_{ingested}$(Anions-Cations)=$_{excreted}$(Anions-Cations)+$_{endogenous}$ H^+ + BEecf or,

$_{ingested}$ $(Na^+ + K^+ - Cl^-)$ = $_{excreted}$ (Anions - Cations) + $_{endogenous}$ H^+ + BEecf

Liquid acid excretion = anion mEq – cation mEq

= Na + K + Ca + Mg – Cl – P – S

Which can be reduced to = mEqNa + mEqK – mEqCl

However, it should be pointed out that other cations (Ca^{+2}, Mg^{+2}) and anions (HPO_4^{-2}, $H_2PO_4^-$, SO_4^{-2}) although to a lesser extent, can affect the acid-base and electrolyte balances in birds, thus having an impact on their performance (Patience, 1990).

Borges *et al.* (2003a,b) have estimated DEB values that maximized performance of broiler chickens under thermoneutrality or moderately high ambient temperatures and relative humidities. The aim of this study was to assess the effects of the electrolyte balance on the performance of broilers in tropical winter.

Materials and Methods

Two trials were carried out in the winter using 1,120 21-day-old Cobb male chicks. During the starting phase (1 to 21 days) birds were subjected to standard rearing and feeding conditions. At 21 days of age birds were weighed and placed in pens with linear feeders and bell drinkers, with the floor covered with around 8 cm of wood shavings following management of commercial operations.

In order to minimize the interference of experimental conditions, diets were formulated in such a way as to contain the same amounts of corn, soybean meal, oil, phosphate, lime, mineral and vitamin supplements, in accordance with NRC (1994) requirements for protein, metabolizable energy, calcium and phosphorus (Table 1). Feed ingredients, diets and water samples were analyzed for Na, K and Cl. The LABTEST kit (1996) was employed for the water. Na and K levels in feed ingredients and diets were determined by flame spectrophotometry (AOAC, 1990), whereas Cl was determined by $AgNO_3$ titration (Lacroix *et al.*, 1970). Water supplied to birds showed traces of Na.

Maximum and minimum average temperatures were recorded daily using a Dry Bulb Thermometer placed at the center of the building at 0.10 m from the floor. Relative humidity was obtained with a Thermohygrograph and a Wet Bulb Thermometer. Water temperature and pH were recorded twice a day during the trial: between 06:00 and 07:00h and between 13:00 and 14:00h, corresponding, respectively to the times of the day with the lowest and highest temperatures.

In both trials I and II, the experimental design was the completely randomized, with four treatments defined by the Na + K – Cl ratio, expressed in mEq/kg of feed (40, 140, 240 and 340 mEq/kg). In Trial I the electrolyte balance was achieved by the addition of increasing levels of Na and there were five replications of 40 birds each. Bell drinkers were individually equipped with an independent water supply system made of a hose, a valve and a five-liter container to allow an assessment of the evaporation rate (Borges, 1997). In trial II, the electrolyte balance was achieved by the addition of increasing levels of Na and K and there were four replications of 20 birds each.

Weight gain, feed intake, feed conversion and mortality were assessed in both trials. Water consumption, litter moisture and rectal temperatures were assessed exclusively in Trial I. Water consumption was calculated weekly from the difference between water supplied and left over multiplied by the evaporation rate and divided by the number of birds. Five pens were equipped with drinkers connected to independent containers as described above. Evaporation was estimated from the difference in water volume between the beginning and the end of the period. To assess litter moisture, three 500 g-samples were collected at equidistant random points and homogenized to originate a single sample (100 to 200 g) per plot, for each replication, at every seven-day interval. Dry matter was determined by drying that sample in a forced ventilation stove at 55±5°C for 72 hours and assessed by weight difference. Two birds per plot were identified and had their temperatures measured with rectal probes twice daily (Thermoteter MT-520) in the morning (06:00 to 07:30h) and in the afternoon (13:00 to 14:00h), corresponding to the coolest and hottest hours of the day. Results were subjected to regression analysis and, whenever necessary, to the Tukey's test.

Results and Discussion

Average minimum and maximum temperatures inside the buildings varied from 17.0 to 27.0°C and 21.0 to 28.0°C, respectively, with relative humidity levels of respectively 69.0 and 74.8% in trials I and II. The maximum and minimum temperatures peaked at 29 and 12°C, respectively, both recorded just once. Water temperature varied between 17.4 and 22.5°C and water pH between 6.94 and 7.02. These results enable us to assume that birds were not subjected to heat stress. Previous reports emphasized the positive effects of electrolyte addition to the feed of growing and finishing broilers as a way to minimize the effects of high temperatures on performance in the summer (Borges, 1997; Borges *et al.*, 2003a).

In diets formulated with the electrolyte balance concept (Trial I), varying Na and Cl levels affected the performance of the birds (Table 2). Diets with 40mEq/kg

Table 1: Composition of experimental diets

Item	Composition of diets (%)							
	Trial I				Trial II			
Iingredients (%)	40	140	240	340	40	140	240	340
Corn	59.31	59.31	59.31	59.31	59.31	59.31	59.31	59.31
Soybean meal	30.08	30.08	30.08	30.08	30.08	30.08	30.08	30.08
Soybean oil	5.51	5.51	5.51	5.51	5.51	5.51	5.51	5.51
Dicalcium phosphate	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Limestone	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
NaCl	0.30	0.30	0.30	0.30	0.30	0.20	0.20	0.20
$NaHCO_3$	0.08	0.45	0.82	1.19	0.08	0.41	0.60	0.78
$KHCO_3$	0.0	0.0	0.0	0.44	0.0	0.47	0.73	0.98
NH_4Cl	0.67	0.37	0.07	0.00	0.67	0.60	0.31	0.03
Vitamin-mineral mix	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Builders sand	0.95	0.88	0.81	0.07	0.85	0.22	0.06	0.00
Total	100	100	100	100	100	100	100	100
Calculated analysis								
ME. kcal/kg	3200	3200	3200	3200	3200	3200	3200	3200
Crude protein. %	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Calcium. %	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Phosphorus. %	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Methionine. %	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
Methionine + Cystine. %	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
Lysine. %	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04
Sodium. %	0.15	0.25	0.35	0.45	0.15	0.20	0.25	0.30
Chloride. %	0.70	0.50	0.30	0.26	0.70	0.59	0.40	0.21
Potassium. %	0.68	0.68	0.68	0.85	0.68	0.87	0.97	1.06

*Vitamin-mineral mix: Iron 35.000 mg, copper 50.000 mg, manganese 35.000 mg, zinc 30.000 mg, iodine 600 mg, selenium 90 mg, vitamin A 2.300.000 UI, vitamin D_3 400.000 UI, vitamin E 1.800 mg, vitamin K_3 300 mg, vitamin B_1 150 mg, vitamin B_2 1.400 mg, vitamin B_{12} 3.500 mcg, panthotenic acid 2.000 mg, nicotinic acid 7.000 mg, pyridoxine 250 mg, folic acid 150 mg, biotin 20 mg, choline 125 g, anticoccidial 125 g, antibiotic 30 g, antioxidant 20 g, carrier 1.000 g.

reduced feed intake ($P<0.01$) and weight gain ($P<0.01$) and diets with 340 mEq/kg resulted in worse feed conversion ($P<0.05$). The former result may be a response of the Na:Cl imbalance due to excess Cl (0.70%) and low Na levels (0.15%) and the latter result may be due to the imbalance caused by excess Na (0.45%) in the diet . Weight gain and feed conversion showed quadratic responses, with minimum and maximum points of 235 and 202 mEq/kg, respectively, (Fig. 1). Feed intake was greatest with 264 mEq/kg (Fig. 2), showing that the Na:Cl imbalance caused by high Na^+ contents and/or high electrolyte ratios can decrease feed intake by birds.

The effects of high Cl and Na contents in the feed had been previously described by Miller and Soares (1972) who found better weight gain in broilers when the Cl content in the diet containing fish meal was reduced from 0.542 to 0.228%. Diets with 0.20% of Na^+ and high concentration of Cl^- (0.912%) resulted in a decrease in growth rate, which was reversed when Na^+ content was increased to 0.60%. Hurwitz *et al.* (1973), when assessing the impact of the cation/anion ratio on the acid-base balance in broilers, blood pH and performance, concluded that maximum growth took place at a blood pH of 7.28, with a decrease in growth when pH levels were greater than 7.30 or lower than 7.20. The electrolyte ratio in the diet for maximum growth varied from 226 to 260 mEq/kg. Therefore, the high Cl contents (0.70%) used in this study may have resulted in metabolic acidosis, since the acid Cl^- sources titer blood HCO_3^- and Cl^- replaces HCO_3^- (Rondón, 1999), thus accounting for the worse performance of these birds. However, if the response is due to changes in pH or other electrolytic or metabolic effects, it is not yet clear.

Mongin (1981), when manipulating the electrolyte balance by adding Na^+, concluded that 250 mEq/kg is the optimal level for maximum performance. However, Johnson and Karunajeewa (1985) concluded that a diet

Table 2: Effects of electrolyte ratio of the diet on feed intake (FI), weight gain (WG), feed conversion (FC) and mortality (MT) in 21 to 42 days broilers in winter

	Trial I[1]				Trial II[2]			
Meq/kg	FI (g)	WG (g)	FC	MT (%)	FI (g)	WG (g)	FC	MT (%)
40	3307[b]	1823[b]	1.81[ab]	2.50	3329[b]	1860[b]	1.79[ab]	3.75
140	3418[a]	1887[b]	1.81[ab]	5.00	3467[a]	1927[ab]	1.80[ab]	3.75
240	3474[a]	1971[a]	1.762[b]	6.25	3504[a]	1996[a]	1.76[b]	2.50
340	3452[a]	1898[ab]	1.82[a]	6.87	3408[ab]	1869[b]	1.82[a]	2.50
CV %	1.42	2.44	1.66	27.24	1.89	2.80	1.69	60.85

[1]Varying Na; [2]varying Na e K; ($P<0.05$)

with less than 180 mEq/kg or more than 300 mEq/kg decreased weight gain in birds assessed at 42 days. Likewise, Hulan *et al.* (1987), when investigating the effect of diets containing $Na^+ + K^+ - Cl^-$ in different ratios and varying calcium level, found that the worst and the best weight gains were achieved when the electrolyte balances were 174 and 215 mEq/kg with 1.38 nd 0.95% of calcium, respectively. Weight gain and feed conversion results (235 and 202 mEq/kg) shown in Fig. 1 reinforce the theory that diets have to be formulated taking into account the proper ratio among electrolytes, since they are easily available at low costs.

When the electrolyte balance was achieved by increasing the addition of Na and K (Trial II), lower feed intake ($P<0.05$) and weight gain ($P<0.05$) were observed for 40 and 340 mEq/kg (Table 2) and worse feed conversion was found for 340 mEq/kg of feed ($P<0.05$). These responses could be the result of the Na:Cl imbalance due to low Na contents (0.15%) and/or high Cl contents (0.70%) in the former case, and high K contents (1.06%) associated with Na (0.30%) in the latter. Weight gain and feed intake showed quadratic responses, with the maximum point being 200 mEq/kg and 213 mEq/kg of feed, respectively. These responses are similar to those achieved by the addition of Na (Fig. 1 and 2). However, in the experiment conducted by Borges (1997) greater weight gain was achieved by adding 0.5 and 1.0% of KCl to the diet of growing and finishing broilers in the summer, totalling 0.98 and 1.23% of K, 0.13% of Na and 172 mEq/kg. This enables us to suggest that response to supplemental K is linked to ambient temperature and that, once nutritional requirements are met, the ratio among those three electrolytes is a determining factor for performance.

Response to supplemental K was different from that obtained with the addition of Na to achieve the desired electrolyte balance. This was probably the case because K exceeded birds requirements, since NRC (1994) points out to a 0.30% requirement for this mineral. However, under a heat stress situation there is lower retention and greater excretion of K^+, thus decreasing its

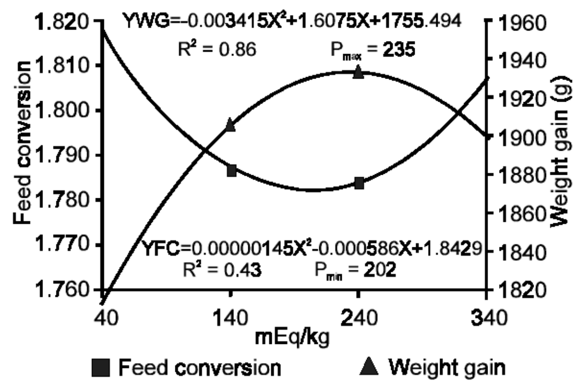

Fig. 1: Effects of the electrolyte ratio of the diet on weight gain and feed conversion in 21 to 42 days broilers in winter (Trial I)

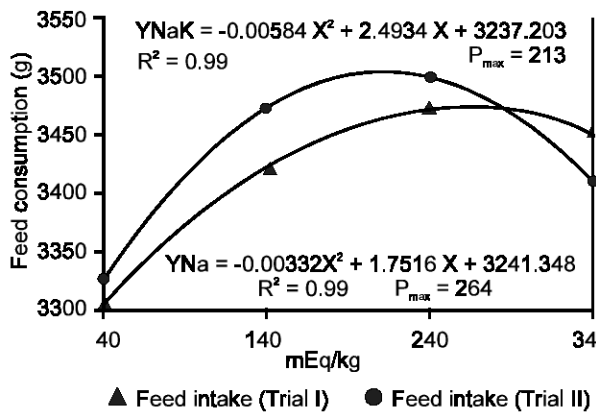

Fig. 2: Effects of the electrolyte ratio of the diet on feed intake of broilers from 21 to 42 days in winter

plasma concentration (Huston, 1978; Teeter and Smith, 1986). K^+ competes with buffer anions in the renal tubule fluid, preventing H^+ removal, which in turn is reabsorbed, may result in acidosis (Bacila, 1980) and cause K^+ deficiency at the cellular level, if an adequate amount is not supplied. Teeter and Smith (1986) recommended

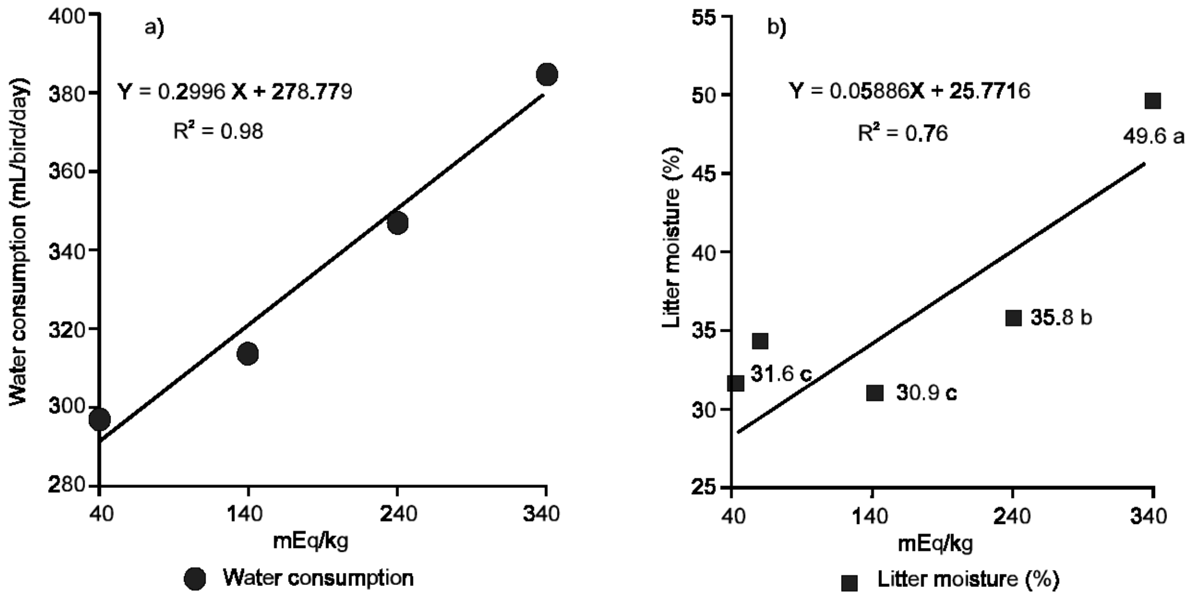

Fig. 3: Water consumption (mL/bird/day) and litter moisture (%) in broilers fed with different electrolyte ratios in winter (Trial I)

0.73% of K^+ for heat stress situations. In other studies, Rondón (1999) concluded that the best electrolyte balance in the diet for 21 to 42 days broilers is between 249 and 261 mEq/kg when Na and Cl are handled in diets with high K contents (0.93 to 0.96%).

In pre-starter diets formulated by the electrolyte balance concept with increasing supplementation of K, the greatest weight gain was achieved with 127 mEq/kg (Borges *et al.*, 1999c). However, for growing diets this value was 200 mEq/kg. This may be related to intracellular K concentration, particularly in the cytoplasm of muscle cells, because this concentration increases with bird age, achieving a plateau around the 12th day of life (Kravis and Kare, 1960). If changes in K^+ homeostasis affect cell function (Thier, 1986), older birds would withstand higher levels of supplemental K in the diet due to a higher metabolic demand for this ion, even under thermoneutrality conditions.

Changes in the acid-base balance and imbalances in $Na^+ + K^+ - Cl^-$ cause lack of appetite, with reduction in weight gain, affecting feed conversion. High mortality rates may result when imbalances are not compensated for (Mongin, 1981). The quadratic response for feed intake achieved in both trials with maximum feed intake points of 264 and 213 mEq/kg (Fig. 2) reinforces this theory and can be an indication that birds are sensitive to the association of high K and Na levels in the diet. Taking into account that Cl^- in body fluids has an acidogenic effect by reducing blood bicarbonate concentration, and that Na^+ and K^+ have alkalogenic effects (Ruíz-López and Austic, 1993; Borges *et al.*, 1999a,b), the ratio among them should be maintained under control. This can be explained by the intestinal and renal homeostatic regulation of electrolytes (Teeter, 1997), because excess electrolyte supplementation makes homeostasis difficult, since plasma regulation of HCO_3^- depends on the relative rate between H^+ excretion and Cl^- reabsorption. Therefore, HCO_3^- plasma concentrations increase if H^+ excretion increases in relation to Cl^- reabsorption (Riella, 1988).

Water consumption showed a linear trend ($P<0.01$) as the electrolyte balance was increased (Fig. 3a), resulting in greater litter moisture ($P<0.01$). Greater water consumption and excretion is a response of birds to maintain body water balance. Diets with 340 mEq/kg resulted in litter moisture levels above acceptable thresholds (Fig. 3b). Water consumption increase is particularly important at high temperatures, where it can contribute to bird survival. However, the electrolyte balance did not affect the liveability ($P>0.05$) of birds in both trials. In this specific case, as ambient temperature was mild, water consumption was of secondary importance in the maintenance of body temperature. This was confirmed by rectal temperatures, which varied from 40.4 to 40.6°C, showing no effect of electrolyte balance and ambient temperature on the body temperature of birds.

Summarizing, the electrolyte ratio (Na + K – Cl) of the diet affected the performance of broilers. The best electrolyte balance in the growing phase is between 202 and 235 mEq/kg. Water consumption and litter moisture increase linearly with electrolyte balance. When formulating diets with the concept of electrolyte balance for broilers in the growing phase, high Cl contents (0.70%) in the diet should be avoided.

Acknowledgements

The authors acknowledge the support of Química Geral do Nordeste S.A., (a Church & Dwight Company), Rio de Janeiro, BRAZIL.

References

AOAC. Official Methods of Analysis, 1990. 15th ed. Association of Official Analytical Chemists. Arlington, VA.

Bacila, M. [Veterinary Biochemistry], 1980. São Paulo: ed. J. M. Varela, 534p.

Borges, S.A., 1997. Suplementação de cloreto de potássio e bicarbonato de sódio para frangos de corte durante o verão. 84p. Masters Dissertation. UNESP-Jaboticabal.

Borges, S.A., J. Ariki, A.V. Fischer Da Silva, V.M.B. Moraes and M. Macari, 1999a. Efeitos do estresse calórico agudo e da relação (Na+K-Cl) sobre o desempenho e parâmetros fisiológicos de frangos de corte. Revista Brasileira de Ciência Avícola, 1: 61. (Supplement).

Borges, S.A., J. Ariki, V.M.B. Moraes, A.V. Fischer Da Silva, A. Maiorka and J.O.B. Sorbara, 1999b. Relação (Na+K-Cl) em dietas de frangos de corte durante o verão. Revista Brasileira de Ciência Avícola, 1: 20, (Supplement).

Borges, S.A., J. Ariki, E. Santin, Fischer Da Silva and A. Maiorka, 1999c. Balanço eletrolítico em dieta pré-inicial de frangos de corte durante o verão. Revista Brasileira de Ciência Avícola, 1: 175-179.

Borges, S.A., A.V. da Silva, J. Ariki, D.M. Hooge and K.R. Cummings, 2003a. Dietary electrolyte balance for broiler chickens under moderately high ambient temperatures and relative humidities. Poult. Sci., 82: 301-308.

Borges, S.A., A.V. da Silva, J. Ariki, D.M. Hooge and K.R. Cummings, 2003b. Dietary electrolyte balance for broiler chickens exposed to thermoneutral or heat-stress environments. Poult. Sci., 82: 428-435.

Edwards, H.M. Jr., 1984. Studies on the etiology of tibial dyschondroplasia in chickens. J. Nutr., 114: 1001-1013.

Hulan, H.W., P.C.M. Simons, P.J.W. Van Schagen, K.B. Mcrae and F.G. Proudfoot, 1987.Effects of dietary cationic-anionic balance and calcium content on general performance and incidence of leg abnormalities of broiler chickens. Can. J. Anim. Sci., 67: 165-177.

Hurwitz, S.I., A. Cohen Bar and H. Bornstein, 1973. Sodium choride requeriments of the chick: relationship to acid-base balance. Poult. Sci., 52: 903-909.

Huston, T.M., 1978. The effects of environmental temperature on plasma potassium concentrations in the blood of the domestic fowl. Poult. Sci., 57: 54-56.

Johnson, R.J. and H.E. Karunajeewa, 1985. The effects of dietary minerals and electrolytes on the growth and physiology of the young chick. J. Nutr., 115: 1680-1690.

Kravis, E.M. and M.R. Kare, 1960. Changes with age in tissue levels of sodium and potassium in the fowl. Poult. Sci., 39: 13-15.

Labtest, 1996. Sistema para determinação colorimétrica de cloretos. Labtest Diagnóstica, Catálogo 49, janeiro, p: 2.

Lacroix, R.L., D.R. Keeney and L.M. Welsh, 1970. Potentiometric titration of chloride in plant tissue extracts using the chloride ion electrode. Communications in Soil Science Plant Analysis, 1: 1-6.

Miller, D. and J.H. Soares Jr, 1972. Effect of mineral mixture composition on chick growth and intestinal pH´s. Poult. Sci., 51: 182.

Mongin, P., 1981. Recent advances in dietary cation-anion balance: applications in poultry. Proceedings Nutrition Society, Cambridge, 40: 285-294.

National Research Council, 1994. *Nutrient requirements of poultry*. Washington: National Academy Press, 155p.

Patience, J.F., 1990. A review of the role of acid-base balance in amino acid nutrition. J. Anim. Sci., 68: 398-408.

Riella, M.C., 1988. Princípios de nefrologia e dstúrbios hidroeletrolíticos. 2 ed. Guanabara Koogan. Rio de Janeiro.

Robbins, K.R., J.P. Hitchcock and N.S. Mitchell, 1982. Potassium induced changes in muscle free amino acid concentrations in chicks. J. Nutr., 112: 2122-2129.

Rondón, E.O.O., 1999. Exigências nutricionais de sódio e de cloro para frangos de corte. 77p. Masters Dissertation. UEM-Maringá.

Ruiz-Lopez, B. and R.E. Austic, 1993. The effect of selected minerals on the acid-base balance of growing chicks. Poult. Sci., 72: 1054-1062.

Teeter, R.G., 1997. Balancing the electrolyte equation. Feed Mix, 5: 22-26.

Teeter, R.G. and M.O. e Smith, 1986. High chronic ambient temperature stress effects on broiler acid-base balance on their response to suplemental ammonium chloride, potassium chloride and potassium carbonate. Poult. Sci., 65: 1777-1781.

Thier, S.O., 1986. Potassium physiology. Am. J. Med., 80: 3-7.