Indian Journal of Animal Sciences **83** (12): 1335–1339, December 2013

Effect of supplementation of organic minerals on the performance of broilers

S K MISHRA[1], R K SWAIN[2], N C BEHURA[3], A DAS[4], A MISHRA[5], G SAHOO[6] and A K DASH[7]

Orissa University of Agriculture and Technology, Bhubaneswar, Odisha 751 003 India

Received: 15 May 2013; Accepted: 28 August 2013

ABSTRACT

Effect of supplementation of organic minerals on the performance of broilers was studied on 225 coloured synthetic broiler chicks randomly divided into 5 groups. The inorganic minerals viz. Zn, Cu and Mn were added @ 40, 8 and 60 ppm, respectively in control group (T_1). The inorganic minerals of treatment group were replaced with organic minerals in T_2 (8 ppm organic Cu), T_3 (40 ppm organic Zn) and T_4 (60 ppm organic Mn) and T_5 (8, 40, and 60 ppm Cu, Zn and Mn, respectively). Weekly body weight and feed consumption were recorded. At 42 day, serum biochemical indices, total ash and mineral content of tibia and carcass parameter were determined. The body weights of broiler till third weeks of age of all the treated groups did not differ significantly. The sixth week body weight of T_3 was significantly higher than that of T_1. The FCR of all the treated groups did not differ significantly. The studied biochemical parameters viz. serum glucose, albumin, globulin, albumin and globulin ratio, protein, urea, calcium, phosphorus, and SGOT levels of all the treatments of the experimental broilers did not differ significantly. Significantly lower serum cholesterol and higher SGPT and ALP levels were observed in organic Zn fed groups. Carcass characteristics and tibia bone parameters of the broilers of different dietary treatments at sixth week of age did not differ significantly. From this experiment, it may be concluded that replacement of inorganic zinc with Zn-methionine resulted in better body weight of broilers.

Key words: Broilers, Organic minerals, Performance, Tibia bone

Zinc (Zn), copper (Cu) and manganese (Mn) are supplemented in broiler diets using inorganic salts such as oxides and sulphates. But the trace minerals tend to dissociate in the low pH environment of upper gastrointestinal tract, leaving the minerals susceptible to various nutrients and ingredient antagonisms that impair absorption (Underwood and Shuttle 1999). Chelated minerals can be utilized at a much lower concentration in the diet than inorganic minerals, without a negative impact on production performance. Higher bioavailability of proteinates and aminoacid chelates (Wedekind and Baker 1989, Wedekind *et al*. 1992, Cao *et al*. 2000) along with lowered mineral load in manure (Pierce *et al*. 2005) has resulted in increased use of these forms of trace minerals in feeding of livestock and poultry. Abdallah *et al.* (2009) observed that chicks fed diets containing 100% organic minerals (Zn, Cu, Mn and Fe) had significantly higher body weight and better feed conversion on comparision with those of inorganic minerals. In contrast to this, Peric *et al*. (2007) observed no significant performance differences in performance between birds fed inorganic and organic minerals. The present experiment was undertaken to evaluate the effect of chelated trace minerals (methionate complexes of Cu, Zn and Mn) replacing inorganic minerals (sulphates) on the performance of broilers.

Present address: [1]Associate Professor (sumantakmishra @gmail.com), [2]Professor and Head (rkswainovc@yahoo.com), [4,5]Ex Post-Graduate student, Department of Animal Nutrition, [3]Associate Professor (ncbehura@gmail.com), P G Department of Poultry Science, [6]Associate Professor (gr_sahoo@gmail.com), Department of Veterinary Biochemistry, [7]Ex-SRF, AICRP on Sheep, College of Veterinary Science and Animal Husbandry, Bhubaneshwar.

MATERIALS AND METHODS

To study the effect of supplementation of organic minerals on the performance of commercial broilers (225) coloured synthetic straight run broiler chicks were randomly divided into 5 groups and each group was further divided into 3 replication having 15 chicks in each replication. The chicks were reared in cages and experiment feeding period was continued for 42 days. The experiment was carried out in 2 phases: a starter phase (0–28 days) and a finisher phase (28–42 days). Samples of experimental feeds were analyzed for proximate composition as per AOAC (1975). The ingredients composition and chemical compositions of the experimental feed are given in Tables 1 and 2, respectively. The inorganic minerals, viz. Zn, Cu and Mn were added @ 40, 8 and 60 ppm, respectively in control group (T_1). The inorganic minerals of treatment group were replaced with organic minerals (Zn-methione, Cu-methionine and Mn-methionine)

Table 1. Ingredient composition of the experimental diet

Ingredients	Starter (%)	Finisher (%)
Maize	57	64
Soyabean meal	38	30
Deoiled rice bran	2	3
Mineral mixture*	2.7	2.7
Common salt	0.3	0.3
Total	100	100
Additives	0.09	0.04

*Without zinc, copper and manganese.

Table 2. Proximate composition of broiler experimental rations (% on DM basis)

Components	Starter mash	Finisher mash
Crude protein	22.70	19.63
Ether extract	3.82	4.30
Crude fibre	4.45	4.17
Total ash	8.91	8.38
Acid insoluble ash	2.43	2.21
Nitrogen-free extract*	60.12	63.52
Calcium	1.21	1.05
Total phosphorus	0.53	0.57
ME (kcal/kg)*	2800	2900

* Calculated value.

in treatment groups as T_2 (8 ppm organic Cu), T_3 (40 ppm organic Zn) and T_4 (60 ppm organic Mn) and T_5 (8, 40, and 60 ppm Cu, Zn and Mn, respectively). Weekly body weight and feed consumption were recorded. At 42 day, 3 birds of each treatment were bled to collect blood and subsequently serum was harvested for serum biochemical study. Serum biochemical indices determined were serum glucose, urea, alkaline phosphate (ALP), glutamic-oxalloacetic transaminase (SGOT or AST), glutamic- pyruvic transaminase (SGPT or ALP) and total protein by using crest biosystems kit.

At 42 day, 3 birds were randomly chosen from each treatment and slaughtered for carcass parameter study. The birds were kept off fed overnight before bleeding and only water was provided. The live weight of the birds was recorded as pre slaughter weight. The broiler birds were bled by modified Kosher's method (Panda and Mohapatra 1989). The weight of the dried tibia was recorded with the help of electronic balance. The tibia bones were ashed in a muffle furnace at 600°C for 4 h. The total ash was determined on per cent weight basis. The tibia bone calcium was determined according to the method modified by Talapatra *et al.* (1940) and available phosphorus was determined as per IS: 1374–1968. For determination of tibia Zn, Cu and Mn contents, 0.2 g of ash samples were solubilised in 5 ml of 50% HCl and the mineral extract was filtered into a volumetric flask. The extract was diluted using triple distilled water to the required volume and Zn, Cu and Mn concentrations were determined.

Data obtained from the experiment were subjected to statistical analysis. Analysis of variance was obtained according to Snedecor and Cochran (1998).

RESULTS AND DISCUSSION

Body weight and feed conversion ratio: The weekly body weight of the experimental broilers and feed conversion ratio are presented in Tables 3 and 4, respectively. The body weights of broiler till third weeks of age of all the treated groups did not differ significantly ($P<0.05$). This corroborated with the findings of Baker and Halpin (1987) for Mn, Burrell *et al*. (2011) for Zn, Dozier *et al*. (2011) for Cu and Zhao *et al*. (2010) for Zn, Cu and Mn supplementation in form of organic minerals. The sixth week body weight of T_3 was significantly ($P<0.05$) higher than that of T1. This corroborated with the findings of Abdallah *et al*. (2009) who reported that the body of weight chicks at 35th day fed with 100% organic zinc were significantly higher than the group fed with 50% organic and 50% inorganic zinc and group fed with 100% inorganic zinc. Similar findings were also reported by Swiatkiewicz *et al*. (2001). In contrast to this finding, Tronina *et al*. (2007) reported that at 21 day, the body weight of chicken receiving zinc oxide was lower by approximately 2% compared to chicken received zinc-glycine while on 42 day, the birds receiving ZnO had significantly higher body weight than zinc-glycine fed group.

Nonsignificant difference was observed between T_2 and T_1 throughout the experimental period. This result are in

Table 3. Weekly body weight of broilers (g) on supplementation of organic minerals

Weeks/ treatments	T_1	T_2	T_3	T_4	T_5
0 week	40.48± 0.53	40.18± 0.58	39.94± 0.51	39.46± 0.43	39.64± 0.57
First week	85.39±1.03	88.61±1.36	89.61±1.36	86.97±1.04	89.29±1.06
Second week	277.68±3.41	274.11±2.22	280.01±2.37	271.65±6.43	282.56±4.80
Third week	504.35±8.11	497.61±8.67	515.27±6.64	498.29±10.83	517.05±7.87
Fourth week	684.73^c±12.63	679.45^c±10.70	776.43^a±9.00	696.61^c±15.43	730.88^b±9.00
Fifth week	972.19^b±18.68	960.72^b±16.28	1073.11^a±17.38	972.55^b±16.18	1053.51^a±19.82
Sixth week	1343.76^c±18.11	1327.53^c±16.51	1468.33^a±17.19	1340.73^c±19.23	1402.13^b±21.36

Means with same superscript in a row did not differ significantly ($P<0.05$).

Table 4. Feed conversion ratio of broilers on supplementation of organic minerals

Weeks/ treatments	T_1	T_2	T_3	T_4	T_5
First week	1.64±0.03	1.65±0.02	1.60±0.00	1.67±0.04	1.60±0.00
Second week	1.80±0.05	1.79±0.02	1.83±0.04	1.78±0.08	1.77±0.04
Third week	1.84±0.03	1.85±0.09	1.82±0.02	1.87±0.04	1.82±0.03
Fourth week	1.87±0.04	1.88±0.04	1.88±0.03	1.93±0.04	1.87±0.01
Fifth week	1.92±0.04	1.94±0.01	1.93±0.06	1.97±0.05	1.91±0.07
Sixth week	2.04±0.16	2.05±0.23	1.99±0.27	2.07±0.13	1.97±0.18

accordance with Banks *et al.* (2004) and Zhao *et al.* (2010) who reported no significant difference with respect to body weight in poultry by replacing inorganic Cu at 50% and 100% level with organic. Except $T_{2,}$ broilers fed diets containing inorganic minerals were significantly recorded the lowest live body weight than that of organic minerals fed group. This is in agreement with the findings of Abdallah *et al*. (2009). They reported significantly lower body weight in 100% inorganic mineral fed groups than feeding organic minerals to broiler birds. The lower body weight in T_1 might be due to the reason that use of organic mineral sources can improve intestinal absorption of trace elements as they reduce interference from agents that form insoluble complexes with the ionic trace elements (Van and Kemme 2002). The significantly higher body weight in T_3 than that of other treated groups might be due to higher feed intake as the first sign of Zn deficiency in broiler chickens is decreased feed intake followed by poor growth. Under conditions of Zn deficiency, broiler chickens did not benefit from supplemental Cu and Mn, suggesting that Zn mainly affected bird feed intake and the deficiency of primary nutrients strongly depressed broiler growth rate (Bao *et al*. 2007).

The feed conversion ratio (FCR) of all the treated groups did not differ significantly (P>0.05). This is in agreement with the findings of Rossi *et al*. (2007) who reported that the feed consumption and feed conversion were not influenced by addition of increasing levels of dietary organic Zn in experimental quails and Swiatkiewicz and Koreleski (2008) by feeding Zn and Mn both from organic and inorganic sources. Contradictory findings were reported by Abdullah *et al*. (2009).

Serum biochemical parameters: Biochemical constituents, viz. blood glucose (mg/dl), cholesterol (mg/dl), total protein (g/dl), blood urea (mg %), blood urinary nitrogen (mg %), albumen (g/dl), globulin (g/dl), A:G ratio, calcium (mg/dl), phosphorus (mg/dl), SGPT (IU/l), SGOT (U/l), ALP (IU/l) of broilers at sixth week of age, under different treatments of zinc are presented in Table 5. The studied biochemical parameters, viz. serum glucose, albumin, globulin, albumin and globulin ratio, protein, urea, calcium, phosphorus, and SGOT levels of all the treatments of the experimental broilers did not differ significantly (P>0.05). Similar observations were also recorded earlier (Chowdhury *et al*. 2004, Idowu *et al*. 2011 and Parak and Strakova 2011). However, some contradictory results were reported by Al-Daraji and Amen (2011).

The significantly (P<0.05) lower serum cholesterol and higher SGPT and ALP levels were observed in organic Zn fed groups. Herzig *et al.* (2009) proved that there was a significant decrease of plasma cholesterol when broilers were fed with high amounts of zinc in diet. Though the T_1, T_3 and T_5 groups received same level of zinc, the lower cholesterol level in T_3 and T_5 might be due to higher bioavailability of zinc from organic source. The serum SGPT level of organic zinc fed birds were found to be significantly higher than the inorganic zinc fed and control groups. A significant difference in SGPT level was found in birds of T_3 and T_5 fed with same

Table 5. Serum biochemical parameters of broilers on supplementation of organic minerals

Weeks/ treatments	T_1	T_2	T_3	T_4	T_5
Glucose (mg/dl)	273.97±3.17	279.17±4.06	289.63±7.50	276.06±8.64	283.02±5.59
Cholesterol (mg/dl)	94.53^a±0.66	94.30^a±0.36	84.70^b±0.87	93.47^a±0.41	85.97^b±0.80
Triglycerides (mg/dl)	72.63^a±0.52	66.63^{bc}±0.49	65.03^c±1.36	68.60^b±0.53	71.60^a±0.64
Total protein (g/dl)	2.80±0.05	2.82±0.12	3.06±0.12	2.94±0.19	2.98±0.07
Urea (mg%)	8.27±0.29	8.10±0.32	8.33±0.29	8.27±0.24	8.97±0.33
SGPT (IU/L)	6.10^e±0.26	8.37^d±0.34	17.53^a±0.55	12.50^c±0.44	15.57^b±0.46
SGOT (IU/L)	108.63±0.52	108.50±0.52	109.83±0.28	109.43±0.69	108.93±0.24
ALP (IU/L)	87.50^c±0.61	88.27^c±0.85	98.47^a±0.48	86.57^c±0.46	94.37^b±0.49

Means with same superscript in a row did not differ significantly (P<0.05).

Table 6. Carcass characteristics of broiler at the end of sixth week under different dietary treatments

Parameters	T_1	T_2	T_3	T_4	T_5
Dressing yield (%)	72.83±2.26	74.76±1.48	73.35±3.30	74.17±2.63	73.30±2.17
Eviscerated yield (%)	68.88±1.53	69.89±0.96	69.49±1.18	69.33±0.57	69.45±0.50
Giblet yield (%)	6.22±0.57	5.81±0.45	6.09±0.36	6.31±0.56	6.29±0.49
Neck yield (%)	8.36±0.31	8.11±0.64	8.27±0.71	7.47±0.35	7.51±0.79
Wings yield (%)	9.47±0.22	10.13±0.17	9.61±0.40	10.30±0.28	9.85±0.25
Back yield (%)	17.70±0.57	18.53±0.75	17.21±0.29	19.12±0.73	19.04±1.00
Breast yield (%)	18.12±1.62	15.88±1.24	17.36±1.99	17.44±0.86	17.19±1.27
Thighs yield (%)	11.59±0.54	12.53±0.38	11.49±0.50	12.55±0.70	11.69±0.43
Drumsticks yield (%)	10.63±0.64	9.82±0.33	10.53±0.62	10.98±0.47	11.10±0.91

Table 7. Tibia bone parameters of broilers on supplementation of organic minerals

Parameters/ treatments	T_1	T_2	T_3	T_4	T_5
Bone weight (g)	5.03±0.23	5.28±0.18	4.90±0.15	5.07±0.03	4.93±0.13
Tibia ash (%)	50.38±1.09	47.12±1.12	52.48±2.34	50.05±1.20	53.13±2.53
Tibia Ca (%)	31.71±1.52	33.74±1.25	34.66±1.94	31.09±1.48	30.68±1.20
Tibia P (%)	13.58±0.86	14.21±1.80	16.33±1.40	16.31±0.64	15.24±1.47
Tibia Zn (ppm)	182.10±6.04	171.70±8.51	188.07±2.79	181.07±4.22	191.23±7.01
Tibia Cu (ppm)	3.13±0.08	3.86±0.17	3.21±0.12	3.10±0.21	3.45±0.36
Tibia Mn (ppm)	13.10±1.02	12.98±0.23	12.68±0.65	13.16±0.29	13.05±0.52

levels of Zn-Met. The ALP level in the serum of zinc supplemented birds was found to be significantly different ($P<0.05$) from the control. Idowu *et al*. (2011) also observed significant difference in the levels of ALP between control and zinc proteinate groups with higher levels in zinc proteinate and opined that due to zinc binding capacity of serum, alkaline phosphate acts as good indicator of zinc status. The increase in ALP level on zinc supplementation might be due to increase in corticosteroid hormone secretion, epinephrine and nor-epinephrine (Al-Daraji and Amen 2011). In contrast to this, nonsignificant level of serum ALP in organic zinc fed groups was reported by Parak and Strakova (2011).

Carcass characteristics: Carcass characteristics of the broilers of different dietary treatments at sixth week of age are presented in the Table 6. The live weight, dressed weight, eviscerated weight, drum stick yield, thigh yield, back yield, neck yield, breast yield and wing yield of all the treatments of the experimental broilers did not differ significantly ($P>0.05$). This finding corroborated with the findings of Waldroup *et al*. (2003), Rossi *et al*. (2007) and Zhao *et al*. (2010). In contrast to this, Britanico *et al*. (2012) reported that dressing percentage was observed to be significantly superior in higher level of chelated mineral inclusion in the diet of broiler.

Effect on tibia bone: Tibia bone parameters of broilers at 42^{nd} day of age in different dietary treatments are presented in Table 7. The tibia wt (g), tibia ash (%), tibia Ca (%), tibia P (%), tibia Cu (ppm) and tibia Mn (ppm) of all the treatments of experimental broilers did not differ significantly. Similar results were also reported by Abdallah *et al*. (2009) who reported that supplementation of organic Zn, Cu and Mn at 50% and 100% levels in the diet of broilers did not have any significant effect on the tibia wt (g), tibia length (mm), tibia Ca (%) and tibia P (%) levels. Underwood and Shuttle (1999), Zhao *et al*. (2010) and Britanico *et al*. (2012) had also the similar findings. However, contradictory observations were reported by Wedekind and Baker (1989), Bao *et al*. (2007), Wang *et al.* (2008) and Idowu *et al*. (2011). With replacement of inorganic minerals with chelated minerals in the experimental diets, no significant difference was observed in the tibia mineral levels. This is in agreement with the findings of Zhao *et al*. (2010). They reported that by replacing 50% of the inorganic Zn, Cu and Mn in the control ration with chelated minerals in dietary treatments, no significant difference was observed between the control and treatment groups for tibia mineral content.

ACKNOWLEDGEMENT

Authors are highly obliged to the All India coordinate research project on “Improvement of feed resources and nutrient utilization in raising animal production” of ICAR, New Delhi, for providing all financial support to carry out this research work.

REFERENCES

Abdallah A G, El-Husseiny O M and Abdel-Latit K O. 2009. Influence of some dietary organic mineral supplementations on broiler performance. *International Journal of Poultry Science* **8** (3): 291–98.

Al-Daraji H J and Amen M H M. 2011. Effect of dietary zinc on certain blood traits of broiler breeder chickens. *International Journal of Poultry Science* **10** (10): 807–13.

AOAC. 1995. *Official Methods of Analysis*. 16th edn. Association of Official Analytical Chemist, Benjamin Frankin Station, Washington D C.

Baker D H and Halpin K M. 1987. Research note : Efficacy of manganese protein chelate compared with that of manganese for chicks. *Poultry Science* **66**: 1561–63.

Banks K M, Thempson K I, Rush J K and Applegate T J. 2004. Effects of copper source on phosphorus retention in broiler chicks and laying hens. *Poultry Science* **83**: 990–96.

Bao Y M, Choct M, Iji P A and Bruerton K. 2007. Effect of organically complexed copper, iron, manganese and zinc on broiler performance, mineral excretion and accumulation in tissues. *Journal of Applied Poultry Research* **16**: 448–55.

Britanico E B, Merca F E, Angeles A A, Acda S P and Luis E S. 2012. Effects of supplementing diets with amino acid chelates of copper, zinc, manganese and iron on the performance of broilers. *Philippines Journal of Veterinary and Animal Science* **38** (1): 1–10

Burrell A L, Dozier W A, Davis A J, Compton M M, Freeman M E, Vendrell P F and Ward T L. 2011. Responses of broilers to dietary zinc concentrations and sources in relation to environmental implications. *British Poultry Science* **45:** 255–63.

Cao J, Henry P R, Guo R, Holwerda R A, Toth J P, Littell R C, Miles R D and Ammerman C B. 2000. Chemical characteristics and relative bioavailability of supplemental organic zinc sources for poultry and ruminants. *Journal of Animal Science* **78**: 2039–54.

Chowdhury S D, Paik, I K, Namkung H and Lim H S. 2004. Responses of broilers chickens to organic copper fed in the form of copper-methionine chelate. *Animal and feed Science Technology* **115**: 281–93.

Dozier W A, Davis A J, Freeman M E and Ward T L. 2002. Zinc and copper excretion of broiler chicks fed gradient concentrations of zinc and copper from three different sources. *Poultry Science* **81** (Suppl. 1): 141.

Herzig I, Navratilova M, Totusek J, Suchy P, Vecerek V, Blahova J, Zraly Z. 2009. The effect of humic acid on zinc accumulation in chicken broiler tissues. *Czech Journal of Animal Science* **54**: 121–27.

Idowu O M O, Ajuwon R O, Oso A O and Akinloye O A. 2011. Effects of zinc supplementation on laying performance, serum chemistry and zinc residue in tibia bone, liver, excreta and egg shell of laying hens. *International Journal of Poultry Science* **10** (3): 225–30.

Panda B and Mohapatra S C. 1989. Bleeding of Poultry modified by Kosher's method. *Poultry Production*. P-121. ICAR Publication, New Delhi.

Parak Tomas and Strakova E. 2011. Zinc as a feed supplement and its impact on plasma cholesterol concentrations in breeding cocks. *Acta Veterinaria Brno* **80**: 281–85.

Pierce Ao T, Power J L, Dawson R, Pescatore K A, Cantor A J A H and Ford M J. 2006. Evaluation of Bioplex Zn as an organic Zn source for chicks. *International Journal of Poultry Science* **5**: 808–11.

Power R, Lyons T P and Jacques K A. 2006. Organic mineral absorption: Molecular mimicry or modified mobility. Nutritional Biotechnology in the Feed and Food Industries. *Proceedings of the 22nd Annual Symposium.* Pp. 228–35. Nottingham University Press, Nottingham, U K.

Rossi P, Rutz F, Anciuti M A, Rech J L and Zauk N H F. 2007. Influence of graded levels of organic Zinc on growth performance and carcass traits of broilers. *Journal of Applied Poultry Research* **16**: 219–25.

Shyam Sunder G, Panda A K, Gopinath N C S, Rama Rao S V, Raju M V LN, Reddy M R and Vijay Kumar Ch. 2008. Effects of higher levels of zinc supplementation on performance, mineral availability and immune competence in broiler chickens. *Journal of Applied Poultry Research* **17**:79–86.

Snedecor G W and Cochran W G. 1998. *Statistical Methods.* 6th edn. Oxford and IBH Publishing Company, Kolkata, India.

Swiatkiewicz S, Koreleski J and Dai Q Z. 2001. The bioavailability of Zinc from inorganic and organic sources in broiler chickens as affected by addition of phytase. *Journal of Animal and Feed Science* **10**: 317–28.

Talapatra S K, Ray S C and Sen K C. 1940. The analysis of mineral constituents in biological materials. 1. Estimation of phosphorus, chloride calcium, magnesium and potassium in food stuff. *Indian Journal of Veterinary Science and Animal Husbandry* **10:** 243–58.

Tronina W, Kinal S and Lubojemska B. 2007. Effect of various forms of zinc applied in concentrate mixtures for broiler chickens on its bioavailability as well as meat composition and quality. *Polish Journal of Food and Nutrition Sciences* **57** (4C): 577–81.

Underwood E J and Suttle N F. 1999. *The Mineral Nutrition of Livestock.* 3rd edn. CABI Publishing, Wallingford, Oxon, UK.

Van der Klis J D and Kemme P A. 2002. An appraisal of trace elements: Inorganic and organic. *Poultry Feedstuffs: Supply, Composition and Nutritive Value*. (Eds) McNab J M and Boorman K N. CABI Publishing, Wallingford, UK: 99–108.

Waldroup P W, Fritts C A and Yan F. 2003. Utilization of Biomos mannanoligosaccharide and Bioplex copper in broiler diets. *International Journal of Poultry Science* **2**: 44–52.

Wang Z, Cerrate S, Yan F, Sacakli P and Waldroup P W. 2008. Comparison of different concentrations of inorganic trace minerals in broiler diets on live performance and mineral excretion. *International Journal of Poultry Science* **7** (7): 625–29.

Wedekind K J and Baker D H. 1990. Zinc bioavailability in feed-grade sources of zinc. *Journal of Animal Science* **68**: 684–89.

Wedekind K J, Hortin A E and Baker D H. 1992. Methodology for assessing zinc bioavailability: Efficacy estimates for zinc-methionine, zinc sulphate and zinc oxide. *Journal of Animal Science* **70**:178–87.

Zhao J, Shirley R B, Vazquez-Anon M, Dibner J J, Richards J D, Fisher P, Hampton T, Christensen K D, Allard J P and Giesen A F. 2010. Effects of chelated trace minerals on growth performance, breast meat yield, and footpad health in commercial meat broilers. *Journal of Applied Poultry Research* **19**: 365–72.