JOURNAL OF ADVANCED VETERINARY AND ANIMAL RESEARCH
ISSN 2311-7710 (Electronic)
http://doi.org/10.5455/javar.2019.f313
A periodical of the Network for the Veterinarians of Bangladesh (BDvetNET)

March 2019
VOL 6, NO. 1, PAGES 66–73

ORIGINAL ARTICLE

Comparative effects of inorganic and three forms of organic trace minerals on growth performance, carcass traits, immunity, and profitability of broilers

Anguara Khatun[1], Sachchidananda Das Chowdhury[1], Bibek Chandra Roy[1], Bapon Dey[1], Azimul Haque[2], Bakthavachalam Chandran[2]
[1]Department of Poultry Science, Bangladesh Agricultural University, Mymensingh, Bangladesh
[2]Kemin Industries South Asia Pvt. Ltd., #C-3, 1st Street, Ambattur Industrial Estate, Chennai, India

ABSTRACT

Objective: The experiment was conducted to investigate the comparative effects of inorganic trace minerals (ITM) and three forms of organic trace minerals (OTM) (propionate, metho-chelated, and proteinate) on growth performance, edible meat yield, immunity, and profitability of commercial broilers.
Materials and methods: A corn-soya based mash diet comprising four treatments each of 10 replicates were fed to 720 day-old Cobb 500 broiler chicks for 35 days (starter diet 0–21 days and grower diet 22–35 days). The diets for comparison were as follows: diet 1: control diet with ITM premix at 1 kg/ton of feed (T_1); diet 2: control diet supplemented with propionate trace minerals at 600 gm/ton (T_2); diet 3: control diet supplemented with metho-chelated trace minerals at 500 gm/ton by reducing 225 gm methionine/ton of feed (T_3); and diet 4: control diet supplemented with proteinate trace minerals at 500 gm/ton of feed (T_4). Growth performance, carcass yield, and antibody titer (AT) data were recorded. Data were analyzed and interpreted using SAS Computer Package Program version 9.1.
Results: Feeding propionate and proteinate OTM showed similar performance. Birds fed these two types (propionate and proteinate) or OTM had better performance in comparison with those receiving ITM and metho-chelated one. Proteinate group produced more wing meat and propionate group showed higher breast and drumstick meat yield as compared with those received the metho-chelated trace mineral and ITM. The birds belonging to OTM groups showed significantly higher AT level against infectious bursal disease. Proteinate minerals groups showed higher profitability followed by propionate fed broilers.
Conclusion: Two forms of OTM, propionate and proteinate improved performance of commercial broilers over those of ITM and metho-chelated one.

ARTICLE HISTORY

Received November 12, 2018
Revised December 26, 2018
Accepted December 27, 2018
Published February 03, 2019

KEYWORDS

Cobb 500; inorganic trace mineral; meat yield; performance; profitability

Introduction

Trace minerals are indispensable components in the poultry diets. They are required for growth, bone development, well feathering, enzyme structure and function, and appetite. Trace minerals act as catalysts for many biological reactions within the body [1,2]. There are two sources of trace elements: inorganic and organic. Common sulfates, oxides, chlorides, and carbonates are inorganic sources and they are reluctance in their bioavailability. A combination of amino acids and hydrolyzed protein produced organic trace minerals (OTM) from the chelation of a soluble salt [3]. Through a coordinated bond, chelated minerals are attached with an organic ligand. The relative bioavailability and efficacy of the OTM may vary depending on the ligand attached to the mineral, bond strength, and Ligand to Mineral (L:M) ratio. Propionic acid is the ligand attached to metal propionates whereas the OTM of proteinate are attached with soy protein. The organic mineral in other product is attached with methionine hydroxy analogue [3].

Correspondence Anguara Khatun anjuarabau@gmail.com Department of Poultry Science, Bangladesh Agricultural University, Mymensingh, Bangladesh.

How to cite: Khatun A, Chowdhury SD, Roy BC, Dey B, Haque A, Chandran B. Comparative effects of inorganic and three forms of organic trace minerals on growth performance, carcass traits, immunity, and profitability of broilers. J Adv Vet Anim Res 2019; 6(1):66–73.

It is well recognized that organic chelates play a crucial role in absorption of nutrients in the gut and enhance the bioavailability. Iron, copper, zinc, manganese, chromium, and selenium are the common organically bound trace minerals. The main function of zinc and copper is to improve health and performance. Organic manganese is important for the enhancement of growth, bone development, and fertility of animals [1]. Iron helps in transporting oxygen and carbon dioxides in the body. In commercial practice, inorganic trace minerals (ITM) are used to supply 2–10 times more trace minerals than the amounts recommended by the National Research Council for poultry diets [4] in order to avoid trace mineral deficiencies and allowing birds to reach their genetic growth potential [5]. Increased levels of ITM in the feed can interfere with bioavailability of other minerals because of the wide safety margins of ITM. They are excreted in high levels because of their low retention rate with a consequent detrimental effect on environment. OTM are highly bioavailable than ITM [6–8]. Poultry diet requires lower concentration of OTM in diet and they had no negative impact on production performance and environment [9]. The various forms of organic minerals may vary in their retention rate and consequently their effect on productivity, meat yield, and other traits may also differ, and therefore, their comparative efficacy needs investigation. A few research works have been done with inorganic minerals in Bangladesh but to our knowledge, no comparative study was done between ITM and OTM, particularly, with propionate, metho-chelated, and proteinate trace minerals. This is probably the first time we have done this research work with OTM and ITM with specific doses. Therefore, the present study was designed to investigate the comparative effect of different forms of OTM (propionate, metho-chelated, and proteinate) side by side with commonly used ITM on growth performance, edible meat yield characteristics, and antibody titer (AT) level against infectious bursal disease (IBD) and cost effectiveness in commercial broilers.

Materials and Methods

Ethical approval

All protocols and ethical use of experimental animals were approved by the Animal Welfare and Ethical Committee, Bangladesh Agricultural University, Mymensingh-2202 (No. 09/AWEC/BAU/2018).

Experimental birds, diets, and management

The experiment was conducted in an open-sided house at Bangladesh Agricultural University (BAU) Poultry Farm, Mymensingh. The period of experiment was October 25 to November 30, 2014 (35 days). Seven hundred and twenty day-old chicks (DOCs) were considered for the research to determine the productivity, carcass traits, AT level against IBD, and profitability of commercial broilers. The broiler chicks were divided into four dietary groups. Each group was then replicated to 10 sub-groups each of having 18 chicks. A corn-soybean meal-based diet was formulated by including ITM to meet the nutrient requirements of Cobb 500 commercial broiler [10]. Here, ITM group was considered as control group. First group of chicks was maintained on diet 1: control diet with ITM premix at 1 kg/ton of feed (T_1). The second group of chicks was fed diet 2 containing the control diet supplemented with propionate minerals at 600 gm/ton (T_2). The third group (diet 3) was maintained containing control diet supplemented with metho-chelated trace minerals at 500 gm/ton by reducing 225 gm methionine/ton (T_3). The fourth group of chicks was fed diet 4 containing control diet supplemented with proteinate trace minerals at 500 gm/ton of feed (T_4). Metho-chelated trace mineral itself contained methionine, whereas other OTM did not contain methionine. This was the reason why 225 gm methionine/ton of feed had been reduced in metho-chelated group to minimize cost. The ingredient and nutrient composition of the control diet are shown in Table 1.

Table 1. Ingredient and nutrient composition of control diets (100 kg).

Ingredients	Starter diet (0–21 days)	Grower diet (22–35 days)
Corn	51.16	61.45
Soybean meal, 44%	41.71	31.63
Soybean oil	3.38	3.1
Dicalcium phosphate	1.63	1.725
Calcium carbonate	0.953	0.94
Sodium chloride	0.273	0.273
Sodium bicarbonate	0.23	0.23
DL-methionine	0.305	0.252
L-lys-HCl	0.08	0.11
L-threonine	0.03	0.04
Vitamin-mineral premix	0.25	0.25
Inorganic minerals	0.1	0.1
Nutrient composition		
ME, kcal/kg	2900	3000
Crude Protein, %	22.7	19.2
Ca, %	0.90	0.86
Av. P %	0.40	0.39
Lysine %	1.41	1.17
Methionine %	0.68	0.58

T_1=0.1kg ITM/100 kg of feed; T_2=0.06 kg prpopinate minerals/100 kg of feed; T_3=0.05 kg methochelated minerals-225 gm metheonine/100 kg of feed; T_4=0.05 kg proteinate minerals /100 kg of feed; ME = metabolizable energy; kcal = kilo calorie; kg = kilogram; Lys = Lysine; Ca = Calcium; Av. = available phosphorus; % = percentage.

All birds were kept under identical condition of management. The room area was 400 sq. ft. The room was partitioned into 40 pens of equal size. Wire net and bamboo materials were used for partitioning the pen. The area of each pen was 21 square feet (7 ft × 3 ft). Chicks were purchased from a reputed commercial hatchery (CP Bangladesh Ltd.). After arrival, birds were placed randomly on the floor of pens. At first, their initial body weight was recorded. Glucovet powder (a mixture of 490 gm glucose and 10 gm vitamin C in 500 gm powder, manufactured by the ACME Laboratories Ltd, Bangladesh) was added in drinking water to overcome dehydration. For the first 3 days, feeds were supplied every 4-h interval and then from 4 to 13 days three times daily and finally twice daily (early in the morning at 6:00 AM and evening at 8:00 PM). For first 5 days, feeds were given on a newspaper along with one plastic drinker in each pen. Afterward, two round plastic tube feeders and one medium plastic drinker (8 l capacity) were allotted for the birds of each pen during 3 weeks and onwards. Feeds were offered *ad libitum*. Fresh and clean drinking water was supplied three times daily (morning, noon, and evening). Therefore, the birds had free access to both feed and water. Feeders were cleaned every day in the evening, while drinkers were washed two times daily (morning and evening). The birds were exposed to 23 h of lighting and a dark period of 1 h daily. A foot bath was maintained at the gate of the shed where bleaching powder and TH_4^+ solution was used alternatively as a disinfectant. Spraying was done outside the shed twice daily (morning and evening). Fresh and dry rice husks were spread on the floor of the pens as litter materials.

Strict vaccination program was maintained throughout the experimental period as a most effective part of the disease prevention program. On day 6, birds were vaccinated against infectious bronchitis and Newcastle disease by (ND) MA5+Clone30. Vaccination was performed by 228E on day 10 against IBD and its booster dose was applied at day 17, whereas the vaccination with the booster dose of ND was done by Clone30 at day 21. All vaccines were manufactured by INTERVET BV (Netherlands) and administered according to the recommendation.

Data collection and record keeping

Body weight, feed intake, feed conversion ratio (FCR), and survivability were measured at 7, 14, 21, 28, and 35 days of age, respectively. Temperature and relative humidity (RH) both at chick level were recorded four times (6.00 AM, 12.00 PM, 4.00 PM, and 10.00 PM) daily. Temperature and RH were recorded by using an automatic thermo-hygrometer. During extreme condition, especially at the late afternoon and evening, temperature and RH were recorded more frequently. Maximum temperature (35.5°C) was recorded at first week of November when birds' sufferings were more due to heat stress.

Processing of broilers

At the end of experiment (35 days), 10 birds from each of four treatments comprising five replications each (one male and one female from each replication), close to average weight of each replication, were selected for the determination of carcass characteristics. The birds were sacrificed by cervical dislocation and allowed to bleed for 2 min and immersed in hot water (51°C–55°C) for 120 sec in order to lose the feathers [11]. The official guidelines were followed to ensure the animal welfare. Feathers were removed by hand pinning. Dressed broilers were cut into different major parts such as breast, thigh, drumstick, and wing. Finally, each cutup parts were weighed and recorded. Carcass yield was calculated by combining male and female data.

Collection of blood sample

Blood samples were collected on days 6, 10, 17, and 35. Falcon tubes were used to collect the blood during slaughtering. The first time collection was done from all dietary groups at sixth day of age by sacrificing and the remaining collections at different ages were performed from jugular vein. Total number of collected samples was 8, 20, 40, and 40 on days 6, 10, 17, and 35, respectively. Blood samples were preserved in a refrigerator (+4°C) for 3 days. After 3 days, separated serum was poured into Eppendorf tube from the collected blood. If any blood was present in serum then we have centrifuged the samples to avoid blood. The speed of centrifuge machine was 2,000 rpm for 5 min. Afterward, the serum samples were preserved in fridge (−20°C) for 15 days. Then, the samples were transferred to "Paragon Poultry Care Laboratory" (Gazipur, Dhaka) for the determination of AT against IBD. AT was measured by enzyme-linked immunosorbent assay (ELISA) test, as described by the manufacturer of the ELISA kit (Biochek, Holland).

Economic analysis

Cost of production was calculated based on some specific items such as chicks, feed, vaccine, test ingredients, and casual labor. Some of these cost heads were widely varied due to fluctuating market price. However, the total production cost per bird and per kg broiler was calculated. The additional costs incurred for test ingredients were also considered in performing cost benefit analysis.

Statistical analysis

Data of body weight, body weight gain, feed consumption, FCR, survivability, and edible meat characteristics of

Table 2. Performance of commercial broilers fed inorganic and different forms of organic trace minerals.

Variables	Dietary treatments				*p* value
	Inorganic (T_1)	Propionate (T_2)	Metho-chelated (T_3)	Proteinate (T_4)	
ILW (gm/b)	45 ± 0.61	45 ± 0.45	45 ± 0.30	45 ± 0.83	0.80
FLW (gm/b)	1,762 ± 31.7	1,790 ± 20.3	1,785 ± 24.0	1,810 ± 24.8	0.63
LWG (gm/b)	1,717 ± 31.7	1,745 ± 20.4	1,740 ± 23.9	1,765 ± 24.8	0.63
FC (gm/b)	2,888 ± 27.8	2,882 ± 25.88	2,913 ± 14.16	2,908 ± 23.6	0.75
FCR	1.68 ± 0.03	1.65 ± 0.03	1.67 ± 0.03	1.65 ± 0.02	0.61
Sur (%)	98.88 ± 0.08	99.94 ± 0.06	99.94 ± 0.06	99.89 ± 0.07	0.56

T_1 = inorganic trace minerals; T_2 = propionate minerals; T_3 = metho-chelated; T_4 = proteinate trace minerals; ILW = initial live weight; FLW = final live weight; LWG = live weight gain; FC = feed consumption; FCR = feed conversion ratio; Sur = survivability; gm/b = gram per bird; ± Indicates standard error of mean (SEM).

broilers were recorded. The data were subjected to analysis of variance in a completely randomized design by using statistical software computer program. Duncan's Multiple Range Test was used to compare the differences in mean values [12].

Results and Discussion

Table 2 represents the productive performance of broilers receiving diets supplemented with inorganic and three forms of OTM. The initial body weight of birds belonging to different treatments was similar. At the end of 35 days of age, the highest live weight was found in broilers fed proteinate minerals (1,810 gm). This was followed by broiler belonging to propionate group (1,790 gm), metho-chelated (1,785 gm), and inorganic group (1,762 gm), respectively. Numerically, 2.72% higher body weight was noted in broilers fed proteinate, 1.59% in propionate, and 1.31% in metho-chelated minerals treated birds, respectively, compared with inorganic mineral group although differences in values among the dietary treatments were statistically non-significant ($p > 0.05$). It is well established that OTM are environment-friendly because of their lower excretion rate and it remains long time in the gut consequently improves the growth performance [13]. They are highly bioavailable because they have higher retention rate in the body compared with inorganic minerals [9]. They acted as a performance enhancer. It was shown that the final body weight did not differ statistically between the birds fed OTM and ITM containing feeds [14] which were also in agreement with our result. Pacheco et al. [15] reported that organic Zn and inorganic Zn had no significant effect on the body weight which was also found by several authors [16–20]. In another study [21], broiler birds fed yeast proteinate-supplemented diet had better effect on body weight (BW) compared with negative control, ITM, and methionine chelates of trace minerals (Met-TM) groups ($p < 0.001$) which agreed with our numerically higher results. Bao et al. [22] found that OTM had positive effects on live weight gain. But, there was no significant difference ($p > 0.05$) in BW gain between OTM and the positive (inorganic) control which supports the results of our study. Our result was coincided with the result of another study [13], where it was shown that although OTM facilitated greater bioavailability, they did not significantly affect body weight gain of birds.

The average feed consumption pattern of the broilers in different treatment groups are shown in Table 2. Higher feed intake was observed in metho-chelated (2,913 gm/bird), proteinate (2,908 gm/bird), inorganic (2,888 gm/bird), and propionate (2,882 gm/bird) groups, respectively. The lowest feed consumption was found in propionate (2,882 gm/bird) trace minerals-treated birds. Feed consumption data revealed that birds of all groups consumed more or less similar amounts of feed up to 35 days of age and so, the differences in feed intake did not differ significantly ($p > 0.05$). Organic minerals are chelating agents that help in better feed absorption and utilization in the body tissue and decline mineral excretion from the body. Therefore, OTM enhanced feed intake. Baloch et al. [23] reported that OTM supplementation did not significantly affect feed intake. The finding agreed with the present result. Sunder et al. [19] also found that feed intake was not significantly affected by feeding OTM and ITM. Osama et al. [24] mentioned that OTM reduced feed intake compared with ITM. In our research, OTM groups consumed more feed although not significant, compared with inorganic group which was opposite to the result of Osama et al. [24].

In this study, FCR was better in proteinate (1.65) and propionate (1.65) trace minerals fed groups over metho-chelated (1.67) and inorganic group (1.68). Since the values were close to each other in different dietary treatments, there was no statistical difference. OTM are easily absorbed in intestinal wall and excrete lower amounts from the body. They effectively converted feed into body muscle. Baloch et al. [23] observed that OTM and ITM, when used in the diet, had no significant effect on FCR, which agreed with our result. Zhao et al. [25] also showed that FCR was not affected by chelated Cu and three different sources of Zn as compared with inorganic zinc. Feed conversion, mortality, and tibia Zn were not affected by dietary treatments ($p > 0.5$). Singh et al. [21] found that yeast proteinate group had improved FCR compared with ITM and other OTM fed groups. Their results were similar to our findings. Sunder et al. [19] also reported that OTM had no significant effect on FCR which resembled our result. The birds that fed OTM diets, tended to improve FCR [9] which was coherent with our results.

The survivability of inorganic group was 98.8% and in OTM fed groups 1% more (99.8%). Thus, OTM fed groups showed better survivability compared with ITM although differences among treatments were not significant. Mortality occurred during 3–6 PM when the environmental temperature and RH were nearly 35°C and 60%, respectively. During this particular time, birds of all groups showed open mouth panting which was the response of birds to heat stress. The birds spread wings and squatted close to the ground, showed very limited movement, slowness and lethargic attitudes, increased respiratory rate, gasping, water intake, and voided more amount of dropping. Post-mortem examination revealed that heart muscle increased in size at the right atrium with significant amount of blood accumulation and crop and gizzard were empty and dry. External and post-mortem symptoms clearly indicated that birds from all groups suffered more or less from heat stress but the control (ITM) group had lower ability to combat heat stress. Higher mortality was recorded in control group as they suffered more. This was because of the fact that ITM were less absorbed due to interactions with fiber, phytate, oxalate, silicates, or other minerals in the gastrointestinal tract [26], and, therefore, could not boost up immunity similar to OTM fed birds. It is well established that OTM are more bioavailable [6,7] and that they boost up immunity, and therefore improved the growth [27]. Better survivability in OTM fed groups indicates that birds belonging to inorganic group were less efficient to adopt with hot humid conditions. These findings agreed with the results of the recent studies [23,25,28].

Edible meat yield characteristics of broilers fed ITM and different forms of OTM are shown in Table 3. Dressing percentage (DP) did not show any significant difference among the dietary groups. Numerically, the highest DP was found in birds that received OTM compared with inorganic group. The higher values (8.5%) for thigh meat were observed in proteinate (T_4) and those of the lowest values were for inorganic (T_1) and metho-chelated (T_3) groups. There were no statistical differences among organic minerals with respect to drumstick and breast meat but the highest drumstick (7.1%) and breast meat (29.9%) was found in propionate (T_2) group. The wing meat value (5.3%) was numerically higher in proteinate group compared with inorganic and other OTM groups. The heart weight was numerically higher in ITM group compared with others organic minerals groups. Feeding OTM had no significant effect on liver, gizzard, and giblet weight. The wing meat was higher in proteinate group compared with other OTM and inorganic diet group. Manangi et al. [29] found that male birds had significantly higher wing meat yield ($p < 0.01$) in OTM group as compared with ITM which was more or less similar with the results of our research. Zhao et al. [5] have also shown that OTM had no significant effects on DP and giblet weight which was similar to our outcomes. The OTM had no significant effect on liver, gizzard, and giblet weight which agreed with the results of previous researchers [22,30].

Antibody titre against IBD as obtained by ELISA test is shown in Figure 1. The maternal AT level was high on the sixth day of age, as would be expected. The titer level was decreased with the advancement of age as detected at 10th day. Following vaccination by IBD at 10th day, it took 6–7 days to develop immunity as reflected by an increased titer

Table 3. Effects of inorganic and organic trace minerals on meat yield characteristics.

Variables	Dietary treatments				*p* value
	T_1	T_2	T_3	T_4	
Dressing (%)	69 ± 1.3	69.4 ± 0.8	70.7 ± 0.2	70.0 ± 0.9	0.5
Thigh (%)	8.2 ± 0.04	8.4 ± 0.2	8.2 ± 0.2	8.5 ± 0.24	0.6
Drumstick (%)	7.0 ± 0.2	7.1 ± 0.09	6.8 ± 0.2	6.7 ± 0.12	0.3
Breast (%)	28.6 ± 0.26	29.9 ± 0.5	29.7 ± 0.6	29.1 ± 0.85	0.5
Wing meat (%)	5.2 ± 0.07	5.2 ± 0.09	4.6 ± 0.1	5.3 ± 0.15	0.08
Heart (%)	0.7 ± 0.02	0.6 ± 0.01	0.6 ± 0.01	0.6 ± 0.03	0.09
Liver (%)	3.5 ± 0.12	3.4 ± 0.14	3.4 ± 0.2	3.33 ± 0.17	0.85
Gizzard (%)	2.6 ± 0.11	2.54 ± 0.11	2.6 ± 0.12	2.6 ± 0.22	0.98
Giblet (%)	6.5 ± 0.02	6.5 ± 0.25	6.6 ± 0.11	6.5 ± 0.29	0.96

T_1 = inorganic trace minerals; T_2 = propionate minerals; T_3 = metho-chelated; T_4 = proteinate trace minerals; ± Indicates standard error of mean (SEM); % = percentage.

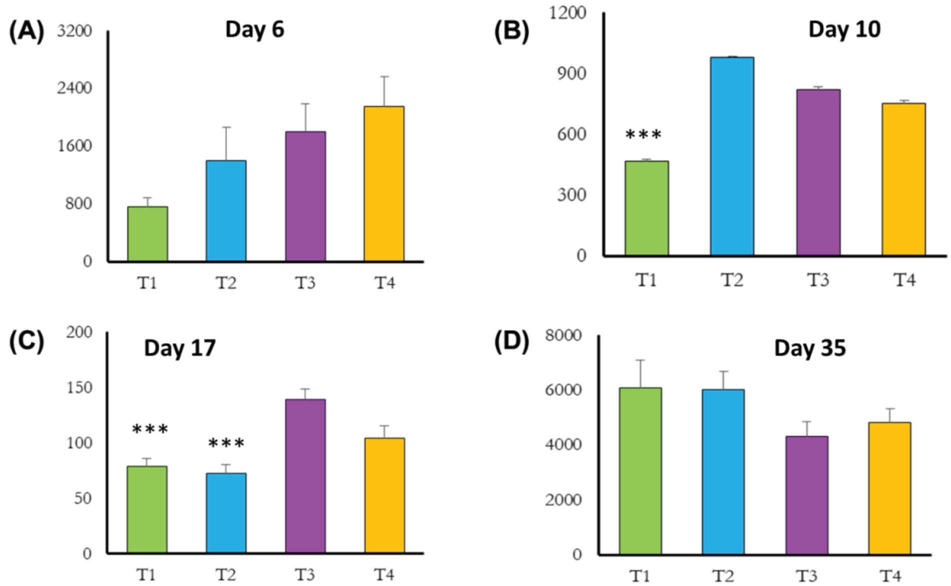

Figure 1. AT against IBD as obtained by ELISA test at different ages (A–D), where T_1: Inorganic; T_2: Propionate; T_3: Metho-chelated; and T_4: Proteinate. There were no significant differences in the IBD titre at day 6 and day 35 among dietary treatment groups (A and D). The inorganic group had significantly lower IBD titre level than other treatment groups in 10 days of birds age (B). On the other hand, inorganic and propionate groups had significantly lower titre level than other two treatment groups at 17 days of bird age (C). *** = highly significant.

Table 4. Cost benefit analysis for feeding different forms of organic trace minerals to broilers.

Items	T_1	T_2	T_3	T_4
Feed intake (kg/bird)	2.89	2.88	2.91	2.91
Final weight (kg/bird)	1.76	1.79	1.79	1.81
Feed price (kg)	35.95	35.96	35.94	35.93
Inorganic at Tk.190/kg	0.19	0.00	0.00	0.00
Propionate at Tk.210/kg	0.00	0.125	0.00	0.00
Metho-chelated at Tk.225/kg	0.00	0.00	0.113	0.00
Proteinate at Tk.225/kg	0.00	0.00	0.00	0.113
Feed cost/kg	36.14	36.08	36.05	36.04
Feed cost/bird	104.44	103.94	104.91	104.88
Others (Chicks, vaccines, litter, disinfectants, transport, labor etc.)	65.00	65.00	65.00	65.00
Total cost production Tk./broiler	169.44	168.94	169.91	169.88
Total cost of production Tk./kg	96.27	94.38	94.92	93.86
Sale price Tk. /broiler at 120/kg	211.20	214.80	214.80	217.20
Profit Tk./broiler	41.76	45.86	44.89	47.32
Profit Tk./kg	23.72	25.62	25.08	26.14
Profit Tk./kg (over control)	0.00	1.90	1.36	2.72

T_1 = inorganic trace minerals; T_2 = propionate minerals; T_3 = metho-chelated; T_4 = proteinate trace minerals; kg = kilogram; Tk. = Taka, / = per.

level at 17th day of age for all dietary treatments. More improvement in titer level was observed in OTM groups against IBD after completing booster dose at 17th day of age and it was found as maximum at the point of termination of the experiment (35 days).

The AT level in OTM-treated groups was significantly higher than that of ITM-treated group at 10 and 17 days of age of birds. Among the OTM treated groups, propionate showed significantly relatively lower AT level than metho-chelated and proteinate groups at 17 days of bird age. Improvement of AT against IBD in OTM might be attributed to better immune-modulatory effects on phagocytic cells, T and B lymphocytes, CD+ cell, and other immune organs which are involved in enhancing the immune response consequently increased AT against diseases was achieved. It might be a reason why OTM containing diets receiving birds showed higher AT than ITM group. These findings agreed with the results of previous studies [31,32].

Data related to cost and return over investment (ROI) were evaluated and the results of the cost-benefit analysis for economic status of broiler chicks fed on diets containing different trace minerals are presented in Table 4. Feed cost was highest in birds fed inorganic minerals (at BDT 36.14/kg) and lowest in proteinate fed minerals (at BDT 36.04/kg). The total cost of production was maximum in inorganic (at BDT 96.27/kg) and lowest in proteinate group (at BDT 93.86/kg). The highest extra cost was incurred in inorganic fed group and lowest extra cost was incurred in metho-chelated and proteinate treated birds, respectively. Supplementation of proteinate minerals in the diet of commercial broiler was more profitable (Table 4). In this research, it was found that OTM-supplemented diet reduced production cost by increasing profit which was also indicated previously in a number of studies [23,30,31].

Conclusion

The effects of feeding propionate and proteinate OTM to broilers on growth performance are either similar to or better than their inorganic counterpart and metho-chelated OTM. Wing meat was increased in proteinate fed group compared with propionate and metho-chelated minerals and inorganic minerals. Finally, the highest AT against IBD was produced in propionate fed broilers compared with birds that received other organic minerals and inorganic minerals. Using proteinate mineral was the most cost effective.

Acknowledgement

The first two authors are grateful to Kemin Industries South Asia Pvt. Ltd., India for funding this piece of research work. The authors are also thankful to Saravanan Sankaran, Kemin Industries South Asia Pvt. Ltd., India for providing technical support and to Dr. Sukumar Saha, Department of Microbiology and Hygiene, Bangladesh Agricultural University, Mymensingh for a useful discussion on immunity status of experimental birds.

Conflict of Interest

None.

Authors' contribution

Conception and design of study was accomplished by Anguara Khatun, Sachchidananda Das Chowdhury, Bibek Chandra Roy, Azimul Haque, and Bakthavachalam Chandran. Acquisition of data was performed by Anguara Khatun and Bibek Chandra Roy. Analysis and/or interpretation of data were completed by Anguara Khatun and Bibek Chandra Roy. Drafting of the manuscript was done by Anguara Khatun, Sachchidananda Das Chowdhury, Bibek Chandra Roy, Bapon Dey, and Azimul Haque. Critical revision was completed by Sachchidananda Das Chowdhury, Bibek Chandra Roy, Bapon Dey, and Bakthavachalam Chandran.

References

[1] Underwood EJ, Suttle N. The mineral nutrition of livestock. 3rd edition, CAB International, Wallingford, UK, 1999; https://doi.org/10.1079/9780851991283.0000

[2] Ayaşan T. Organic minerals in animal nutrition. J Fac Agric *Çukurova Univ* 2007; 22(1):21–8.

[3] AAFCO. Official publication of the Association of American Feed Control Officials incorporated (Ed. Paul. M. Bachman). pp. 237–8, 1998.

[4] Esenbuga N, Macit M, Karaoglu M, Aksu MI, Bilgin OC. Effects of dietary hamate supplementation to broilers on performance, slaughter, carcass and meat color. J Sci Food Agric 2008; 88(7):1201–7; https://doi.org/10.1002/jsfa.3199

[5] Zhao J, Shirley RB, Vazquez-anon M, Dibner J, Richards P, Fisher T, Hampton T, Christensen KD, Allard JP, Giesen AP. Effects of chelated of trace elements: on growth performance, breast meat yield and footpad health in commercial meat broilers. J Appl Poult Res 2010; 19(4):365–72; https://doi.org/10.3382/japr.2009-00020

[6] Aksu T, Aksu M I, Yoruk MA, Karaoglu M. Effects of organically complexed minerals on meat quality in chickens. Br Poult Sci 2011; 52(5):558–63; https://doi.org/10.1080/00071668.2011.606800

[7] Wang ZS, Cerrate C, Coto F, Waldroup PW. Evaluation of mintrex copper as a source of copper in broiler diets. Int J Poult Sci 2007; 6(5):308–13; https://doi.org/10.3923/ijps.2007.308.313

[8] Predieri GL, Elviri M, Tegoni I, Zagnoni E, Cinti G. Metal chelates of 2-hydroxy-4-methylthiobutanoic acid in animal feeding, Part 2: further characterizations, *in vitro* and *in vivo* investigations. J Inorgan Biochem 2005; 99(2):627–36; https://doi.org/10.1016/j.jinorgbio.2004.11.011

[9] Nollet L, Van der klis JD, Lensing M, Spring P. The Effect of replacing inorganic with organic trace minerals in broiler diets on productive performance and mineral excretion. J Appl Poult Res 2007; 16(4):592–7; https://doi.org/10.3382/japr.2006-00115

[10] Cobb Breeder Management Guide. 2012. Available via https://www.cobb-vantress.com (Accessed 1 December 2018).

[11] Yalcin S, Ozkan S, Acikgoz Z, Ozkan K. Effect of dietary methionine on performance, carcass characteristics and breast meat composition of heterozygous naked neck (Na-1na+) birds under spring and summer conditions. Br Poult Sci 1999; 40(5):688–94; https://doi.org/10.1080/00071669987098

[12] SAS Statistical Package. SAS Institute. Version 9.1. 2009. Available via http://support.sas.com (Accessed 1 December 2018).

[13] Leeson S, Caston L. Using minimal supplements of trace minerals as a method of reducing trace mineral content of poultry manure Anim Feed Sci Technol 2008; 142(3–4):339–47; https://doi.org/10.1016/j.anifeedsci.2007.08.004

[14] Rajkumar U, Vinoth A, Reddy PK, Shanmugam E, Rama M, Rao SV. Effect of supplemental trace minerals on hsp-70 mrna expression

in commercial broiler chicken. Anim Biotechnol 2018; 29(1):20–5; http://doi.org/10.1080/10495398.2017.1287712
[15] Pacheco BHCI, Nakagi VSI, Kobashigawa EH, Faria DEI. Dietary levels of zinc and manganese on the performance of broilers between 1 to 42 Days. Brazil J Poult Sci 2017; 19(2):171–8; https://doi.org/10.1590/1806-9061-2016-0323
[16] Bun SD, Guo YM, Guo FC, Ji FJ, Cao H. Influence of organic zinc supplementation on the antioxidant status and immune responses of broilers challenged with *Eimeria tenella.* Poult Sci 2011; 90(6):1220–6; https://doi.org/10.3382/ps.2010-01308
[17] Salim HM, Lee HR, Jo C, Lee SK, Lee BD. Effect of sex and dietary organic zinc on growth performance, carcass traits, tissue mineral content, and blood parameters of broiler chickens. Biol Trace Element Res 2012; 147(1–3):120–9; https://doi.org/10.1007/s12011-011-9282-8
[18] Yalcinkaya I, Cinar M, Yildirim E, Erat S, Basalan M, Gungor T. The effect of prebiotic and organic zinc alone and in combination in broiler diets on the performance and some blood parameters. Italian J Anim Sci 2012; 11(3):298–302; https://doi.org/10.4081/ijas.2012.e55
[19] Sunder GS, Kumer CV, Panda AK. Effect of supplemental organic Zn and Mn on broiler performance, bone measures, tissue mineral uptake and immune response at 35 days of age. Poult Sci 2013; 3(1):1–11; http://doi.org/10.1007/s12011-010-8647-8
[20] Vieira MM, Ribeiro AML, Kessler AM, Moraes ML, Kunrath MA, Ledur VS. Different sources of dietary zinc for broilers submitted to immunological, nutritional, and environmental challenge. J Appl Poult Res 2013; 22(4):855–61; https://doi.org/10.3382/japr.2013-00753
[21] Singh AK, Ghosh TK, Haldar S. Effects of methionine chelate- or yeast proteinate-based supplement of copper, iron, manganese and zinc on broiler growth performance, their distribution in the tibia and excretion into the environment. Biol Trace Element Res 2015; 164(2):253–60; https://doi.org/10.1007/s12011-014-0222-2
[22] Bao YM, Choct M, Iji PA, Bruerton K. Effect of organically complexed copper, iron, manganese, and zinc on broiler performance, mineral excretion, and accumulation in tissues. J Appl Poult Res 2007; 16(3):448–55; https://doi.org/10.1093/japr/16.3.448
[23] Baloch Z, Yasmeen N, Pasha TN. Effect of replacing inorganic with organic trace minerals on growth performance, carcass characteristics and chemical composition of broiler thigh meat. Afr J of Agric Res 2017; 12(18):1570–5; https://doi.org/10.5897/AJAR2016.12104
[24] Osama M, EL-Husseiny OM, Hashish SM, Ali RA, Arafa SA, ABD EL-Samee LD, Olemy AA. Effects of feeding organic zinc, manganese and copper on broiler growth, carcass characteristics, bone quality and mineral content in bone, liver and excreta. Int J Poult Sci 2012; 11(6):368–77; https://doi.org/10.3923/ijps.2012.368.377
[25] Zhao J, Robert B, Shirley, Julia J, Dibner J. Superior growth performance in broiler chicks fed chelated compared to inorganic zinc in presence of elevated dietary copper. J Anim Sci Biotechnol 2016; 7(1):13–21; https://doi.org/10.1186/s40104-016-0072-1
[26] Akter M, Lji PA, Graham H. Increasing zinc levels in phytase supplemented dites improves the performance and nutrient utilization of broiler chickens. South Afr J Anim Sci 2017; 47(5):648–60; https://doi.org/10.4314/sajas.v47i5.8
[27] Overton TR, Yasui T. Practical applications of trace minerals for dairy cattle. J Anim Sci 2014; 92(2):416–26; https://doi.org/10.2527/jas.2013-7145
[28] Tavares T, Mourão JL, Kay Z. The effect of replacing inorganic trace minerals with organic Bioplex® and Sel-Plex® on the performance and meat quality of broilers. J Appl Anim Nutr 2014; 2(10):1–7; https://doi.org/10.1017/jan.2014.2
[29] Manangi MK, Vazquez-Añon M, Richards JD. Impact of feeding lower levels of chelated trace minerals versus industry levels of inorganic trace minerals on broiler performance, yield, footpad health, and litter mineral concentration. Appl Poult Res 2012; 21(4):881–90; https://doi.org/10.3382/japr.2012-00531
[30] Bao YM, Choct M. Trace minerals nutrition for broiler chickens and prospects of application of organically complexed trace minerals: a review. Anim Prod Sci 2009; 49(4):269–82; https://doi.org/10.1071/EA08204
[31] Oviedo-Rondon EO, Leandro NM, Ali R, Koci M, Moraes V, Brake J. Broiler breeder feeding programs and trace minerals on maternal antibody transfer and broiler humoral immune response1. J Appl Poult Res 2013; 22(3):499–510; https://doi.org/10.3382/japr.2012-00708
[32] Soni N, Mishra SK, Swain R, Sethy K. Bioavailability and immunity response in broiler breeders on organically complexed zinc supplementation. Food Nutr Sci 2013; 4(2):1293–300; https://doi.org/10.4236/fns.2013.412166