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Effect of Dietary Supplementation of Organic Trace Minerals at Reduced Concentrations on Performance, Bone Mineralization, and Antioxidant Variables in Broiler Chicken Reared in Two Different Seasons in a Tropical Region

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Abstract

Two experiments were conducted to study the performance, antioxidant activity, and bone mineral variables in broilers fed organic trace minerals (OTM) at lowered concentrations in the diet. In experiment 1, a total of 1500 day-old broiler male chicks were randomly distributed into six groups with 10 replicates of 25 chicks each and housed in floor pens (1.90 × 1.22 m). One group was fed the maize-soybean meal–based control diet, supplemented with inorganic trace mineral (ITM) premix containing Mn, Zn, Fe, Cu, Se, and Cr at 50, 45, 40, 7.5, 0.30, and 0.25 mg/kg, respectively. The remaining groups of chicks were fed the diets, where the ITM premix was replaced with OTM mix so as to provide the respective minerals at graded levels in the diet (100, 75, 50, 40, and 30% of the control diet). Similarly, in experiment II, a total of 1350 day-old male broiler chicks were divided at random into six groups with 9 replicates of 25 chicks each and fed the maize-soybean meal–based control diet having ITM at levels similar to those of experiment I or the test diets, where the ITM was replaced with OTM so as to provide the minerals at 100, 80, 60, 40, and 20% of the ITM-based control diet. Each diet was fed ad libitum from 0 to 42 days of age. The body weight gain, feed intake, and feed efficiency were not affected by supplementing OTM at 30 and 20% in experiments I and II, respectively. Slaughter variables, activities of glutathione peroxidase and super oxide dismutase, and lipid peroxidation and ferric reducing activity in serum were not affected by supplementing OTM at the lowest level of 20% in the diet. Similarly, bone-breaking strength, ash, and Mn contents were not affected by supplementing OTM at 20% of the mineral concentration in control diet containing ITM. Deposition of Ca, P, Cu, and Fe in tibia ash increased with increased concentration of OTM in the diet. However, Zn content in tibia ash reduced with reduction in OTM level in the diet. Based on the results, it is concluded that trace mineral supplementation in organic form even at 20% of the concentration recommended for ITM may be sufficient in maize-soybean meal–based diet to support the optimum growth, bone ash, bone strength, and serum antioxidant status in commercial broilers.

Keywords Organic trace minerals · Performance · Antioxidants · Broiler chickens

Introduction

Trace minerals play a vital role in metabolic processes in the body, which are critical to sustain production and ensure proper skeletal development [1] in chicken. Inadequate intake and interactions among different trace minerals cause mineral deficiency in chicken. Conventionally, inorganic minerals are used in poultry diet for reasons of easy accessibility and low price. However, it has been documented that absorption of inorganic trace minerals (ITM) in chickens is low [2] and the bioavailability of Cu, Zn, Mn, Se, and Cr from organic source is higher than the ITM [3–6]. The organic trace minerals (OTM) are tagged to small peptides/organic compounds

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and have higher bioavailability [7]. The bioavailability of OTM is 1.2 to 1.85 times higher compared to that of ITM [8]. The performance of chicken fed organic form of Se [9, 10], Cr [11, 12], and other trace (Cu, Zn, Mn) minerals [4, 5] was reported to be higher or equal when the minerals were included at lower concentrations compared to those fed the recommended levels of ITM in the diet. Organic form of trace minerals (OTM) exerts benefits through modulating (Se) the antioxidant system [13], resistant to antagonisms (Zn vs Cu) in the gastrointestinal tract due to stronger chemical (coordinate-covalent) bonds [14], and also upregulating (Se) transcription of genes encoding energy-associated mitochondrial proteins and protein synthesis [15].

The trace mineral requirements suggested [3] for broiler are mostly based on research work conducted using inorganic forms. The bioavailability of minerals from organic source is higher than from inorganic sources [4, 5, 9, 16]. The use of OTM in poultry diet gained wider acceptability due to several advantages associated with their use as mentioned before. Therefore, the OTM are added at a much lower concentration in the diet [10], without any negative effect on performance. This will further lead to reduced mineral excretion with eventual reduced environmental pollution [17]. Large volume of information is available about the beneficial effects of supplementing single organic trace mineral at a time on different production, immune, and antioxidant variables in broilers. However, limited information is available on feeding of diets supplemented with cocktail of different OTM in broilers during different seasons. In majority of the tropical regions, the broilers are reared in open-sided poultry houses and the variations in environmental temperature and humidity directly impact the physiology and performance of broilers. The broilers have limited ability to dissipate heat at higher ambient temperature and relative humidity. This leads to physiological changes that are accompanied by reduction in feed intake (FI) so as to reduce metabolic heat production [18], which results in lowered performance [19]. Heat stress reduces the FI and supplementing the TM at the standard concentration during summer period may not meet the broiler requirement. Hence, the minerals with higher bioavailability (i.e., OTM) could be of great choice to support the performance and immune response, and reduce antioxidant stress in tropical conditions [10–12, 20].

Considering the higher bioavailability of OTM [10, 21, 22], it is hypothesized that the requirement of TM may be reduced proportionately to realize the advantage of the higher bioavailability in organic form compared to the suggested mineral requirement. Information regarding the effect of lower levels of OTM complex on immune responses, bone mineralization, and antioxidant responses in broiler is limited. Therefore, two experiments were conducted in two different seasons to investigate the effect of feeding reduced concentrations of OTM on performance, bone strength, mineral deposition, and serum antioxidant responses in broilers reared in a tropical region.

Materials and Methods

Experimental Birds, Management, and Diets

Two experiments were conducted on broilers (Cobb 400) to study the hypothesis. A total of 1500 day-old male broiler chicks were randomly distributed into six experimental groups with 10 replicates of 25 chicks each in experiment I, which was conducted during summer season (23.2 to 38.6 °C). Experiment II was conducted during early monsoon season (16.8 to 25.4 °C), where a total of 1350 day-old male broiler chicks were randomly distributed into 6 groups with 9 replicates of 25 chicks each. The chicks of both the experiments were housed in litter floor pens (1.90 × 1.22 m). The brooder temperature was maintained at about 36 ± 0.5 °C until 7 days of age and gradually decreased to room temperature by 21 days of age. Broilers were vaccinated against Newcastle (6th and 25th days) and infectious bursal diseases (12th and 17th days). The experimental protocols were approved by the Institute Animal Ethics Committee (IAEC/DPR/17/1; 21/10/2017).

Maize and soybean meal–based basal diet, devoid of supplemental trace minerals, was prepared to contain 2950 kcal ME/kg and 22.5% CP during starter phase (1 to 21 days) and 3150 kcal ME/kg and 20.0% CP in finisher phase (22 to 42 days) (Table 1) and served as the basal diet.

In experiment 1, a total of 1500 day-old broiler male chicks were randomly distributed into six groups with 10 replicates of 25 chicks each and housed in floor pens (1.90 × 1.22 m). One group was fed the maize-soybean meal–based control diet, supplemented with ITM containing Mn, Zn, Fe, Cu, Se, and Cr at 50, 45, 40, 7.5, 0.30, and 0.25 mg/kg, respectively. The remaining groups of chicks were fed the diets, where the ITM premix was replaced with OTM mix so as to provide the respective minerals at graded levels in the diet (100, 75, 50, 40, and 30% of the control diet). Similarly, in experiment II, a total of 1350 day-old male broiler chicks were divided at random into six groups with 9 replicates of 25 chicks each and fed the maize-soybean meal–based control diet having ITM at levels similar to those of experiment I or the test diets, where the ITM was replaced with OTM so as to provide the minerals at 100, 80, 60, 40, and 20% of the ITM-based control diet (Table 2). The concentrations of Zn, Mn, Fe, Cu, Se, and Cr in both trace mineral premixes and compounded diets were analyzed with an atomic absorption spectrophotometer (AAnalyst 400, Perkin Elmer, Shelton, CT, USA) and required quantities of the premixes were added in the diets to get the required concentrations of trace minerals in the test diets.

Table 1 Ingredient and nutrient composition (g/1000 g) of broiler starter (1–21 days) and finisher (22–42 days of age) diets

Ingredient	Starter	Finisher
Maize	544.26	579.29
Soybean meal	389.5	329.4
Vegetable oil	27.24	52.20
Salt	3.50	3.50
Dicalcium phosphate	19.7	19.0
Oyster shell grit	7.37	8.57
DL-Methionine	2.18	1.79
L-Threonine	0.35	0.35
Additives[1]	5.90	5.90
Nutrient, g/100 g		
Metabolizable energy, kcal/kg	2950	3150
Crude protein[2]	22.5	20.0
Lysine[3]	1.26	1.10
Methionine[3]	0.5	0.8
Threonine[3]	0.77	0.69
NPP[2]	0.45	0.43
Calcium[2]	1.0	1.0

[1] Supplied per kg of diet: retinol acetate 9200 IU, cholecalciferol 1200 ICU, α-tocopherol 10 IU, thiamin 1 mg, pyridoxine 2 mg, cyanocobalamine 0.01 mg, niacin 15 mg, pantothenic acid 10 mg, riboflavin 10 mg, biotin 0.08 mg, menadione 2 mg, choline 650 mg, copper 8 mg, iron 45 mg, manganese 80 mg, zinc 60 mg, selenium 0.18 mg, monensin sodium 50 mg, and hydrated sodium calcium aluminosilicate 800 mg

[2] Calculated concentrations. [3] Calculated based on analyzed ingredient composition

Performance and Slaughter Parameters

Body weight (BW) and FI were recorded at 14-day intervals (0, 14, 28, and 42 days of age) and feed efficiency (FE) was calculated as the BW gain (BWG) per unit FI. At the end of experiment II, one broiler from each replicate representing the mean BW was slaughtered by cervical dislocation to record slaughter parameters. Ready to cook yield and relative weights of abdominal fat, liver, and breast were recorded and expressed in relation to the pre-slaughter live BW of the respective broiler.

Bone Mineralization

The tibia bone was dissected from the carcasses of broiler slaughtered in experiment II and the soft tissue was freed from the bone. The bones were soaked in petroleum ether for 48 h and dried in a hot air oven at 100 °C for 3 h to remove fat. The right tibia of each broiler was used to determine the breaking strength, which was measured using a 3-point method with a universal testing machine (EZ Test, Shimadzu, Japan). The bone was placed on two points with a gap of 50 mm and pressure was applied with pressure sensitive load cell (490 N) at the center of the two points, which coincided with the middle of the bone with a speed of 5 cm per minute. Both the tibias of a broiler were subjected for ashing at 600 ± 20 °C for 6 h.

The bone ash was dissolved in hydrochloric acid (1:10) and filtered through a filter paper (Whatman® Grade No. 1), and the final volume was made to 250 ml with Milli-Q water (Millipore Corporation, Bedford, MA, USA). The mineral aliquot was estimated for P using molybdovanadate reagent [23], and Ca, Zn, Mn, Fe, and Cu using an atomic absorption spectrophotometer (AAnalyst 400, PerkinElmer, Shelton, CT, USA). The atomic absorption spectrophotometer was calibrated with various concentrations of the Ca, Zn, Mn, Fe, and Cu standards. The standards and samples were positioned and aspirated through a nebulizer. The concentration of each element was retrieved using the software provided with the equipment.

Stress Parameters

Blood samples were collected from one broiler per replicate at 42 days of age during experiment II for measuring activities of glutathione peroxidase (GSHPx) and super oxide dismutase (SOD) enzymes. Approximately 3 ml of blood from each broiler was drawn at the 35th day of age from the brachial vein into a centrifuge tube containing citrate (citrate 0.8 g 100 ml) buffer (1.5 ml 10 ml blood) for erythrocyte separation and enzyme estimation. Blood samples were centrifuged at

Table 2 Analyzed and calculated concentrations (mg/kg) of trace minerals in various experimental diets

Treatment	Zn	Mn	Cu	Fe	Se	Cr
100% ITM	45.0 (55.62)	50.0 (62.41)	7.50 (9.69)	40.0 (59.85)	0.30 (0.36)	0.25 (0.31)
100% OTM	45.0 (57.08)	50.0 (67.78)	7.50 (9.61)	40.0 (61.51)	0.30 (0.39)	0.25 (0.33)
80% OTM	36.0 (45.48)	40.0 (50.26)	6.00 (8.21)	32.0 (51.25)	0.24 (0.33)	0.20 (0.32)
60% OTM	27.0 (36.71)	30.0 (39.63)	4.50 (6.19)	24.0 (43.45)	0.18 (0.29)	0.15 (0.23)
40% OTM	18.0 (29.78)	20.0 (31.2)	3.00 (5.68)	16.0 (36.1)	0.12 (0.21)	0.10 (0.15)
20% OTM	9.00 (19.94)	10.0 (22.02)	1.50 (4.11)	8.00 (25.62)	0.06 (0.13)	0.05 (0.12)

The values given in parenthesis are analyzed concentrations of the minerals

500×*g* for 15 min at 4 °C to separate the buffy coat and RBC pellet. The RBC was washed thrice with PBS (pH 7.4). The RBC pellet was mixed with an equal volume of PBS and then lysed using distilled water (RBC:distilled water 1:20). The same procedure was applied for quantifying the lipid peroxides [8]. The degree of peroxidation was expressed as nanomoles of malondialdehyde (MDA)/mg protein. The ferric reducing activity in plasma (FRAP) was estimated through a standard protocol [24].

Statistical Analysis

Statistical analyses were performed using SAS version 9.2 (SAS Institute Inc., Cary, NC, USA). The variations in the different parameters were analyzed using the one-way analysis of variance procedure, wherein different dietary treatments were designated as the fixed factors and different parameters were taken as the dependent variables. The statistical model of variance analysis used was as follows:

$$Yij = \mu + Ti + eij$$

where μ was the overall mean, Ti was the fixed effect of dietary treatment, and eij was the random error present in the jth observation on the ith treatment. On the detection of overall significant difference, the means of different treatments were separated using Tukey's test.

Results

The analyzed concentrations of all the trace minerals in compounded diets were higher than the included levels, which could be due to contribution of the minerals from maize and soybean meal of the basal diets.

Experiment I

The performance variables (BWG, FI, and FE) were not affected ($P > 0.05$) during pre-starter (1–14 days) phase by replacing 100% ITM with 30% OTM (Table 3). Similarly, BWG and FE were not affected during 0–28 days of age with inclusion of 30% OTM in place of 100% ITM in the diet. Though the FI (0–28 and 0–42 days) was affected with dietary treatments, the trend was not clear to infer any specific development. The FE (0–48 days) was significantly ($P = 0.05$) affected by the dietary treatments during 0 to 42 days of age. The FE in groups fed 100% OTM was significantly higher than in those fed 50% OTM and FE in other groups was intermediate between 100 and 50% OTM.

Experiment II

Slaughter Variables

Replacement of 100% ITM with OTM at reduced concentration of up to 20% did not influence the slaughter variables like ready to cook yield and relative weights of the breast, liver, and abdominal fat (Table 4).

Bone Mineral Parameters

The total ash content, breaking strength, and Mn concentration in the tibia bone were not affected ($P > 0.05$) by replacing 100% ITM with 20% OTM (Table 4). Deposition of Ca and P in tibia ash increased significantly ($P < 0.05$) at the lowest concentration of OTM in the diet. Whereas, the concentrations of Cu and Fe in tibia ash of broilers fed OTM were either similar or higher than of those fed the ITM. The deposition of Zn in tibia ash was lower in broilers fed lower levels (< 80%) of OTM compared to that in those fed 100% ITM or OTM-based diets.

Antioxidant Responses

Supplementation of OTM at reduced levels (up to 20% of recommended concentration) replacing 100% ITM did not affect ($P > 0.05$) lipid peroxidation, FRAP, and the activities of GSHPx and SOD in broilers (Table 5).

Discussion

Though the difference was not significant, the FE in broilers fed on 100% OTM-supplemented diets showed an improvement over those fed on the ITM diet in experiment I but not in experiment II, which suggests the potential benefits are perceived by supplementing OTM during heat stress conditions. The previous results from our lab [5, 20] also indicate an improvement in broiler performance by supplementing the diets with OTM. Similarly, these results agree with the earlier reports in broiler [25, 26] and a rural chicken variety (*Vanaraja*) [5], where significant improvement in chicken performance is reported when diets were supplemented with OTM. In the present study, the performance parameters were not affected with reduction in the levels of OTM in the diet. Similarly, the performance parameters were not affected with OTM supplementation in experiment II, which was conducted during pre-monsoon season (23.2 to 38.6 °C), when the ambient temperature was relatively lower than that of summer season (23.2 to 38.6 °C). The OTM supplementation is reported to improve the chicken performance compared to the inorganic form [10–12] and the response is more prominent during heat stress condition [20]. It is reported that the organic

Table 3 Performance of commercial broilers fed different concentrations of organic trace minerals (OTM)

	0–14 days			0–28 days			0–42 days		
	BWG, g	FI, g	FE	BWG, g	FI, g	FE	BWG, g	FI, g	FE
Experiment I									
ITM 100	363.0	387.6	0.937	1406	1739^{ab}	0.809	2264	3689^{ab}	0.614^{ab}
OTM 100	358.5	377.0	0.951	1411	1764^{a}	0.800	2262	3761^{ab}	0.601^{b}
OTM 75	379.1	394.5	0.961	1403	1766^{a}	0.794	2339	3780^{a}	0.619^{ab}
OTM 50	346.9	369.5	0.939	1360	1649^{b}	0.825	2245	3570^{b}	0.629^{a}
OTM 40	355.6	382.6	0.929	1425	1779^{a}	0.801	2352	3809^{a}	0.617^{ab}
OTM 30	350.4	373.6	0.938	1379	1691^{ab}	0.815	2312	3712^{ab}	0.623^{ab}
P value	0.070	0.200	0.970	0.76	0.030	0.530	0.160	0.010	0.050
n	10	10	10	10	10	10	10	10	10
SEM	1.02	1.000	0.005	9.31	9.970	0.005	13.10	18.30	0.007
Experiment II									
ITM 100	415.0	524.5	0.791	1468	2150	0.683	2709	4623	0.586
OTM 100	413.7	513.8	0.805	1436	2108	0.681	2629	4478	0.587
OTM 80	410.4	503.7	0.815	1442	2103	0.686	2635	4463	0.590
OTM 60	404.3	515.4	0.784	1406	2096	0.671	2635	4446	0.593
OTM 40	394.2	496.4	0.794	1437	2116	0.679	2665	4514	0.590
OTM 20	416.9	526.2	0.792	1446	2120	0.682	2623	4457	0.589
P value	0.110	0.250	0.270	0.11	0.780	0.561	0.180	0.780	0.49
n	9	9	9	9	9	9	9	9	9
SEM	2.61	4.13	0.01	6.21	10.89	0.01	10.87	17.9	0.01

BWG body weight, *FI* food intake, *FE* food conversion efficiency, *ITM* inorganic trace minerals, *SEM* standard error of mean, *N* number of replicates

forms of Se, Cr, and Zn are known to enhance performance [9], antioxidant activity [5, 11], and immune response [27] in broiler.

Antioxidant and immune responses in broiler were reported to be affected during stress conditions [7, 28]. Furthermore, heat stress increases mineral excretion [29] and the numerical improvement in FE observed in 100% OTM fed group could be due to the positive role of OTM compared to ITM. It is reported that the OTM are tagged to small peptides and have higher bioavailability [30]. The higher net availability of

Table 4 Carcass variables and bone mineral parameters in commercial broilers fed different concentrations of organic trace minerals (OTM)—experiment II

Treatment	Slaughter parameters				Tibia parameters							
	RTC g/1000 g pre-slaughter weight	Breast	Liver	Abd fat	Ash %	Strength *N*	Ca g/kg	P	Cu mg/kg	Mn	Zn	Fe
ITM 100	777.0	229.0	20.13	15.92	48.17	136	336.5^{c}	167.8^{d}	8.66^{bc}	13.79	235.1^{ab}	255.0^{c}
OTM 100	775.7	239.9	21.34	14.96	48.04	129	334.6^{c}	166.4^{d}	10.38^{ab}	13.11	240.6^{a}	303.8^{abc}
OTM 80	758.3	229.1	19.83	13.66	47.19	134	340.2^{c}	169.8^{cd}	8.27^{c}	11.95	206.5^{cd}	365.2^{a}
OTM 60	770.1	233.0	21.69	14.86	47.60	145	356.5^{b}	179.3^{b}	10.18^{abc}	13.79	211.3^{cd}	299.6^{abc}
OTM 40	765.9	226.4	20.43	15.66	48.10	132	346.0^{bc}	175.3^{bc}	10.83^{a}	12.54	219.7^{bc}	288.0^{bc}
OTM 20	775.4	236.4	19.17	16.23	47.62	128	370.2^{a}	186.7^{a}	10.00^{abc}	13.34	199.7^{d}	326.3^{ab}
P value	0.549	0.672	0.37	0.60	0.547	0.553	0.001	0.001	0.001	0.122	0.001	0.001
n	9	9	9	9	9	9	9	9	9	9	9	9
SEM	3.250	2.570	0.360	0.440	0.200	2.7	1.80	1.00	0.190	0.230	2.530	5.900

ITM inorganic trace minerals, *OTM* organic trace minerals, *SEM* standard error mean, *N* number of replicates, *RTC* ready to cook yield, *Abd fat* abdominal fat

Table 5 Antioxidant and immune responses in commercial broilers fed different concentrations of organic trace minerals (OTM)—experiment II

Treatment	FRAP (μM)	GSHPx (units/mL)	SOD (units/mL)	LP (nmol MDA/mg protein)
ITM 100	1716	141.4	4.974	2.921
OTM 100	2907	134.6	4.311	2.771
OTM 80	2507	135.2	3.790	2.440
OTM 60	2077	138.7	6.529	2.514
OTM 40	2246	137.8	2.773	2.192
OTM 20	2363	137.5	4.708	2.610
P	0.416	0.974	0.184	0.401
N	9	9	9	9
SEM	116.0	2.37	0.45	0.11

FRAP ferric reducing activity in plasma, *GSHPx* glutathione peroxidase, *LP* lipid peroxidation, *N* number of replicates, *ITM* inorganic trace minerals, *OTM* organic trace minerals, *SEM* standard error mean, *SOD* superoxide dismutase

essential minerals, particularly during stress, might have elicited better response in terms of improved FE during experiment I.

In both the experiments, the BWG and in experiment II the FE were not affected by reducing the TM concentration to 20% in organic form compared to those fed 100% ITM, which suggest the possibility of reducing the dietary levels of TM to about 20% of the standard recommended levels without affecting performance, slaughter variables, and antioxidant variables (lipid peroxidation, activities of GSHPx and SOD) in serum. The higher bioavailability of OTM (1.2 to 1.85 times) compared to that of ITM [22] might be responsible for sustaining the broiler performance and other parameters even at the sub-optimal levels of their inclusion in diets. The slaughter variables did not differ among the groups fed diets supplemented with graded levels of OTM and ITM. Similar results were reported earlier in broiler [31].

However, the concentrations of Ca, P, Cu, and Fe in the bone ash increased in groups fed diets supplemented OTM compared to those in groups fed ITM. The contents of Ca and P in tibia ash were higher in broilers fed diets with lower levels of OTM. Similarly, it has been reported that retention of minerals in organic form is higher compared to their inorganic form [32, 33], which results in higher retention of minerals in target organs and lower excretion. Furthermore, the higher bioavailability of OTM is reported to reduce the interference and prevent the formation of insoluble complex with other related trace elements in the gut [33]. Also, it was observed that the dietary supplementation of OTM at lower concentrations did not affect the performance and antioxidant responses in rural chicken (*Vanaraja*) [5]. Increased tibia mineral concentration in chickens fed OTM compared to those fed ITM also confirms the hypothesis that mineral availability is higher in organic form than in inorganic form.

The activities of antioxidant enzymes (GSHPx and SOD) alter naturally for the sustenance and well-being of living organisms. Trace elements are essential components of the antioxidant system in any living being including broiler. In the present study, the activities of GSHPx and SOD, FRAP, and lipid peroxidation did not differ by reducing the concentrations of OTM up to 20%. This indicates that OTM even at the lower level of inclusion in the diet maintained the activities of antioxidant enzymes, ferric reducing ability of plasma, and lipid peroxidation in serum compared to those fed 100% ITM. The absence of negative effects on antioxidant system could be due to the higher bioavailability of OTM [22] and therefore, the absolute availability of the minerals even at lower levels probably met the requirement. Results of the present study revealed increased Ca and P deposition and reduced Zn deposition among the groups fed lower supplemental levels of OTM compared to those groups fed ITM-based diets. Reasons for the reduced Zn deposition in tibia ash with reduction in dietary concentrations of OTM needs further research. Whereas, increased deposition of Ca and P was reported in broilers fed diets with lower levels of organic minerals during starter phase [34].

Conclusions

Results of the present study indicate that the supplemental levels of trace minerals can be reduced considerably to 20% (Zn 9.0, Mn 10.0, Cu 1.50, Fe 8.0, I 0.4, Se 0.06, and Cr 0.05 mg/kg and the analyzed values of these minerals in the 20% OTM diet were Zn 19.94, Mn 22.02, Cu 4.11, Fe 25.62, Se 0.13, and Cr

0.12 mg/kg) of the recommended concentration when they were supplemented in the form of OTM in maize-soybean meal–based diet for supporting optimum performance and antioxidant activity in commercial broilers. Furthermore, supplementation of OTM at low concentrations significantly improved the feed efficiency of broilers reared during tropical summer season.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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