The effect of feeding broiler with inorganic, organic, and coated trace minerals on performance, economics, and retention of copper and zinc

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Primary Audience: Nutritionist, Poultry Producer, Scientist, Environmentalist

SUMMARY

An experiment was conducted to evaluate efficacy of 3 forms of trace minerals on broiler performance, economics, and retention of copper and zinc. A total of 384 Ross 308 male broilers were randomly allocated to 4 dietary treatments × 8 replicates × 12 birds/pen. The treatments were as follows: T1, classical inorganic trace minerals (ITM) at levels used in the industry (mg/kg: Fe 40, Cu 15, Mn and Zn 100 each, all as sulfate; Se 0.3 as selenite and I as potassium iodide); T2, organic trace minerals (OTM, mg/kg: Cu 5, Mn 40, and Zn 30, as methionine chelates; Fe 20 as sulfate; Se 0.3 as hydroxyl selenomethionine and I 1.25 as potassium iodide); T3, all-in-one coated trace minerals (CTM with levels of trace minerals in line with those of T2) as micropellets at inclusion levels 300/250/200 g/mt, respectively, for starter, grower, and finisher phases; T4, CTM at higher doses (H-CTM 400/350/300 g/mt), for the respective 3 phases. The birds were fed on typical corn-soybean meal–based diets from day 1 to 35, in floor pens, with starter from day 1 to 12, grower from day 12 to 24, and finisher from day 24 to 35. The results showed no significant improvements in performance by feeding OTM over ITM, although numeric improvements were observed (weight gain increased by 1.39%, FCR reduced by 1.2%, and performance index increased by 1.3%, $P > 0.05$). The birds fed on CTM significantly improved overall performance compared with those fed on ITM ($P < 0.05$) and OTM ($P < 0.05$). Feeding OTM and CTM reduced overall feed cost per bird, in comparison with ITM. Furthermore, the birds fed on CTM and OTM tended to retain more minerals, with ranking CTM > OTM > ITM for both copper (28.1, 20.7, and 18.2%) and zinc (24.0, 13.2, and 9.7%). It can be concluded that 1) broilers can perform well on reduced levels of trace minerals in the form of OTM or CTM, comparing with general industry recommendations; 2) there are cost savings by using OTM and CTM over the classical ITM; 3) CTM shows clear advantages on broiler performance, economics, and mineral retention.

Key words: mineral, encapsulation, retention, broiler

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DESCRIPTION OF PROBLEM

It is well recognized that trace minerals play essential roles in metabolism, thus are indispensable for health, immunity, growth, and reproduction. Inorganic trace minerals (ITM, e.g., sulfates and oxides) have been widely used in the livestock industry for decades as a cost-effective solution to meet the trace mineral requirements of animals. The disadvantages of classical ITM are reactive, not only among minerals themselves (Henry and Miles, 2000) leading to chemical changes, but also interactions with other nutrients in premixes or mixed diets, such as enzymes, vitamins, fatty acids, and pigments, resulting in destruction and deterioration of the overall nutritive value of the final diets (Santos et al., 2015; Lu et al., 2020). Therefore, the suitability to use ITM in animal feeds has been frequently questioned.

Early research illustrated interactions between inorganic trace minerals and vitamins in premixes. An experiment (Coelho, 2002) demonstrated that vitamin K vanished entirely within 6 mo, followed by vitamins A, B1, and biotin (approx. 47% lost), yet vitamin E was relatively stable at a loss of 20%. These results explain the common industry practice to separate vitamins and minerals until final feed mixing, to avoid such interactions. Feed enzymes as live protein molecules are even more sensitive to oxidation. When mixing 3 commercial phytase preparations with classical ITM, the phytase was deactivated significantly and rapidly (Santos et al., 2015). The same study also revealed that losses of enzyme potency were associated not only with classical inorganic trace minerals such as sulfates, but also with the minerals chelated with protein, glycine, or carbohydrates. These findings suggest that all forms of trace minerals may significantly deactivate phytase and other feed enzymes when they come into contact. Lu et al. (2020) confirmed the detrimental impact of classical trace minerals on vitamins, which can further deteriorate the value of complete diets, such as shelf-life and animal performance. Under the tropical climate, a pig weaner diet with 3% added fresh soybean oil without added trace minerals can be stored for 23 d before it emitted a rancid smell. After adding trace minerals (in mg/kg: Cu 20, Fe 120, Mn 25 and Zn 120) in sulfate form, rancid smell can be detected as early as 13 d of storage. Adding high copper (150 mg/kg, in sulfate) further shortened the shelf-life to 7 d. Using all trace minerals in their organic forms only slightly improved shelf-life to 9 d. By contrast, using the similar levels of trace minerals but encapsulated with carbohydrates matrix (coated trace minerals [CTM]), the shelf-life of the diet lasted for 22 d, approximately the same length as the control diet without added trace minerals (Lu et al., 2020).

The objective of this study was to investigate the effect of trace mineral forms at their recommended levels on broiler performance, economics, and retention of copper and zinc, by using inorganics, that is, ITM, organic trace minerals (OTM), and all 6 trace minerals coated as one micropellet by a proprietary carbohydrate matrix coating technology, that is, CTM at 2 application levels.

MATERIALS AND METHODS

The experiment was conducted between February and April, 2020, at the NKP Poultry Research Farm in Thailand, following the Guideline of Using Animal for Scientific Purpose, under the National Research Council of Thailand (Act B.E. 2558).

Experimental Design

A total of 384 day-old Ross 308 male broilers were randomly allocated into 4 treatments each with 8 replicates. Trace mineral sources were used as treatments: Inorganic trace minerals at application dosage following recommendations for Ross 308 (Aviagen, 2012), in mg/kg: Fe 40, Cu 15, Mn and Zn 100 each, all as sulfate; Se 0.3 as sodium selenite and I at 1.0 as potassium iodide. Organic trace minerals with levels as recommended by their suppliers, in mg/kg: Fe 20 in sulfate; Cu 5, Mn 40, and Zn 30, as methionine chelates; Se 0.3 as hydroxyl selenomethionine and I at 1.25 as potassium iodide). Doses of CTM were generally in line with those of OTM but applied at 2 dosages and allocated higher proportion to the starter and lower inclusion to the finisher phase. The sources and doses of the trace minerals are

Table 1. Source and level of trace minerals used for the broiler study.

Minerals[1]	Trt 1, ITM (inorganic)	Trt 2, OTM (organic)	Trt 3, CTM[2] (300/250/200)	Trt 4, H-CTM[3] (400/350/300)
Iron, mg/kg	40	20 ($FeSO_4.H_2O$)	42/35/28	56/49/42
Copper, mg/kg	15	5 (Cu-Met)	3.9/3.25/2.6	5.2/4.55/3.9
Manganese, mg/kg	100	40 (Mn-Met)	36/30/24	48/42/36
Zinc, mg/kg	100	30 (Zn-Met)	36/30/24	48/42/36
Selenium, mg/kg	0.3	0.3 (OH-SeMet)	0.24/0.20/0.16	0.32/0.28/0.24
Iodine, mg/kg	1	1.25 (KI)	0.24/0.20/0.16	0.32/0.28/0.24

Abbreviations: CTM, coated trace minerals; H-CTM, CTM at higher doses; ITM, inorganic trace minerals; OTM, organic trace minerals.

[1]Sources of trace minerals: iron, $FeSO_4.H_2O$; copper, $CuSO_4.5H_2O$; manganese, $MnSO_4.H_2O$; zinc, ZnO; iodine, potassium iodide (KI); selenium, Na_2SeO_3. OTM: Availa Cu; Availa Mn; Availa Zn; Se (Selisseo 2% Se).

[2]CTM: All 6 trace minerals were coated in a matrix of carbohydrates (MinCo, Syno Biotech Co., Ltd.). Application dosages CTM: 300, 250, and 200 g/mt diet, respectively, for stater, grower, and finisher.

[3]H-CTM: MinCo at dosage of 400, 350, and 300 g/mt diets, respectively, for stater, grower, and finisher.

shown in Table 1. The 3 sources of trace minerals were premixed with their respective carriers then added to the experimental diets during ingredients' mixing to avoid prior contact with other components in the diets. All the diets were fed as crumbles to birds during the first 12 d and as pellets thereafter until day 35. Each treatment had 8 replicate pens each housing 12 birds. The basal diets were corn-soybean meal based with 3 phases: starter (day 1–12), grower (day 12–24), and finisher (day 24–35). Dietary ingredient and nutrient compositions are shown in Table 2. Note the levels of nutrients in Table 2 just reflected calculated results of the feed ingredients used, the contributions of phytase and nonstarch polysaccharides-degrading enzymes (Rovabio Advance Phy T) were additional (assumed to contribute ME 80 kcal/kg, digestible amino acids 3% and available phosphorus 0.15 percentage units).

The birds were raised in a facility equipped with tunnel ventilation and evaporative cooling system with controlled temperature. Rice hulls were used as bedding material in the floor pens. All birds were vaccinated for Newcastle and Infectious Bronchitis diseases at 7 d of age and Gumboro disease at 14 d of age. Birds were provided with feed in a tube feeder and water with 2 nipple drinkers in each pen *ad libitum*. All management procedure followed the guidelines for Ross 308 (Aviagen, 2012).

Measurements

Live weight and feed intake were measured on a pen basis at 12, 24, and 35 d of age. Number and weight of dead and culled birds were recorded daily. Live weight gain, feed intake, feed conversion ratio (FCR), livability, European performance index, feed and trace mineral costs per kg gain and per bird were calculated for the period of 0 to 12, 12 to 24, 0 to 24, 24 to 35, and 0 to 35 d of age, respectively. At 35 d of age, all the birds were weighed individually, to calculate live weight uniformity in each pen, expressed as 100% − % coefficient of variation of live weight.

Mineral Retention

Additional 60 day-old Ross 308 male broiler chicks from the same batch used for the growth study were allocated to 3 dietary treatments (ITM T1, OTM T2, and CTM T3); each treatment had 2 pens of 10 birds/pen; the birds received their respective diets for starter (0–12 d) and grower (12–16 d). At 16 d of age, grower diets of T1, T2, and T3 used in the growth study were prepared by including 0.3% chromic oxide marker, and fed to the birds for a 5-d balance measurement. During this period, clean plastic sheets were placed in each pen to enable fecal collection on day 21. Fresh and clean excreta samples of each pen were collected on the last day of the period (day 21), mixed within pen, and dried by a hot air oven at 80°C for 24 h. The feed samples were also collected from the feed bag in front of each pen. The diet and dried fecal samples were analyzed for dry matter, copper and zinc, and chromic oxide

Table 2. Composition and calculated nutrients of basal diets (as feed basis, the calculated nutrients excluded contributions of phytase and NSPase).

Ingredient, %	Starter (0–12 d)	Grower (12–24 d)	Finisher (24–35 d)
Corn 7.55% 191112	57.27	61.02	63.32
SBM (dh) 48% 191015	33.64	28.37	24.18
Rice bran full fat	3.00	4.00	5.00
DDGS 190730	2.00	3.00	4.00
Soybean oil	0.72	0.74	0.99
MDCP 16.8/21.7	0.60	0.07	
Limestone 39.9% Ca	0.99	1.14	0.93
Pellet binder (Pelex Dry)	0.30	0.30	0.30
Salt	0.24	0.25	0.25
L-Lysine HCl	0.20	0.17	0.16
DL-Methionine	0.26	0.22	0.20
L-Threonine	0.08	0.05	0.04
Sodium bicarbonate	0.17	0.13	0.12
Choline chloride 60%	0.08	0.08	0.09
Antimold (Proimpex)	0.20	0.20	0.20
Sacox (Coccidiostat)	0.05	0.05	
Rovabio Advance Phy T[1]	0.01	0.01	0.01
Vitamin premix[2]	0.10	0.10	0.10
Trace mineral premix[3]	0.10	0.10	0.10
Nutrients			
Dry matter	88.93	88.92	88.95
ME, Kcal/kg	2,900	2,950	3,000
Crude protein	22.28	20.35	18.72
Crude fat	5.54	5.96	6.56
Linoleic acid	1.71	1.80	1.98
Crude fiber	3.35	3.54	3.78
Dig. Lysine	1.20	1.05	0.95
Dig. Methionine	0.57	0.52	0.47
Dig. TSAA	0.88	0.81	0.75
Dig. Threonine	0.79	0.70	0.64
Dig. Tryptophan	0.23	0.20	0.18
Dig. Arginine	1.35	1.21	1.09
Dig. Valine	0.94	0.87	0.80
Dig. Isoleucine	0.79	0.72	0.66
Dig. Leucine	1.68	1.58	1.48
Calcium	0.65	0.60	0.50
Phosphorus (total)	0.56	0.44	0.43
Phosphorus (available)	0.25	0.15	0.13
Potassium	0.93	0.85	0.78
Choline	1,700	1,600	1,550
Sodium	0.16	0.16	0.16
Chloride	0.23	0.23	0.23
Salt	0.28	0.29	0.29
Electrolyte balance, mEq/kg	243	221	204

[1]Rovabio Advance Phy T, provides per kg diet: phytase 1,000 FTU and xylanase 1,250 Visco U, assumed to contribute ME 80 kcal/kg, digestible amino acids 3% and available phosphorus 0.15 percentage units.

[2]Vitamin premix provides per kg diet: vitamin A 12,000 IU, vitamin D3 2,400 IU, vitamin E 60 mg, vitamin K 3 mg, B1 3 mg, B2 8 mg, B6 4 mg, B12 0.02 mg, niacin 50 mg, pantothenic 15 mg, biotin 0.4 mg, folic acid 2 mg.

[3]The contents of trace mineral premixes are explained in the footnote of Table 1.

concentrations, following methods described by Bolin et al. (1952) for chromium oxide and the official methods of analysis of AOAC (2016) for copper and zinc.

Statistical Analysis

Data of all variables were analyzed using one-way ANOVA with SAS Software Version

Table 3. Performance and economics of broiler fed on ITM (inorganic trace minerals), OTM (organic trace minerals), and CTM (coated trace minerals).[1,2,3,4,5,6]

Performance	ITM	OTM	CTM	H-CTM
0–12 d				
Initial weight, g	46	46	46	46
End weight, g	431^{a}	430^{a}	414^{b}	422^{a,b}
Weight gain, g	385^{a}	384^{a}	368^{b}	376^{a,b}
Feed intake, g	424^{a}	429^{a}	410^{b}	420^{a,b}
FCR	1.103	1.117	1.113	1.116
Livability, %	98.6	100.0	100.0	100.0
Performance Index	287.0	286.8	275.8	281.1
0–24 d				
End weight, kg	1.348	1.364	1.346	1.366
Weight gain, kg	1.302	1.318	1.300	1.321
Feed intake, kg	1.741	1.749	1.720	1.734
FCR	1.337	1.326	1.323	1.313
Livability, %	98.6	98.6	100.0	100.0
Performance Index	400.0^{b}	408.2^{a,b}	409.6^{a,b}	419.0^{a}
0–35 d				
End weight, kg	2.418^{b}	2.451^{a,b}	2.456^{a,b}	2.486^{a}
Weight gain, kg	2.372^{b}	2.405^{a,b}	2.411^{a,b}	2.440^{a}
Feed intake, kg	3.640	3.648	3.628	3.634
FCR	1.535^{a}	1.517^{a,b}	1.505^{b,c}	1.489^{c}
Livability, %	98.6	97.2	98.6	100.0
Performance Index	435.1^{b}	440.7^{b}	451.2^{a,b}	468.2^{a}
Uniformity, %	90.4	91.4	91.6	91.7
$ Cent TM/bird	0.46	1.78	0.49	0.69
$ Feed/bird	1.5663	1.5621	1.5363	1.5215

[1]Statistics: Means in the same row not bearing the same alphabet differ significantly $P < 0.05$.

[2]Feed conversion ratio: corrected for mortality and culling.

[3]Livability: removed dead and culled birds.

[4]Performance index = (% Livability × BWG)/(Days × FCR) × 100.

[5]Live weight uniformity = 100 − % coefficient of variation of live weight in each pen.

[6]Cost of trace minerals and feeds: using actual cost and prices collected in Thailand and Malaysia.

9.4 (SAS, 2015). Means were compared by Duncan's multiple range tests, with $P < 0.05$ as significant difference.

RESULTS AND DISCUSSION

As shown in Table 3, the overall performance of the birds exceeded Ross 308 breed performance target (Aviagen, 2012): average live weight of 2.42 kg/bird vs. target 2.25 kg, feed intake of 3.60 kg/bird vs. target 3.52 g, FCR of 1.50 vs. target 1.566. The flocks in this study achieved excellent liveability (>97%) and performance index (>435).

Growth Performance

Starter Phase The birds fed on ITM, OTM, CTM, and H-CTM had average feed intake 424, 429, 368, and 420 g/bird, respectively, corresponding to weight gain 385, 384, 410, and 376 g/bird. Those fed on ITM and OTM showed significantly higher feed intake and weight gain than the birds receiving CTM ($P < 0.05$). No significant differences were observed on FCR and PI ($P > 0.05$) among the 4 treatments. Although the flock on ITM had 98.6% liveability, the rest 3 flocks had zero mortality.

During 1 to 24 d of age, the prior differences in feed intake and weight gain during starter phase seemed to have diminished. Feed intake was 1.741, 1.749, 1.720, and 1.734 kg/bird, corresponding to the 4 treatments ($P > 0.05$), weight gain 1.302, 1.318, 1.300, and 1.321 kg/bird, and FCR 1.337, 1.326, 1.323, and 1.313 ($P > 0.05$). The PI of the 4 flocks were 400.0, 408.2, 409.6, and 419.0, respectively. The flock of T4 (H-CTM) achieved significantly higher PI than ITM (T1), and numerically higher than OTM, indicating the nutritional advantages of CTM gradually accumulated. Liveability of the ITM and OTM flocks remained high at 98.6%, while the 2 CTM flocks had no death.

For the entire life cycle of 0 to 35 d of age, the 4 flocks had feed intake 3.640, 3.648, 3.628, and 3.634 kg/bird ($P > 0.5$), they grew 2.372, 2.405, 2.411, and 2.440 kg/bird ($P < 0.05$) with mortality corrected FCR 1.535, 1.517, 1.505, and 1.489 ($P < 0.05$), respectively, for ITM, OTM, CTM, and H-CTM. Significant differences in PI were observed (435.1, 440.7, 451.2, and 468.2 ($P < 0.05$)). While no differences in feed intake were observed among the 4 flocks, these results tend to suggest a small degree of nutritional advantage of OTM over ITM, although not statistically significant in this study. Coated trace minerals (T3 and T4) achieved superior growth performance comparing with the birds fed on ITM, and T4 (H-CTM) showed outstanding performance among all treatments, with extra weight gain by 67 g and FCR 4.6 points over ITM (T1). The ranking of performance index was T4>T3>T2>T1. The extra performance of the birds fed on CTM may be attributed to better preservation of the sensitive nutrients in the CTM diets, and more retention and utilization of nutrients in their respective diets, as illustrated by the early findings in our laboratory (Lu et al., 2020) that diets containing CTM showed less losses of enzymes and vitamins comparing with those containing classical ITM or OTM.

Economics

Local market prices of basic feed ingredients, mineral, and vitamin premixes were used to assess the economics based on the average selling price of live birds at farm gate, against the costs of trace minerals per metric ton of feed and per bird (2.40 kg). The costs and return of CTM, OTM, and OTM were compared and shown in Table 3. The actual cost on trace minerals per bird was 0.46, 1.78, 0.49, and 0.69 US cents, respectively, for the diets using ITM, OTM, and the 2 CTMs, with the highest cost being OTM. By contrast, when all feed ingredients were counted in, the overall feed cost per bird was USD 1.5663, 1.5621, 1.5363, and 1.5215, respectively, for the birds fed ITM, OTM, CTM, and H-CTM, revealing the use of OTM in the feed was not more costly than ITM. On the other hand, the use of CTM reduced feed cost by 2 and 3%, respectively, for the normal inclusion (T3 300/250/200 g/mt) and high inclusion (T4 400/350/300 g/mt).

Table 4. Addition, retention, and excretion of copper and zinc using different mineral sources.

Minerals turn-over	ITM[1]	OTM[2]	CTM[3]
Feed conversion	1.535	1.517	1.509
Feed consumption, kg/bird	3.6134	3.5710	3.5428
Copper			
Added to diet, mg/kg	15.00	5.00	3.25
Analyzed in diet, mg/kg	21.9	9.5	9.0
Analyzed in feces, mg/kg	59.3	24.0	21.9
Cu consumed/bird, mg	54.2	17.8	11.5
Cu retention rate, %	18.2	20.7	28.1
Cu excreted/bird, mg	44.3	14.2	8.3
Zinc			
Added to diet, mg/kg	100.00	30.00	30.00
Analyzed in diet, mg/kg	132.0	63.1	64.1
Analyzed in feces, mg/kg	386.0	176.5	164.5
Zn consumed/bird, mg	361.3	107.1	106.3
Zn retention rate, %	9.7	13.2	24.0
Zn excreted/bird, mg	329.9	93.0	80.8

[1]ITM (inorganic trace minerals).

[2]OTM (organic trace minerals).

[3]CTM (coated trace minerals).

Mineral Retention and Excretion

In this study, the levels of copper and zinc were determined in laboratory in the diets and excreta of T1, T2, and T3, to measure their retention and excretion. The results in Table 4 showed copper retention rates were 18.2, 20.7, and 28.1% by the flocks fed on ITM, OTM, and CTM, respectively. Likewise, the retention rates of zinc were 9.7, 13.2, and 24.0% for the 3 respective treatments. The results ranked the retention rates of both copper and zinc as CTM > OTM > ITM. As this study had constraint of only 2 samples per treatment being tested in the laboratory, statistical comparison was not applicable. Nonetheless, these results agreed well with the findings of Nollet et al. (2007) on the copper and zinc levels in excreta and their retention rates, after feeding ITM and OTM to broilers. Based on the results in Table 4, it can be estimated the amounts of copper required to produce 1 million birds were in an order of ITM, 54.2 kg; OTM, 17.8 kg; and CTM, 11.5 kg; resulting in copper excretion 44.3, 14.2, and 8.3 kg, respectively. Likewise, by using ITM, OTM, and CTM, it requires zinc 361.3, 107.1, and 106.3 kg, leading to zinc excretion 329.9, 93.0, and 80.8 kg.

CONCLUSIONS AND APPLICATIONS

1. Modern broilers can perform to meet or exceed their breed target by dietary supplementation with Fe 20 to 40 mg, Cu 2.5 to 5.0 mg, Zn and Mn 30 to 40 mg each per kg diet. These levels are substantially lower than routine supplementations in the industry.
2. Comparing with the birds fed on ITM at recommended levels, the birds fed on OTM tended to improve growth and feed conversion, led to no increases in feed cost, despite the high cost of OTM *per se*.
3. Coated trace minerals is advantageous over ITM and OTM in terms of preventing interactions with other sensitive nutrients in premixes and diets, resulting in improved growth performance, trace mineral retention, and feed cost. Using CTM can save feed cost by 4.48 US Cents (T4 vs. T1), and 4.06 US Cents (T4 vs. T2) per bird.
4. To produce 1 million broiler birds, CTM supplementation (T3) can reduce Cu input by 42.7 kg or 78.8% compared with ITM, resulting in 36.0 kg or 81.3% less Cu excretion. Similarly, using CTM (T3) can reduce Zn input by 255.1 kg or 70.6%, leading to 249.1 kg or 75.5% less Zn excretion.

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DISCLOSURES

The authors declare no conflicts of interest.

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