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Chelated Minerals, Vitamins, and Electrolytes Improve Early Production Performance and Profitability of Broiler Chickens

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ABSTRACT

Feed costs account for over half of total production costs in broiler farming; thus, minimizing them without compromising performance is essential. This study aimed to evaluate the effects of dietary feed additives containing zinc and manganese chelates, vitamins C and D, and sodium bicarbonate ($NaHCO_3$) on growth performance, carcass traits, and footpad dermatitis, and to conduct a cost-benefit analysis. A total of 144 male day-old Cobb 500 broiler chicks were randomly assigned to a completely randomized design (CRD) with four treatments, each replicated four times with nine birds per replicate. The dietary treatments consist of a basal diet without any additive (T1) and the basal diet supplemented with the feed additive at three inclusion levels: 0.5 g/kg (T2), 1 g/kg (T3), and 2 g/kg (T4). These inclusion levels supplied with 5, 10, and 20 mg/kg of chelated Zn and Mn; 424.5, 849, and 1,698 mg/kg of sodium bicarbonate; 4, 8, and 16 mg/kg of vitamin C; and up to 325, 650, and 1,300 IU/kg of vitamin D, respectively. The results showed that supplementing the basal diet with 2 g of Zn and Mn chelates, vitamins C and D, and a $NaHCO_3$ mixture per kg significantly enhanced broiler performance, especially in body weight, feed intake, and weight gain during the second week. Clear linear effects appeared in the early production stages. Additionally, a cost-benefit analysis indicated that higher supplementation was economically beneficial. Furthermore, no adverse effects were observed on carcass characteristics, skin tearing, or footpad dermatitis. In conclusion, increased supplementation with these nutrients improved broiler chicken performance during the early production phase.

Keywords: broiler performance; mineral chelates; vitamin C; vitamin D; sodium bicarbonate

INTRODUCTION

Due to the growing global population, demand for meat, particularly poultry, continues to surge rapidly (Dong *et al*., 2014). Poultry meat derived from broilers is the most widely produced globally (Mramba & Mapunda, 2024). Improved genetics that contribute to a rapid growth rate and enhanced feed efficiency in broilers are considered economically advantageous. However, feed cost remains the primary determinant of profitability in broiler production (Abdalgalil, 2025). For this reason, producers seek sustainable solutions that support efficient growth, preserve meat quality and profitability, and help broilers better withstand heat stress. More recently, broiler nutritionists have focused on alternative nutritional strategies, including the use of chelated trace minerals and vitamins in broiler diets (Alagawany *et al*., 2021; Faghih-Mohammadi *et al*., 2022). Moreover, because broilers are raised primarily for meat production, growth performance and carcass quality remain key economic traits (Tavárez *et al*., 2016). Beyond nutrition, factors such as management, genetics, and post-slaughter handling also play essential roles in determining meat quality in broilers (Mir *et al*., 2017).

Trace minerals are critical for normal physiological and metabolic function in chickens (Byrne & Murphy, 2022). Inorganic trace minerals are less digestible than their organic and chelated counterparts, despite their extensive use (Lee & Kim, 2025). Therefore, to improve the absorption of trace minerals, the chelated form is preferred (Broom *et al*., 2021). Different trace minerals, such as manganese (Mn) and zinc (Zn), have been studied to assess their effects on broiler chickens. Manganese supports metabolism, collagen synthesis, and antioxidant defenses, helping to prevent leg deformities and improve bone health (Olgun, 2017; de Carvalho *et al*., 2021). On the other hand, zinc (Zn) plays a crucial role in the metabolism of energy, proteins, nucleic acids, and carbohydrates (Faghih-Mohammadi *et al*., 2022). Its positive effects on growth performance are well established, and it is also involved in the regulation of key hormones such as glucagon, insulin, and sex hormones

(Abd El-Hack *et al.,* 2018). Moreover, Zn has been shown to enhance immune function, increase daily weight gain, and improve feed utilization efficiency in broiler chickens (Hidayat *et al.,* 2021). When combined with manganese in organic chelated forms, these trace minerals further improve growth performance and carcass yield compared with their inorganic counterparts (Nguyen *et al.,* 2025). Meanwhile, Pacheco *et al.* (2021) found that during the second week of production, chelated Zn and Mn considerably increased broiler body weight and feed conversion ratio. Additionally, recent research indicates that supplementing these minerals in broiler diets improves intestinal health (Bortoluzzi *et al.*, 2020; Franklin *et al.,* 2022).

Vitamins, both fat-soluble and water-soluble vitamins, are vital to broilers' metabolic processes. As a fat-soluble vitamin, vitamin D is especially crucial for controlling the absorption of calcium and phosphorus, which supports immunological function and bone mineralization (Setiyaningsih *et al.,* 2023). On the other hand, by preventing oxidative damage and boosting immunological responses, vitamin C, a water-soluble vitamin, aids in cellular repair (Shakeri *et al.,* 2020). Additionally, Setiyaningsih *et al.* (2023) found that broiler development performance at the later production stage was strongly impacted by the combined supplementation of vitamins C and D. While vitamin C supplementation by itself does not always enhance growth performance, it is essential for controlling broiler reactions to different stressors (Yu *et al.,* 2021). Furthermore, this vitamin is essential for mitigating the adverse effects of heat stress in broilers (Attia *et al*., 2017; Del Barrio *et al*., 2020; Al-Khalaifah *et al*., 2025). Moreover, a diet containing electrolytes, specifically sodium bicarbonate, reduces mortality and also mitigates the adverse effects of heat stress in broilers (Livingston *et al*., 2022).

Although chelated trace minerals, vitamins, and electrolytes have individually demonstrated positive effects on broiler performance, existing studies have evaluated mainly these nutrients in isolation or in limited combinations. Moreover, no work has simultaneously assessed growth performance, carcass traits, footpad health, and economic outcomes under tropical conditions. Having said this, the mixtures of these feed additives had not been explored; thus, the authors hypothesized that higher inclusion rates of mineral chelates, vitamins, and electrolytes would improve broiler performance and provide economic benefits without detrimental effects on carcass yield or foot pad health. Hence, the objectives of this study were to investigate the growth performance, carcass traits, incidence of footpad dermatitis, and economic efficiency in broilers fed diets enriched with chelated Zn and Mn, vitamins C and D, and sodium bicarbonate.

MATERIALS AND METHODS

Ethical Approval

The study was conducted at the Poultry Project, University of Southern Mindanao, Kabacan, Cotabato, Philippines. All handling protocols and ethical procedures for broiler chickens in this study were thoroughly reviewed and approved by the Institutional Animal Care and Use Committee (IACUC) of the University of Southern Mindanao under Protocol No. 2024-0055.

Preparation of Experimental Animals

This study utilized 144 male day-old Cobb 500 broiler chicks, each with an average initial weight of 47.82 grams. All chicks were acquired from a recognized hatchery in Davao City, where they received vaccinations against infectious bronchitis and Newcastle disease. To help reduce transport-related stress, the chicks were given a 5% sugar solution for three hours after arriving at the experimental facility (Broiler Production Committee, 2006).

Each chick was individually weighed to facilitate proper randomization. For identification, lightweight safety pins (1.9 cm in length) were used as wing bands, a method shown to cause minimal distress compared with conventional identification techniques (Dennis *et al.,* 2008). Each pin was fitted with a paper tag bearing a unique identification number (1–144) and secured with transparent tape. During the banding procedure, the chick was gently held in one hand, with the head kept upright and the body fully supported to minimize handling stress. After stabilizing the wing, the safety pin was inserted through the wing web from the ventral side and secured. All chicks were consistently banded on the same wing, preferably the left wing.

To minimize variation in initial body weight while preserving randomization, individual chick weights and corresponding wing-band numbers were recorded in an Excel spreadsheet. Chicks were then stratified into upper and lower weight categories. Each replicate consisted of nine birds, with an equal representation of heavier and lighter chicks to ensure comparable starting weights across replicates. After stratification, replicates were randomly assigned to their respective pens.

Sixteen pens measuring 1.0 × 0.75 m were thoroughly cleaned and disinfected two weeks prior to chick placement (Cobb-Vantress, 2021). Each pen was equipped with a feeder trough, a waterer, and a 25-W brooder heater. To regulate airflow, a Sakoline burlap curtain was installed following the method described by Hidayat *et al.* (2021), and newspapers were used as the initial litter material. Brooder bulbs were switched on four hours before the chicks arrived to stabilize the brooding temperature. Throughout the study, standard biosecurity protocols were strictly observed.

Brooding Management

Ambient temperature during the growing period was maintained between 28 and 32 °C. Continuous lighting was provided during the first two weeks to support early chick growth. After the brooding phase, the lighting program was adjusted to provide illumination from 6:00 p.m. to 6:00 a.m., mimicking natural dusk–dawn conditions. This intermittent lighting schedule promoted feed intake during nighttime hours while allowing adequate rest periods, which are essential for proper digestion and overall health (Broiler Production Committee, 2006; Hu *et al.*, 2021).

Feeding Management

Formulated diets were provided throughout the experiment and were classified into brooder, starter, and grower phases. Broiler chicks were fed *ad libitum* throughout the study, with clean and potable drinking water available at all times. The feed ingredients and nutrient composition of the experimental diets are presented in Table 1. The experiment was conducted with four treatment groups, each replicated four times. There were nine birds per replicate. The dietary treatments consist of a basal diet without any additives (T1) and the basal diet supplemented with the feed additives at three inclusion levels: 0.5 g/kg (T2), 1 g/kg (T3), and 2 g/kg (T4). These inclusion levels supplied with 5, 10, and 20 mg/kg of chelated Zn and Mn; 424.5, 849, and 1,698 mg/kg of sodium bicarbonate; 4, 8, and 16 mg/kg of Vitamin C; and up to 325, 650, and 1,300 IU/kg of Vitamin D, respectively (Table 2).

The formulated basal diet samples (1 kg each) were submitted to Lipa Quality Control Center Inc. (LQCCI, 2025) for analysis. The proximate analysis of poultry feeds was conducted according to the official methods recommended by the Association of Official Analytical Chemists (AOAC, 2016) to determine crude protein, crude fiber, crude fat, moisture, and ash content (Table 1).

Health Care and Sanitation

Strict biosecurity measures were followed throughout the study. Poultry pens were cleaned daily, with newspapers used as bedding during the first week and replaced each day. From day 10 onward, sanitized rice hulls replaced newspapers and were changed every

Table 1. Composition and nutrient profile of the basal diet formulated for booster, starter, and grower phases (in 100 kg diet) for broiler chickens

Feedstuff	Booster	Starter	Grower
	(1-10 days old)	(11-20 days old)	(21-30 days old)
Corn (%)	57.87	59.17	62.74
L-Lysine (%)	0.3	0.25	0.3
L-Threonine (%)	0.2	0.1	0.18
DL Methionine (%)	0.4	0.35	0.35
US soya HP (%)	35	33	29
Coco Oil (%)	1.5	3	3.5
Salt (%)	0.35	0.35	0.35
MDCP (%)	2.4	1.5	1.5
Limestone (%)	1.15	1.4	1.2
Toxin binder (%)	0.2	0.2	0.2
Choline 60% (%)	0.2	0.2	0.2
Vitamin concentrate premix (%)	0.03	0.03	0.03
Mineral premix (%)	0.1	0.15	0.15
Calcium formate (%)	0.3	0.3	0.3
Nutrient analysis[a]			
ME (kcal/kg)	2952.586	3061.944	3129.636
Moisture (%)	12.31	12.25	11.43
Ash (%)	6.55	05.13	05.27
Crude protein (%)	22.22	20.86	20.40
Crude fiber (%)	2.34	02.81	02.37
Crude fat (%)	3.08	04.38	05.98
Nitrogen Free Extract (%)	53.50	54.57	54.55

Note: [a]Obtained from a laboratory analysis of samples submitted to Lipa Quality Control Center Inc. (LQCCI, 2025), except for metabolizable energy (ME).

Table 2. Composition of Zn and Mn chelates, Vitamins C and D, and $NaHCO_3$ mixtures used for broiler chickens

Nutrient composition	Amount[a]	Composition per treatment		
		0.5g/kg[b]	1 g/kg[b]	2 g/kg[b]
Chelated Zinc	10 g/kg	5 mg/kg	10 mg/kg	20 mg/kg
Chelated Manganese	10 g/kg	5 mg/kg	10 mg/kg	20 mg/kg
Sodium bicarbonate	849 g/kg	424.5 g/kg	849 g/kg	1.698 g/kg
Vitamin C	8 g/kg	4 mg/kg	8 mg/kg	16 mg/kg
Vitamin D, IU/kg	< 650,000	up to 325	up to 650	up to 1300

Note: [a]The compositions were based on the analysis by the Vethealth Corporation. [b]Obtained by manual computation following the formula: Nutrient/kg feed = (Inclusion Rate in g/kg) * (Nutrient content in g/kg) / 1000000g (McDonald *et al.*, 2011).

4 days to reduce odors and fly activity. Rice hulls were chosen due to their availability in the area and the proven positive effects on reducing ammonia and the occurrence of footpad dermatitis in broiler (Şahin & Çelen, 2021).

Sampling and Analysis

Body weight (g). The average body weight of the broiler chickens in each pen was recorded weekly using a digital scale, with a maximum capacity of 14 kg and a minimum readability of 2 g.

Weight gain (g/bird). This was determined by taking the difference between the birds' final and initial total weights, then dividing that figure by the number of birds in each cage, as illustrated in the formula below.
Weight Gain (g/bird) = (Total final body weight – Total initial body weight) / No. of birds per cage

Average feed intake (g). Feed intake was determined by accurately recording the amount of feed offered and the feed remaining for each experimental group. These data were used to calculate total feed consumption using the following formula:
Average feed intake (g/bird) = [Feed offered (g) – Feed refused (g)] / No. of birds per cage

Feed conversion ratio. Feed conversion ratio (FCR) was calculated as the ratio of average weekly feed intake to average weekly weight gain, using the following formula:
Feed conversion ratio = Average feed intake (g/bird) / Average weight gain (g/bird)

Carcass Yield and Quality

A total of 32 birds (2 per replication) were selected to determine the carcass characteristics listed below. The researchers ensured that the selected birds per pen were closest to the average weight, as the method described by Taylor *et al*. (2021). Before slaughter, all birds were fasted for 12 hours (Schneider & Gewehr, 2023). By following the procedure described by Faria *et al.* (2010), the birds were slaughtered by severing the carotid artery and the external jugular vein close to the occipital bone and atlas to facilitate bleeding. After bleeding, the birds were immersed in a scalding tank at approximately 60 °C for up to 2 minutes. Manual defeathering was simultaneously followed.

Carcass weight (g). Carcass weight was obtained after the removal of the head, neck, feathers, shank, and visceral parts except the lungs. The weight was obtained using a digital weighing scale.

Carcass yield percentage. This was calculated using the following formula (Faria *et al*., 2010; Bulkaini *et al*., 2022):
Carcass percentage = (Carcass weight/Body weight at slaughter) x 100

Percentage of offal. According to the procedure described by Bulkaini *et al*. (2022), offal weight was measured by weighing the cleaned intestines, liver, heart, and gizzard. The offal percentage was calculated by dividing the total offal weight by the bird's live weight and multiplying by 100%.

Percentage of edible offal. The weight of edible offal (foot, neck, and head) was determined by weighing each part individually. The edible offal percentage was determined by dividing the total weight of these parts by the bird's live weight, then multiplying the result by 100 (Bulkaini *et al*., 2022).

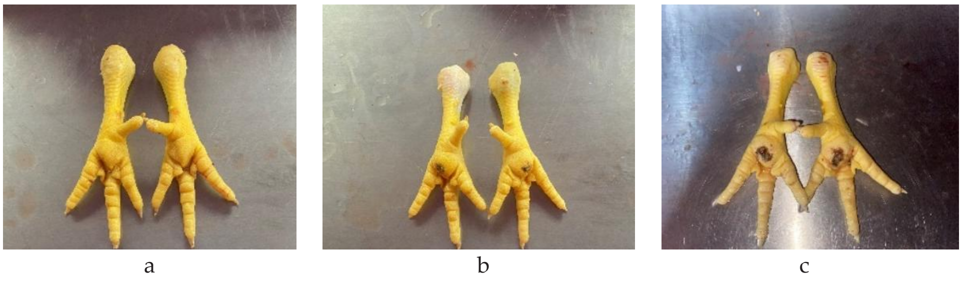
Skin resistance test. At the end of the study, eight birds from each treatment group were slaughtered. A 1 cm incision was made between the thigh and back, and its length was measured with a caliper before scalding and defeathering. After defeathering, the incision was measured again, and the increase in length was recorded as skin tearing (Rossi *et al*., 2007; Zaghari *et al*., 2022).

Occurrence of Footpad Dermatitis

Footpad dermatitis was visually assessed at slaughter in a total of 80 birds (20 birds per treatment) using the scoring system adapted from the European Union Reference Centre for Animal Welfare for Poultry (EURCFAW, 2020). Lesions were scored on a scale from 0 to 2, as illustrated in Figure 1.

Cost-Benefit Analysis

The production cost (expressed in Philippine peso, PHP) was determined by accounting for expenses for



a b c

Figure 1. The footpad dermatitis scale was used in the study. The researchers randomly selected these images from slaughtered broilers. a. scale of 0 (no lesion); b. scale of 1 (mild lesion); c. scale of 2 (moderate to severe lesion).

chicks, feed, and feed additives (Table 5). The cost was based on local prices in the Philippines for January 2025, with an exchange rate of 58.39 PHP per US dollar (Bangko Sentral ng Pilipinas, 2025). The overall production cost was computed on both a per-bird and per-kilogram basis for broilers. In addition, the extra expenses associated with the test ingredients were incorporated into the cost–benefit analysis following the method first described by Khatun *et al*. (2019).

Feed intake (kg/bird) and final weight (kg/bird) were determined from the average measurements collected over the 30-day feeding trial. Feed price was computed based on the composite cost of all feedstuffs used in the formulation. The cost of the feed additives was incorporated using the actual supplier pricing provided by Vethealth Corporation. The total feed cost per kilogram was obtained by adding the basal feed price and the corresponding treatment cost. Feed cost per bird was then calculated by multiplying feed intake by the total feed cost per kilogram.

Production cost included expenses for chicks, feed, and feed additives. These expenses were summed to obtain the total cost of production per broiler. The sale price per broiler was computed by multiplying the average final liveweight by the prevailing liveweight price of PHP 150/kg. Moreover, the cost of production per kilogram was determined by dividing the total production cost by the average final weight. Profit per broiler was calculated as: Profit/broiler = Sale price/broiler − Total cost of production/broiler. On the other hand, the profit per kilogram liveweight was computed by dividing the profit per bird by the final weight. Lastly, to determine the profit PHP/kg (over control), the profit per kilogram for Treatments 2, 3, and 4 was compared with that of the control group.

Statistical Data Analysis

Data were analyzed using analysis of variance (ANOVA) with the Statistical Tool for Agricultural Research (STAR version 2.0.1) software developed by the International Rice Research Institute (2022). The experiment followed a Completely Randomized Design (CRD), and orthogonal polynomial contrasts (linear and quadratic) were applied to evaluate treatment trends, particularly for broiler performance parameters. Mean differences among treatments were further compared using Tukey's Honestly Significant Difference (HSD) test at the 5% and 1% levels of significance. In addition, the percent occurrence of footpad dermatitis was analyzed using the Kruskal–Wallis test at a 5% significance level.

RESULTS

Growth performance of broilers fed diets supplemented with a mixture of chelated zinc, manganese, vitamins, and sodium bicarbonate was assessed using key performance indicators, including body weight, feed intake, livability, and feed conversion ratio. To establish baseline values, all birds were weighed upon arrival on December 6, 2024, and subsequent body weight measurements were recorded weekly up to day 30 to monitor growth patterns throughout the experimental period.

Body Weight and Weight Gain of Broiler Chickens (g)

During the early growth phase (1–21 days), body weight (BW) and weight gain (WG) showed a significant linear response ($p<0.05$), with broilers receiving Treatment 4 (2 g/kg) exhibiting greater body weights. Nevertheless, neither the latter growth phase (22–30 days) nor the entire study period (1–30 days) showed any significant changes ($p>0.05$) (Table 3).

Feed Intake of Broiler Chicken (g)

Feed intake (FI) was monitored daily by recording the amount of feed offered and refused. A highly significant linear effect ($p<0.01$) was observed during days 8–14, indicating increased feed consumption as the levels of Zn and Mn chelates, vitamins C and D, and $NaHCO_3$ supplementation increased (Table 3). In addition, a significant linear response ($p<0.05$) was detected over the entire 30-day experimental period. During the second week, broilers in Treatment 4 consumed significantly more feed ($p<0.05$) than those in the other treatments, with a mean intake of 433.19 g.

Feed Conversion Ratio (FCR)

Feed conversion ratio (FCR) exhibited a significant linear response ($p<0.05$) during the 1–7-day and 15–21-day periods, with the lowest FCR values observed in broilers supplemented with 2 g/kg of Zn and Mn chelates, vitamins C and D, and $NaHCO_3$ (T4), averaging 1.42 and 0.97, respectively. No significant effects ($p>0.05$) were detected outside these periods (Table 3).

Livability (%)

As presented in Table 3, livability exhibited a significant linear response ($p<0.05$) throughout the experimental period, indicating improved survival with increasing levels of supplementation.

Carcass Characteristics

The results are summarized in Table 4, which presents data on carcass weight, dressing percentage, edible offal percentage, and skin resistance to tearing. No significant differences ($p>0.05$) were observed among treatments for carcass weight, carcass yield, offal percentage, or edible offal percentage. Mean offal and edible offal values were 8.67% and 7.87%, respectively, and did not vary significantly across treatments. Similarly, no significant differences ($p>0.05$) were detected in skin resistance to tearing (Table 4). These findings indicate that dietary supplementation with Zn and Mn chelates, vitamins C and D, and $NaHCO_3$ did not adversely affect carcass characteristics in broiler chickens.

Table 3. Growth performance of broiler fed with a mixture of chelated zinc, manganese, vitamins C and D, and sodium bicarbonate in their diet

Variables	Treatments								
	T1 (Control)	T2 + 0.5 g/kg	T3 + 1 g/kg	T4 + 2 g/kg	SEM	Tukey's HSD Test	Orthogonal polynomial contrasts		CV (%)
						P-Value[a]	*P*-Value		
							Linear	Quadratic	
1 day of age									
IW (g)	47.48	47.28	47.05	49.48	1.66	0.72	0.45	0.44	6.94
1-7 days of age									
BW (g)	135.88	135.02	138.11	164.15	8.68	0.10	0.04*	0.14	12.11
FI (g)	148.89	139.25	137.88	162.08	8.01	0.18	0.30	0.06	10.89
WG (g)	88.39	87.74	91.05	114.66	7.59	0.08	0.03*	0.13	15.89
FCR	1.71	1.60	1.53	1.42	0.08	0.12	0.02*	0.96	9.98
8-14 days of age									
BW (g)	385.64[b]	390.14[b]	400.39[b]	475.15[a]	21.53	0.04*	0.01*	0.13	10.43
FI (g)	369.99[b]	374.81[b]	391.33[b]	433.19[a]	11.82	0.01*	<0.01**	0.14	6.03
WG (g)	338.16[b]	342.86[b]	353.33[b]	425.66[a]	20.40	0.03*	0.01*	0.12	11.18
FCR	1.11	1.10	1.11	1.02	0.03	0.25	0.14	0.30	6.23
15-21 days of age									
BW (g)	813.13	837.83	845.50	953.92	37.00	0.08	0.02*	0.28	8.58
FI (g)	792.06	800.84	802.80	874.14	28.17	0.20	0.07*	0.29	6.89
WG (g)	765.65	790.55	798.45	904.44	36.11	0.08	0.02*	0.28	8.86
FCR	1.04	1.01	1.01	0.97	0.02	0.17	0.04*	0.78	4.35
22-30 days of age									
BW (g)	1462.97	1464.69	1448.67	1567.82	45.25	0.43	0.22	0.20	5.76
FI (g)	1440.95	1460.91	1440.24	1431.17	16.19	0.63	0.50	0.39	2.24
WG (g)	1415.49	1417.41	1401.67	1518.33	41.79	0.92	0.14	0.19	5.81
FCR	1.03	1.03	1.03	0.94	0.03	0.21	0.11	0.19	6.47
1-30 days of age									
FW (g)	1462.97	1464.69	1448.67	1567.82	42.79	0.08	0.22	0.20	5.76
FI (g)	2751.89	2775.81	2772.24	2900.59	40.99	0.09	0.03*	0.23	2.93
WG (g)	1415.34	1417.04	1401.61	1519.23	41.83	0.22	0.14	0.19	5.81
FCR	1.95	1.96	1.98	1.91	0.03	0.54	0.46	0.28	3.51
L (%)	91.67	94.44	100.00	100.00	3.10	0.20	0.04*	0.66	6.43

Note: [a]*P*-value less than 0.05 is significantly different; Means with the same letter are not significantly different; * means significant (p<0.05) linear effect; ** means highly significant (p<0.01) linear effect; IW (g) – initial weight; FW (g) – final weight; BW (g) – body weight; FI (g) – feed intake; WG (g) – weight gain; g – gram; FCR – feed conversion ratio; L (%) – livability; SEM – standard error of the means; CV – coefficient of variation. The dietary treatments consist of a basal diet without any additives (T1) and the basal diet supplemented with the feed additives at three inclusion levels: 0.5 g/kg (T2), 1 g/kg (T3), and 2 g/kg (T4).

Table 4. Carcass characteristics of broiler fed with a diet with a mixture of chelated zinc, manganese, vitamins, and sodium bicarbonate

Variables	Treatments						
	T1 (Control)	T2 + 0.5 g/kg	T3 + 1 g/kg	T4 + 2 g/kg	SEM	CV (%)	P-value ns
Carcass weight, g	1147.75	1137.00	1069.25	1180.00	56.17	9.90	0.58
Carcass percentage	74.57	74.66	73.63	74.11	0.35	0.95	0.20
Percentage of offal	9.14	8.20	8.46	8.88	0.50	11.60	0.57
Percentage of edible offal	7.63	7.54	8.00	8.33	0.26	6.51	0.17
Skin resistance test, cm	1.62	1.50	1.39	1.05	0.19	27.42	0.22

Note: ns – no significant difference (p>0.05); SEM – standard error of the means; g – gram; cm – centimeter. The dietary treatments consist of a basal diet without any additives (T1) and the basal diet supplemented with the feed additives at three inclusion levels: 0.5 g/kg (T2), 1 g/kg (T3), and 2 g/kg (T4).

Footpad Dermatitis Assessment

A total of 80 birds (20 per treatment) were used to assess the presence of footpad dermatitis using the scale shown in Figure 1. In the visual assessment conducted, the percentage of birds with footpad dermatitis (mild to severe) in each Kruskal-Wallis test revealed no significant difference (p>0.05) with mean values of 75% (T1), 75% (T2), 80% (T3), and 85% (T4) in all treatments, as shown in Figure 2.

For moderate to severe cases, a notably high incidence was observed in birds fed 1 g of Zn and Mn chelates, Vitamins C and D, and $NaHCO_3$ mixture (Figure 2), but no significant difference ($p>0.05$) was observed among the treatments. The same significance levels were observed in mild cases. Results revealed that supplementation with the said nutrients is comparable to the control treatment in terms of footpad health in broiler chickens.

Cost-Benefit Analysis

Cost-benefit analysis revealed that higher supplementation at 2 g/kg provided the highest profitability, achieving a net profit of ₱117.86 per bird and ₱75.07 per kg liveweight. At an exchange rate of 58.39 pesos per US dollar in January 2025, the net profit per bird is 2.02 US dollars, and 1.29 US dollars per kg liveweight. Lower supplementation levels (0.5 and 1 g/kg) failed to improve profitability compared with the control, mainly because feed costs increased without a corresponding increase in final body weight. Thus, the addition of 2 g of Zn and Mn chelates, Vitamins C and D, and $NaHCO_3$ mixture per kg was economically advantageous (Table 5).

DISCUSSION

Chelated minerals are widely recognized for their higher bioavailability compared with inorganic sources, resulting in improved nutrient absorption and enhanced growth performance (Bhagwat *et al.*, 2021). Meshreky *et al.* (2015) further demonstrated that zinc and manganese supplementation markedly enhanced both humoral and cell-mediated immune responses, highlighting the advantages of chelated minerals over inorganic forms. In the present study, treatment effects became most evident after the first week of growth, a period characterized by rapid physiological development. During this stage, broilers have increased nutritional demands to support skeletal growth, immune maturation, and metabolic activity. Zinc plays a crucial role in bone mineralization and collagen synthesis (Zhang *et al.*, 2018), and its supplementation

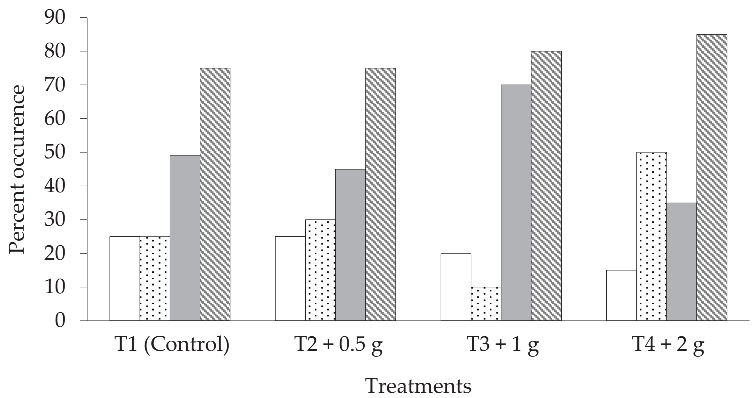


Figure 2. Percent occurrence of footpad dermatitis in broilers fed a diet with a mixture of chelated zinc, manganese, vitamins, and sodium bicarbonate. Note: ☐ No lesion; ☐ Mild; ■ Moderate to severe; ▨ All with lesion. The dietary treatments consist of a basal diet without any additives (T1) and the basal diet supplemented with the feed additives at three inclusion levels: 0.5 g/kg (T2), 1 g/kg (T3), and 2 g/kg (T4).

Table 5. Cost-benefit analysis for feeding diets supplemented with chelated zinc and manganese, vitamins, and sodium bicarbonate in broiler chickens. The cost was based on local prices in the Philippines in January 2025 and expressed in Philippine peso

Variables	Treatments			
	T1 (Control)	T2 + 0.5 g/kg	T3 + 1 g/kg	T4 + 2 g/kg
Feed intake (kg/bird)	2.75	2.78	2.77	2.91
Final weight (kg/bird)	1.46	1.46	1.45	1.57
Feed price (kg)	26.07	26.14	26.22	26.36
Treatment useda	0.00	0.17	0.33	0.66
Total feed cost/kg	26.07	26.31	26.55	27.02
Total feed cost/bird	71.69	73.15	73.53	78.64
Chick price (PHP)	39.00	39.00	39.00	39.00
Total cost of production PHP/broiler	110.69	112.15	112.53	117.64
Total cost of production PHP/kg	75.81	76.81	77.61	74.93
Sale price PHP/broiler at 150/kg liveweight	219.00	219.00	217.50	235.50
Profit PHP/broiler	108.31	106.85	104.97	117.86
Profit PHP/kg	74.19	73.19	72.39	75.07
Profit PHP/kg (over control)	0.00	-1.00	-1.79	0.89

Note: [a] Zn and Mn chelates, Vitamins D and C, and $NaHCO_3$ mixture; PHP – Philippine peso; / - per; kg – kilogram. The dietary treatments consist of a basal diet without any additives (T1) and the basal diet supplemented with the feed additives at three inclusion levels: 0.5 g/kg (T2), 1 g/kg (T3), and 2 g/kg (T4).

has been demonstrated to enhance feed efficiency and average daily gain by supporting enzymatic processes involved in protein synthesis and energy metabolism (Hidayat *et al.,* 2019). Likewise, manganese is essential for carbohydrate and lipid metabolism, contributing to the energy requirements of broilers during the early rapid growth phase (Shokri *et al.,* 2021). Organic chelated forms of Zn and Mn are more efficiently absorbed and utilized than inorganic sources, particularly during periods of accelerated growth (Sunder *et al.,* 2013). In addition, Mn is critical for cartilage development and bone matrix formation, although its direct impact on overall growth may be less pronounced (Pacheco *et al.,* 2017). The significant linear increases in body weight and weight gain observed during the second and third weeks of production suggest that higher inclusion levels of these feed additives enhance economically important traits, consistent with the findings of de Carvalho *et al.* (2021) on different manganese sources in broilers.

Sodium bicarbonate has also been reported to increase feed consumption in broiler chickens by helping maintain optimal physiological conditions that encourage feeding behavior (Osman *et al*., 2015; Turner *et al*., 2025). Earlier research indicates that supplementing with sodium bicarbonate can improve feed intake, promote weight gain, and enhance the feed conversion ratio. However, exceeding recommended levels can have adverse effects, including increased mortality rates (Yasoob & Tauqir, 2017). In broilers, sodium bicarbonate acts as a buffer, maintaining blood pH and counteracting metabolic acidosis, particularly under stress or when diets are high in protein or certain minerals (Martínez *et al*., 2021). Chicks during the first 14 days of life are less efficient at thermoregulation, and sodium bicarbonate can improve their ability to cope with heat stress by promoting water intake and supporting electrolyte balance, thus reducing stress-related mortality and improving overall viability (Osman *et al*., 2015).

Another factor contributing to the observed responses during early growth may be the inclusion of vitamins C and D in the dietary treatments. The first 14 days of a broiler's life are characterized by rapid growth, organ development, and immune system maturation, making this stage particularly responsive to nutritional interventions (Ferronato *et al.,* 2024). During the starter phase, chicks undergo intensive skeletal and metabolic development, processes that rely heavily on adequate vitamin D for calcium and phosphorus utilization, as well as vitamin C for antioxidant protection and immune support (Shojadoost *et al.,* 2021). Most studies evaluating vitamin C supplementation in broiler diets have focused on its role under heat stress conditions (Van Hieu, 2022) or its interaction with other feed additives (Hajati *et al.,* 2015; Attia *et al.,* 2017; Jahejo *et al.,* 2019; Kumar *et al.,* 2021). Amer *et al.* (2021) reported that dietary ascorbic acid at 400 mg/kg significantly improved growth performance during the starter phase, although greater benefits were observed when vitamin C was combined with safflower oil during the grower and finisher phases. These findings generally align with the present study, except for differences in feed intake responses. Similarly, Chand *et al.* (2014) demonstrated that combined supplementation of vitamin C and zinc enhanced growth performance and health status in broilers. Variations between previous studies and the present results may be partly explained by differences in environmental conditions; in the current study, uniform ventilation likely reduced heat stress, whereas birds in the study by Chand *et al.* (2014) were subjected to heat stress during the fourth and fifth weeks of production.

Overall, no notable differences in growth performance parameters, including body weight, weight gain, and feed conversion ratio, were observed across treatments over the entire experimental period. These findings are consistent with several studies reporting limited or no effects of dietary zinc (Salim *et al.,* 2012; Sunder *et al.,* 2013; Zakaria *et al.,* 2017; Yang *et al*., 2017; Foltz *et al*., 2017; Zhang *et al*., 2018), manganese (Ghosh *et al*., 2016; Khakpour Irani *et al*., 2019; Sun *et al*., 2021), or mineral chelates (Yang *et al*., 2017; Pacheco *et al*., 2017) on overall broiler growth performance. In contrast, Zhao *et al.* (2010) reported significant improvements in body weight following supplementation with chelated copper, zinc, and manganese. This discrepancy may be attributed to differences in mineral composition and experimental duration, as the present study evaluated chelated zinc and manganese in combination with vitamins and sodium bicarbonate, without copper, over a shorter 30-day period, whereas Zhao *et al.* (2010) conducted a 52-day trial. Moreover, Rezapour *et al.* (2024) observed significant improvements in body weight during the brooder phase when broilers were supplemented with a mixture of zinc and manganese. Similarly, the present study detected significant responses during the early growth stage, with higher inclusion levels of chelated zinc and manganese outperforming lower levels. Despite differences in mineral sources, inclusion rates, and experimental conditions, these findings consistently indicate that the benefits of mineral chelates are more pronounced during the early stages of broiler growth.

The chelated trace minerals and vitamins used in this study had no adverse effect on carcass characteristics, particularly yield, offal percentage, and skin-tear resistance. This finding is consistent with the results of Zhao *et al*. (2010), which revealed that chelated trace minerals did not significantly improve carcass quality in broilers. Similarly, Sun *et al*. (2021) reported that manganese supplementation had no notable impact on carcass traits. In the current study, the average carcass weight was 1133.50 g, with an average dressing percentage of 74.24%, indicating that the birds maintained uniform carcass quality across treatments. Moreover, this result aligns with the study by Amer *et al*. (2021), which also found that ascorbic acid supplementation had no significant effect on carcass yield. Regarding zinc supplementation, previous studies have shown that it can significantly enhance skin collagen, with male broilers exhibiting thicker skin compared to females (Salim *et al*., 2012). However, the same study noted that zinc supplementation did not affect the skin's resistance to tearing, suggesting that while zinc contributes to skin development, other factors may also influence skin strength and integrity.

Footpad health is widely recognized as an indicator of both nutritional adequacy and effective management practices in broiler production. In the present study, the footpad condition did not differ significantly among treatments, indicating that all inclusion levels of the feed additives produced outcomes comparable to those of the control group. This finding is consistent with the report of Zhao *et al.* (2010), who likewise observed no significant effect of chelated trace minerals on footpad lesion incidence. However, these results contrast with those of Chen *et al.* (2017), who demonstrated that higher dietary concentrations of certain trace minerals, particularly zinc and manganese, enhanced protection against footpad dermatitis by promoting lesion healing and reducing severity over time. The discrepancy between studies may be partly explained by differences in mineral balance, as the present study did not include additional trace minerals that may support tissue repair. Interactions among dietary minerals are complex, and both antagonistic and synergistic effects can influence the absorption and utilization of zinc and manganese (Swiatkiewicz *et al.*, 2017). Elevated levels of certain nutrients may impair mineral bioavailability, potentially limiting their effectiveness in supporting lesion healing. In addition to nutritional factors, litter management plays a critical role in the development of footpad dermatitis. In this study, frequent litter replacement was implemented following the recommendations of Alabi *et al.* (2023), who emphasized that regular litter management, regardless of litter type, is essential for minimizing the incidence and severity of footpad lesions in broilers.

The economics of using Zn and Mn, Vitamin C and D, and sodium bicarbonate were presented in the cost-benefit analysis table (Table 5). Results revealed that a higher inclusion rate of these feed additives in a 2 g/kg diet provided an economic advantage compared to the control and other inclusion levels. This treatment has the highest selling price of 235.50 pesos or 4.03 dollars. The use of organic trace minerals in microchelated forms has consistently shown economic advantages (Khatun *et al.*, 2019). Although Treatment 4 slightly increased feed cost per kilogram, the resulting gain in productivity lowered the overall production cost per kg and yielded the highest profit per bird (₱117.86). This agrees with Levy (2017), who reported that profitability in broiler systems rises when biological performance, especially FCR, growth rate, and survival, improves, as feed accounts for most production costs.

CONCLUSION

Higher supplementation (2 g/kg) of broiler diets with a mixture of Zn and Mn chelates, Vitamins C and D, and $NaHCO_3$ led to improved broiler chicken performance during the early stages of production. It also increased broiler survivability throughout the production cycle. Additionally, these nutrients did not negatively affect carcass characteristics or the occurrence of footpad lesions. Moreover, this inclusion rate provides an economic benefit to farmers. Significant linear effects indicate that higher inclusion levels offer advantages in growth performance during early stages, along with economic benefits. Therefore, we recommend that future studies investigate supplementation levels beyond 2 g/kg and include assessments of intestinal morphology to better understand the physiological mechanisms behind these responses.

CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial, personal, or other relationships with other people or organizations related to the material discussed in the manuscript.

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DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the authors used Grammarly v4 to improve the readability and language of the manuscript. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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