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Effect of Monocalcium Phosphate Supplementation on the Growth Performance, Carcass Characteristic, Gut Histomorphology, Meat and Bone Quality of Broiler Chickens

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ABSTRACT

The aim of this study was to investigate the effect of different concentration of monocalcium phosphate supplementation on the growth performance, carcass characteristics, gut morphology, meat quality, and bone quality of broiler chickens. A total of 108 day-old male broiler chicks (Cobb 500) were randomly divided into 3 treatment groups with 6 replicates and each replicate consist of 6 birds. Treatment 1 (control) was fed available commercial starter and finisher diets containing dicalcium phosphate. Treatment 2 and Treatment 3 were fed the same commercial diet but with added 0.5% and 1.0% of monocalcium phosphate respectively. Weekly body weight, feed intake and feed conversion ratio were calculated to determine their growth performance. A total of 12 chickens per each treatment group were selected randomly and slaughtered for gut histomorphology, carcass characteristics, meat, and bone quality assessment at the end of the 42 days study period. In the present study, birds supplemented with 0.5% MCP showed significant increase ($p > 0.05$) in growth performance (body weight, body weight gain, and feed intake), gut histomorphology (villi height), and bone quality (bone weight, diaphysis diameter, medullary canal diameter, lateral wall thickness, medial wall

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thickness, and bone breaking strength). There were no significant differences ($p > 0.05$) in the carcass characteristics and meat quality between treatment groups. In summary, monocalcium phosphate supplementation could be the key to reduce culling of lame broiler birds based on the positive effect on the growth performance, gut histomorphology and bone quality of broiler chickens without affecting the carcass characteristics and meat quality.

Keywords: Bone quality, broilers, carcass characteristic, growth performance, gut histomorphology, meat quality, monocalcium phosphate

INTRODUCTION

Prosperous as it is on the surface, the broiler industry faces numerous challenges in accordance with the rapidly growing population. To keep up with the demands, extensive researches have been by the combination of genetics enhancement and feed enrichment to boost the feed conversion ratio (FCR) and growth rate in broiler chickens (Gonzalez-Ceron et al., 2015). This knowledge has greatly contributed to the poultry industry, giving birth to fast-growing strains such as Cobb 500 and Ross 308. These breeds are considerably larger than their predecessors and have more amount of muscles especially in the breast area due to very efficient FCR.

In spite of its remarkably rapid growth rate, the undeniable issue regarding leg problems in broiler chickens continues to cause economic losses in the broiler industry. This is due to the late development of bones compared to the fast development of muscles. Other than that, the pressure of the muscle weight on the bones also contributes to leg problems. Examples of common leg problems in broiler chicken are Valgus (VVD), crooked toes, tibial dyschondroplasia (TD), vertebral deformities, twisted legs, osteoporosis of the proximal femur, femoral head necrosis, rupture of the gastrocnemius tendon and rickets (Dinev, 2012). According to Knowles et al. (2008), over 27.6% of birds at the mean age of 40 days showed poor locomotion and 3.3% were almost unable to walk. This is unsettling for the broiler industry, as the skeletal deformities have been observed to cause pain and movement problems, resulting in lameness of the bird, limited movement which leads to loss of appetite and low feed consumption, thus resulting poor growth rate, increased culling rate, increased fatality, and increased carcass condemnation and degrading at slaughter.

In general, broiler chicken receives an inadequate amount of calcium and phosphorus. This is because the calcium (Ca) and phosphorus (P) from vegetable-based diet only fulfil 30% of the amount required by the body, and only half of it will be absorbed by the intestines (Eeckhout & De Paepe, 1994). Supplementing inorganic source of calcium and phosphorus such as monocalcium phosphate (MCP) into the commercial diet are potentially favourable in providing the extra Ca and P needed by the body (Liu et al., 2013). Theoretically, properties of MCP include improvement of digestion and the efficiency of carbohydrate, protein, fat, mineral, and energy metabolism in the body. Thus, the objective of this

study was to investigate the effect of supplementing different concentrations of MCP on the growth performance, gut histomorphology, carcass characteristics, meat quality, and bone quality in commercial broilers.

MATERIALS AND METHODS

Birds, Husbandry and Diets

All experimental procedures were conducted in accordance with the Institutional Animal Care and Use Committee of Research Policy at Universiti Putra Malaysia (UPM). A total of 108 day-old male broiler chicks (Cobb 500) was obtained from a local hatchery. Immediately after arrival, the chicks were weighed and randomly allocated into 3 dietary treatments placed in battery cages with wired flooring in an open-sided house. Each treatment consisted of 6 replications, with 6 broilers per replication. The birds were vaccinated intraocularly with live Newcastle disease (ND) and infectious bronchitis (IB) vaccine on day 7 followed by infectious bursal disease (IBD) vaccine on day 14. Throughout the experimental period, water and feed were provided ad libitum to the birds. The broilers were fed commercial starter and finisher diets from 0 to 21 and 22 to 42 days respectively. The birds were provided with three types of diets. The dietary treatments were Treatment 1 (T1) commercial diet without any supplementation (control); Treatment 2 (T2) commercial diet supplemented with 0.5% MCP and Treatment 3 (T3) commercial diet supplemented with 1.0% MCP. The nutritive value of the starter and finisher diets are presented in Table 1.

Table 1
Nutrient content of starter and finisher diets

	Treatments					
	Starter (0-21 days)			Finisher (22-42 days)		
	T1	T2	T3	T1	T2	T3
Nutrient content						
ME (MJ/kg)	12.90	12.90	12.90	13.30	13.30	13.30
Crude protein (%)	22.00	22.00	22.00	20.00	20.00	20.00
Crude fibre (%)	5.00	5.00	5.00	8.00	8.00	8.00
Crude fat (%)	4.50	4.50	4.50	4.00	4.00	4.00
Moisture (%)	13.00	13.00	13.00	13.00	13.00	13.00
Ash (%)	8.00	8.00	8.00	8.00	8.00	8.00
Calcium (%)	0.90	1.06 (+18%)	1.19 (+32%)	0.85	0.98 (+15%)	1.05 (+23%)
Phosphorus	0.45	0.49 (+9%)	0.53 (+17%)	0.42	0.45 (+7%)	0.47 (+11%)
Cost						
Diets (RM)	132.00	132.00	132.00	130.000	130.000	130.000
MCP (RM)	0.00	2.00	4.00	0.00	2.00	4.00
Total (RM)	132.00	134.00	136.00	130.000	132.00	134.00

Note. T1: 0% MCP (control); T2: 0.5% MCP; T3: 1.0% MCP

Sample and Data Collection

For the growth performance, weekly body weight (BW) and feed intake (FI) were recorded per replicate for the calculation of body weight gain (BWG) and feed conversion ratio (FCR). At day 42, 12 broilers were randomly selected from each treatment group and slaughtered for gut histomorphology, carcass characteristics, meat, and bone quality analysis. The birds were slaughtered at the Department of Animal Science abattoir, Faculty of Agriculture, UPM according to the Halal slaughter procedure (Abdulla et al., 2015).

Gut Histomorphology

Intestinal samples were collected to study the intestinal histomorphology. Five (5) cm of duodenum, jejunum, and ileum were harvested flushed with 10% neutral buffered formalin solution and set overnight. The intestinal samples were then excised, dehydrated in a tissue processing machine and embedded in paraffin wax. Each sample was cut about 4 mm on a slide. Then the samples were stained with haematoxylin and eosin, mounted and viewed under a Nikon DS-U2/L2 light microscope. The villi height and crypts depth were examined, captured, and measured with NIS-Elements D software. The height of the villi were measured from tip to crypt transition while crypts depth were measured at the invagination between two villus. This procedure was conducted at the Histopathology Lab, Faculty of Veterinary Medicine, UPM.

Carcass Characteristics

The carcasses were dissected manually, and the following parameters were recorded: final live weight, kill-out weight, de-feathered weight, dressing percentage, breast muscle weight, drumsticks weight, wings weight, neck weight, head weight, shank weight, full gizzard weight, empty gizzard weight, gastrointestinal tract weight, heart weight, and liver weight.

Meat Quality Analysis

Determination of pH. The right pectoralis major (breast muscle) was collected, snap-frozen in liquid nitrogen (-195°C) and stored at −80°C to preserve the pH properties of the meat. After 24 hours, the samples were crushed using mortar and pestle until it became fine particles. The samples were then homogenized by using a homogenizer. The pH was then taken by a portable pH meter (Mettler Toledo, AG 8603, Switzerland).

Determination of Colour. Thirty (30) g of breast meat from samples of each treatment groups were analysed using a colour flex spectrophotometer (Hunter Lab Reston, VA, USA). The meat samples were bloomed at room temperature (27°C) for 30 minutes prior to analysis. The colour flex spectrophotometer was then standardized and properly set up as required. Once the meat samples were analysed, the colour flex spectrophotometer produced L*, a*, and b* results according to the gross appearance of meat samples' colour.

Drip Loss Measurement. Forty (40) g of breast meat from the samples of each treatment groups were weighed and recorded as initial weight (W1). The meat samples were kept in vacuum-packed plastic bags and kept in the freezer at 4°C. After 48 hours, the samples were removed from the bags, gently blotted with a tissue to dry and final weight was taken (W2). This procedure was done to determine the amount of water loss during storage. The percentage of drip loss will be calculated as (W1-W2)/ W1 x 100.

Cooking Loss Measurement. Thirty (30) g of breast meat from the samples of each treatment groups were weighed and recorded as initial weight (W1). The muscle samples were placed in vacuum-packed plastic bags and fully immersed in the water bath at 80°C for 20 minutes. After cooking, the samples were removed from the water bath and the bags were allowed to cool down to room temperature for 15 minutes. The cooked samples were blotted with tissue paper and weighed, the weight was recorded as final weight (W2). The cooking loss was determined by the amount of water loss from cooking and the percentage was calculated using the formula (W1-W2)/ W1 x 100.

Bone Quality Analysis

Tibiotarsus Length and Weight. The right drumstick from the samples of each treatment groups was taken flesh intact. The samples were kept frozen in the freezer (-20°C) for 36 hours. Then, the sample was thawed and boiled in boiling water (95°C) for 10 minutes. After that, the samples were cooled down to room temperature. The flesh, bone cap, and patella were then removed manually by hand revealing the tibiotarsus. The bones were air-dried for 24 hours at room temperature. Then, the tibiotarsus length was measured using Vernier dial calliper (0-100mm/0.02mm) and weighed. Each bone was put a mark on the midpoint.

Bone-breaking Strength. The bone-breaking strength of tibiotarsus samples was measured using a three-point bending test. The tibiotarsus samples from each treatment group were fixed one by one on a universal testing machine (Model 1000R, with 5000N load cell) and the amount of force required to break the bone when applied at a constant speed of 10 mm/min and distance between supports of 50 mm was recorded.

Tibiotarsal Index. Thickness of the medial and lateral wall of three tibiotarsus samples from each treatment groups was measured using a Vernier dial calliper at the point of breakage (midpoint). Medullary canal diameter was calculated by subtracting the thickness of medial and lateral walls from the diameter at diaphysis. This procedure was done following the bone-breaking strength procedure. Tibiotarsal index was measured as (diaphysis diameter – medullary canal diameter)/ diaphysis diameter x 100.

Ash, Calcium and Phosphorus Content. The tibiotarsus samples from each treatment group were dried in an oven for 24 hours at 105°C. After that, the samples were weighed

and recorded as (W1). Then, the samples were placed in a pre-weighed crucible and put in a muffle furnace at 600°C for 6 hours and were re-weighed and recorded as (W2). Ash content of the tibiotarsus samples was calculated as (W1-W2)/W2 X 100. The ashes samples were then diluted and carried out in a fume cupboard. Dilution process was done by diluting 2 grams of three ashes sample from each treatment group into 100 mL of fuming hydrochloric acid (37%). The mixture was then mixed well. A volume of 0.6 mL of the mixture was pipetted into a test tube containing 14.4 mL of water. The samples were then sealed and sent to for calcium and phosphorus analysis by using atomic absorption spectrometry (Perkin Elmer Analyst 400) and autoanalyser (Lachat Instruments QuikChem 8000Series FIA + System) respectively. This procedure was done following the tibiotarsal index procedure. Upon getting the results, the percentage of calcium and phosphorus in the ashes samples were calculated as calcium level (mg/L) x 100/W1 X 0.0025 and phosphorus level (mg/L) x 100/W1 X 0.0025 respectively.

Statistical Analysis

JMP® Version 11. NC: SAS Institute Inc. software was used to analyse all the data collected. ANOVA with control, Dunnett's test were used to compare means between treatment groups. The data were considered significant at $p<0.05$.

RESULTS AND DISCUSSION

Growth Performance

The impact of supplementing MCP on the growth performance of broilers are presented in Table 2. There were significant differences on the BW, BWG, and FI among treatment groups. Broilers supplemented with 0.5% MCP (T2) had the highest BW, BWG, and FI throughout the 42 days study period. In the case of rapid growth, an adequate nutritional supply of both Ca and P become crucial for the fast-growing broiler. Thus, additional of Ca and P are needed for those birds. According to the Applegate and Angel (2014), chicks require about 1.0% Ca with 0.45% of available P. However, there were reports that chicks needed about 0.65 to 0.7% of total P because the corn-soybean meal diet contained only about 0.2 to 0.25% P due to the indigestibility of phytate (Mitchell & Edwards, 1996). Therefore, supplementing Ca and P were found to increase the growth performance in young broilers (Hamdi et al., 2015). In normal practices, dicalcium phosphate (DCP) is usually added in commercial broiler feed. Even though research has found that the amount of Ca and P availability in MCP are higher than di- or tri sources, farmers are still reluctant to practiced MCP supplementation due to the higher feed cost (Ogino, 1979). In different studies, the addition of 0.6% and 2% MCP were found to increase the growth performance of hybrid African catfish and mirror carp fishes respectively (Kim et al., 1998; Mgbenka & Ugwu, 2005). A feed grade MCP used in this study is a high quality Ca and P source that is used as a feed additive or premix in

the animal feed industry. Nonetheless, there was limited study conducted on the effect of MCP supplementation in commercial broilers.

No significant difference was observed in the FCR for all treatment groups. However, numerically lower parameters were observed in broilers supplemented with 1.0% MCP (T3). These findings were concurrent with Abdulla et al. (2017), who found that broilers fed with diets containing 1.5% of Ca had lower BW and BWG. Agreeing to Mutucumarana et al. (2014), excessive Ca interact with inorganic P causing the Ca to be indigestible. As a result, it will alter the intestinal pH to be more acidic or at pH 5.0. The acidic environment in the small intestine will then decrease the digestibility and absorption of P. Huge Ca and P imbalance will occur if they continue to consume high Ca diet leading to lower FI and higher FCR which was exhibited in this current study (Adeola & Walk, 2013).

Gut Histomorphology

The effect of MCP supplementation on the villus height and crypt depth of broilers are shown in Table 3. There was a significant difference in the villus height among treatment groups. Supplementing 0.5% MCP (T2) was found to increase the villus height in the jejunum and ileum. This finding was supported by Pohl et al. (2012), who reported that inclusion of 1.5% of

Table 2
Effect of MCP supplementation on the growth performance of broilers

Parameters	Treatments			SEM
	T1	T2	T3	
1-21 days				
Initial body weight (g)	54.06	51.61	52.69	0.21
Body weight (g)	971.02^{b}	982.52^{ab}	940.82^{a}	10.01
Body weight gain (g)	916.96^{b}	930.91^{ab}	888.13^{a}	9.17
Feed intake (g)	1205.37	1211.91	1176.92	11.81
FCR	1.24	1.23	1.25	0.01
22-42 days				
Body weight (g)	2396.89^{b}	2488.74^{a}	2365.34^{b}	25.12
Body weight gain (g)	2342.83^{b}	2437.13^{a}	2312.65^{b}	20.92
Feed intake (g)	4462.71^{b}	4604.51^{a}	4410.21^{b}	21.93
FCR	1.90	1.89	1.91	0.01
Feeding Cost				
Starter/bird (RM)	3.17	3.25	3.20	
Finisher/bird (RM)	8.47	8.96	8.67	
Total/bird (RM)	11.64	12.21	11.87	

Note. $^{a, b, c}$ values with superscript within column are significantly different at $P< 0.05$.
T1: 0% MCP (control); T2: 0.5% MCP; T3: 1.0% MCP

calcium formate (CaFo) increased the duodenal villus height compared to the lower and higher concentration of CaFo in broiler chickens. Increased villus height of the intestine corresponds to increase digestive and absorptive functions of the intestine due to the enhanced absorptive surface area leading to feeding efficiency (Zhang & Adeola, 2017). In addition to growth promoting activity, minerals such as Ca and P play a major role in the immune response where mineral inclusion above requirements is required to boost immune responses (Dozier et al., 2003). It will affect the gut pH, gastrin production, acid secretion, epithelial cell proliferation, and nutrient absorption leading to bacteriostatic effect which could have a possible effect on gut histomorphology and villus height (Pohl et al., 2012). When the size and height of intestinal villi increase, nutrient absorption in gastrointestinal tract will be enhanced and result in better feed efficiency of the chicken which was observed in the present study (Ruttanavut & Yamauchi, 2010).

Besides, there was also a significant difference in the crypt depth between treatment groups. Broilers supplemented with 0.5% MCP (T2) had the shortest crypt depth in the duodenum, jejunum, and ileum compared to the other treatment birds. The crypts base or also known as the villus factory are constantly dividing so that the villi structure will be maintained hence more villi will be developed (Chwen et al., 2013). Crypt depth measurements are affected by the enterocytes differentiating activity. Shorter crypt depth results in a slower turnover of the intestinal mucosa resulting in lower maintenance requirement (Gao et al., 2008). As a result, more energy is focused on the production and growth rate where heavier BW and BWG were exhibited by T2 birds. In contrast, a deeper crypt depth observed in T3 birds indicates increased production rate of the enterocyte and migration up the villi. When the turnover is faster, higher maintenance is required for villi regeneration. A deeper crypt is also resulted due to inflammation from

Table 3
Effect of MCP supplementation on the intestinal histomorphology of broilers

Parameters	Treatments			SEM
	T1	T2	T3	
Villus height				
Duodenum (µm)	1038.39	1107.82	1063.99	42.22
Jejunum (µm)	610.91^{b}	765.11^{a}	585.17^{b}	21.50
Ileum (µm)	394.87^{ab}	430.61^{a}	321.98^{b}	7.91
Crypt depth				
Duodenum (µm)	127.85^{b}	122.23^{b}	176.12^{a}	2.29
Jejunum (µm)	162.65^{a}	103.27^{c}	130.35^{b}	3.54
Ileum (µm)	95.32^{ab}	89.72^{b}	104.42^{a}	2.19

Note. $^{a, b, c}$ values with superscript within column are significantly different at $P< 0.05$.
T1: 0% MCP (control); T2: 0.5% MCP; T3: 1.0% MCP

pathogens and toxin which may fasten the tissue turnover (Gao et al., 2008).

Carcass Characteristics

The impact of supplementing MCP on the carcass characteristics of broilers are presented in Table 4. No significant differences were observed in all the parameters among treatment birds. A similar finding was reported by Hamdi et al. (2017), where different sources of Ca and P had no effect on the productive performance of broiler chickens for both 21 and 35 days old. However, higher parameters were observed in broilers supplemented with 0.5% MCP (T2). The quality and quantity of carcass are determined by environmental and genetic factors. According to Abdulla et al. (2017), one of the major contributors to the environmental aspect is the nutrient received by the animal. For example, T2 broilers had a higher dressing percentage, heavier breast muscle, drumsticks, neck, head, and shank probably due to the higher BWG. In addition, heavier gizzard and gastrointestinal tract may be due to the high FI and enhanced gut histomorphology of T2 broilers.

In a report by Al Daraji et al. (2011), birds fed with a too low or too high level of dietary Ca had lower carcass weight due to lower BW and BWG which was demonstrated in T3 birds. This was in accord with findings by Han et al. (2016), which

Table 4
Effect of MCP supplementation on the carcass characteristics of broilers

Parameters	Treatments			SEM
	T1	T2	T3	
Final live weight (kg)	2.34[b]	2.44[a]	2.31[b]	20.92
Kill out weight (%)	97.64	97.72	97.98	0.37
De-feathered weight (%)	93.42	93.41	93.95	0.22
Dressing percentage (%)	73.81	73.86	72.62	0.70
Breast muscle (%)	18.48	22.01	21.44	0.97
Drumsticks (%)	11.38	11.44	11.31	0.86
Wings (%)	9.57	9.41	10.55	0.73
Neck (%)	2.13	2.31	2.22	0.45
Head (%)	2.90	3.12	2.91	0.15
Shank (%)	4.01	4.21	4.05	0.71
Full gizzard (%)	1.57	1.84	1.32	0.17
Empty gizzard (%)	1.25	1.38	1.22	0.07
Gastrointestinal tract (%)	15.29	15.44	14.40	1.13
Heart (%)	0.49	0.49	0.50	0.01
Liver (%)	2.54	2.54	2.07	0.44

Note. [a, b, c] values with superscript within column are significantly different at $P< 0.05$.
T1: 0% MCP (control); T2: 0.5% MCP; T3: 1.0% MCP

suggested that Ca and P imbalance in dietary feed compressed muscle growth and meat production of broiler chickens.

Meat Quality

The effect of MCP supplementation on the meat quality of broilers is shown in Table 5. All experimental broiler birds slaughtered on day 42 showed no significant differences in the meat quality parameters. The result was consistent to Li et al. (2016), who measured the pH values and the cooking loss and significant differences were not observed in broiler groups fed different levels of P. Nevertheless, the meat colour of the breast meat showed significant differences between groups. High P diets resulted in increased lightness (L*) and redness (a*) values (Li et al., 2016). Although broilers supplemented with 1.0% MCP (T3) demonstrated the highest values for all the meat quality parameters in the current work, no significant change in the meat quality was observed. This could be attributable to the P levels in the diet which might not be deficient or excessive enough to affect the meat quality (Rath et al., 2000).

Higher dietary P in broiler feed results in higher P content in the breast meat. It was found that deficient or excessive incorporation of P levels in feed caused detrimental effects on meat quality by decreasing the intramuscular fat content (IMF) and fatty acids of the breast meat (Li et al., 2016). Driver et al. (2006) found that broken clavicles were associated with bloody breast meat affecting the redness of the muscle, but in most cases, the bleeding occurred without any detectable fracture of the bone. This may occur due to Ca and P imbalances in broilers where bleeding occurs from hairline fractures of the bone as a result of poor mineralization. Calcium is also required in activities of blood-clotting proteins that may explain the phenomenon. It has been demonstrated that removing DCP from broiler finisher diet resulted in an increase of blood-splashed breast meat (Chen & Moran, 1994).

Table 5
Effect of MCP supplementation on the meat quality of broilers

Parameters	Treatments			SEM
	T1	T2	T3	
Drip loss (%)	1.78	2.04	2.71	0.50
Cooking loss (%)	19.95	23.60	24.28	3.52
pH	6.26	6.16	6.41	0.29
Colour:				
Lightness (L*)	49.05	47.80	52.04	3.03
Redness (a*)	5.547	5.34	6.43	1.15
Yellowness (b*)	18.88	18.56	20.28	1.60

Note. [a, b, c] values with superscript within column are significantly different at P< 0.05.
T1: 0% MCP (control); T2: 0.5% MCP; T3: 1.0% MCP

Bone Quality

The impact of supplementing MCP on the bone quality of broilers is presented in Table 6. Experimental broilers supplemented with varying concentration of MCP in the diet resulted in some significant differences in the bone quality parameters. Broilers supplemented with 0.5% MCP (T2) had the highest significant values for bone weight, diaphysis diameter, medullary canal diameter, lateral wall thickness, medial wall thickness, and bone breaking strength. Bone quality is a composite of properties that makes bone resist fractures. The present experiment showed that T2 birds had better bone mineralization compared to the other treatments. Supplemental amount of Ca in diets resulted in better tibia mineralization, in particular, higher levels of breaking strength, length, weight, ash weight, and ash Ca contents (Han et al., 2016).

On the other hand, chickens supplemented with 1.0% MCP (T3) demonstrated a higher Ca and P percentages in the bone ash but the weakest bone breaking strength. This was supported by the findings of Hurwitz et al. (1995), where insufficient or excess supply of one or both minerals (Ca and P) interfered with homeostasis of the second one. This homeostasis imbalance resulted in reduced bone mineralization. This was in agreement with an earlier study that observed increased tibia ash and mineral contents were due to high dietary Ca and P content (Nelson et al., 1990). However, according to Venalainen et al. (2006), increase in bone ash content was not proportionate to bone breaking strength. The resistance to breaking of long bones such as tibia and femur appeared to be affected by the Ca and P content in starter diet, while events of broken clavicles were only influenced by the type of diet fed during

Table 6
Effect of MCP supplementation on the bone quality of broilers

Parameters	Treatments			SEM
	T1	T2	T3	
Bone length (mm)	93.67	95.33	91.67	3.76
Bone weight (g)	7.87^{b}	8.45^{a}	6.65^{c}	1.45
Diaphysis diameter (mm)	7.81^{b}	8.95^{a}	7.89^{b}	1.21
Medullary canal diameter (mm)	4.99^{a}	5.67^{a}	4.16^{b}	0.31
Lateral wall thickness (mm)	1.65^{b}	2.31^{a}	1.73^{b}	0.54
Medial wall thickness (mm)	1.16^{b}	2.01^{a}	0.97^{b}	0.20
Tibiotarsal index	35.81	46.05	36.20	0.51
Bone breaking strength (N)	300.06^{ab}	336.59^{a}	256.20^{b}	8.66
Ash (%)	56.37	56.44	56.56	1.71
Ca (%)	2.40^{b}	3.24^{a}	3.69^{a}	0.40
P (%)	1.21^{b}	2.07^{a}	2.28^{a}	0.29

Note. $^{a, b, c}$ values with superscript within column are significantly different at P< 0.05.
T1: 0% MCP (control); T2: 0.5% MCP; T3: 1.0% MCP

grower-finisher phase (Driver et al., 2006). Williams et al. (2003), provided evidence that rapid growth rates, rather than genotype, had a greater effect on bone mineralization. A fast-growing commercial line of broilers showed decreased tibial mineralization and increased bone porosity as compared with a slow growing line of broilers.

CONCLUSION

Dietary inclusion of 0.5% MCP was found to enhance the growth performance, gut histomorphology, and bone quality of broiler chickens. Higher values were also obtained in the carcass characteristics without affecting the meat quality. Therefore, MCP could be used effectively as a Ca and P supplement in the commercial broiler industry to reduce culling of birds with musculoskeletal problems in particularly lameness and skeletal deformities. MCP supplementation may have a greater effect in layers or broiler breeders because of their longer rearing periods and increased calcium requirements.

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REFERENCES

Abdulla, N. R., Loh, T. C., Akit, H., Sazali, A. Q., Foo, H. L., Kareem, K. Y., … Rahim, R. A. (2017). Effects of dietary oil sources, calcium and phosphorus levels on growth performance, carcass characteristics and bone quality of broiler chickens. *Journal of Applied Animal Research*, *45*(1), 423-429.

Abdulla, N. R., Zamri, A. N. M., Sabow, A. B., Kareem, K.Y., Nurhazirah, S., Ling, F. H., … Loh, T. C. (2015). Physico-chemical properties of breast muscle in broiler chickens fed probiotics, antibiotics or antibiotic-probiotic mix. *Journal of Applied Animal Research*, *45*(1), 64-70.

Adeola, O., & Walk, C. L. (2013). Linking ileal digestible phosphorus and bone mineralization in broiler chickens fed diets supplemented with phytase and highly soluble calcium. *Poultry Science*, *92*(8), 2109-2117.

Al Daraji H. J., Al Mashadani, H., Mirza, H., Al Hayani, W., & Al Hassani, A. (2011). Effects of feeds containing different fats on certain carcass parameter of Japanese quail. *ARPN Journal of Agriculture and Biological Science*, *6*(1), 6-11.

Applegate, T. J., & Angel, R. (2014). Nutrient requirements of poultry publication: History and need for update. *The Journal of Applied Poultry Research*, *23*(3), 567-575.

Chen, X., & Moran, E. T. (1994). Response of broilers to omitting dicalcium phosphate from the withdrawal of feed: Live performance, carcass downgrading and further processing yields. *The Journal of Applied Poultry Research*, *4*(1), 69-82.

Chwen, L. T., Foo, H. L., Thanh, N. T., & Choe, D. W. (2013). Growth performance, plasma fatty acids, villous height and crypt depth of preweaning piglets fed with medium chain triacylglycerol. *Asian-Australasian Journal of Animal Sciences*, *26*(5), 700-704.

Dinev, I. (2012). Leg weakness pathology in broiler chickens. *Japan Poultry Science Association*, *49*(2), 63-67.

Dozier, W. A., Davis, A. J., Freeman, M. E., & Ward, T. L. (2003). Early growth and environmental implications of dietary zinc and copper concentrations and sources of broiler chicks. *British Poultry Science*, *44*(5), 726-731.

Driver, J. P., Pesti, G. M., Bakalli, R. I., & Edwards, H. M. (2006). The effect of feeding calcium- and phosphorus-deficient diets to broiler chickens during the starting and growing-finishing phases on carcass quality. *Poultry Science*, *85*(11), 1939–1946.

Eeckhout, W., & De Paepe, M. (1994). Total phosphorus, phytate-phosphorus and phytase activity in plant feedstuffs. *Animal Feed Science and Technology*, *47*(1-2), 19-29.

Gao, J., Zhang, H. J., Yu, S. H., Wu, S. G., Yoon, I., Quigley, J., … Qi, G. H. (2008). Effects of yeast culture in broiler diets on performance and immunomodulatory functions. *Poultry Science*, *87*(7), 1377-1384.

Gonzalez-Ceron, F., Rekaya, R., Anthony, N. B., & Aggrey, S. E. (2015). Genetic analysis of leg problems and growth in a random mating broiler population. *Poultry Science*, *94*(2), 162-168.

Hamdi, M., López-Vergé, S., Manzanilla, E. G., Barroeta, A. C., & Pérez, J. F. (2015). Effect of different levels of calcium and phosphorus and their interaction on the performance of young broilers. *Poultry Science*, *94*(9), 2144-2151.

Hamdi, M., Solà Oriol, D., Franco Rosselló, R., Aligué i Alemany, R. M., & Pérez, J. F. (2017). Comparison of how different feed phosphates affect performance, bone mineralization and phosphorus retention in broilers. *Spanish Journal of Agricultural Research*, *15*(3), e0605. doi: 10.5424/sjar/2017153-11149

Han, J., Wang, J., Chen, G., Qu, H., Zhang, J., Shi, C., … Cheng, Y. (2016). Effects of calcium to non-phytate phosphorus ratio and different sources of vitamin D on growth performance and bone mineralization in broiler chickens. *Revista Brasileira de Zootecnia*, *45*(1), 1-7.

Hurwitz, S., Plavnik, I., Shapiro, A., Wax, E., Talpaz, H., & Bar, A. (1995). Calcium metabolism and requirements of chickens are affected by growth. *The Journal of Nutrition*, *125*(10), 2679-2686.

Kim, J. D., Kim, K. S., Song, J. S., Lee, J. Y., & Jeong, K. S. (1998). Optimum level of dietary monocalcium phosphate based on growth and phosphorus excretion of mirror carp, *Cyprinus carpio*. *Aquaculture*, *161*(1-4), 337–344.

Knowles, T. G., Kestin, S. C., Haslam, S. M., Brown, S. N., Green, L. E., Butterworth, A., … Nicol, C. J. (2008). Leg disorder in broiler chickens: Prevalence, risk factors and prevention. *PLOS One*, *3*(2), e1545.

Li, X., Wang, J., Wang, C, Zhang, C, Li, X., Tang, C., & Wei, X. (2016). Effect of dietary phosphorus levels on meat quality and lipid metabolism in broiler chicken. *Food Chemistry*, *205*, 289-296.

Liu, J. B., Chen, D. W., & Adeola, O. (2013). Phosphorus digestibility response of broiler chickens to dietary calcium-to-phosphorus ratios. *Poultry Science*, *92*(6), 1572–1578.

Mgbenka, B. O., & Ugwu, L. L. C. (2005). Aspects of mineral composition and growth rate of the hybrid African catfish fry fed inorganic phosphorus-supplemented diets. *Aquaculture Research*, *36*(5), 479-485.

Mitchell, R. D., & Edwards Jr, H. M. (1996). Effects of phytase and 1, 25-dihydroxycholecalciferol on phytate utilization and the quantitative requirement for calcium and phosphorus in young broiler chickens. *Poultry Science*, *75*(1), 95-110.

Mutucumarana, R. K., Ravindran, V., Ravindran, G., & Cowieson, A. J. (2014). Influence of dietary calcium concentration on the digestion of nutrients along the intestinal tract of broiler chickens. *Journal of Poultry Science*, *51*(4), 392–401.

Nelson, T. S., Harris, G. C., Kirby, L. K., & Johnson, Z. B. (1990). Effect of calcium and phosphorus on the incidence of leg abnormalities in growing broilers. *Poultry Science*, *69*(9), 1496-1502.

Ogino, C. (1979). Availability of dietary phosphorus in carp and rainbow trout. *Nippon Suisan Gakkaishi*, *45*, 1527-1532.

Pohl, S. A., Caldwell, D. J., Lee, J. T., Coppedge, J. R., Dunn-Horrocks, S. L., Stringfellow, K. D., … Farnell, M. B. (2012). Effects of dietary calcium formate inclusion on broiler performance, skeletal development, and gut maturation. *The Journal of Applied Poultry Research*, *21*(2), 311–317.

Rath, N. C., Huff, G. R., Huff, W. E., & Balog, J. M. (2000). Factors regulating bone maturity and strength in poultry. *Poultry Science*, *79*(7), 1024-1032.

Ruttanavut, J., & Yamauchi, K. (2010). Growth performance and histological alterations of intestinal villi in broilers fed dietary mixed minerals. *Asian Journal of Animal Sciences*, *4*(3), 96-106.

Venalainen, E., Valaja, J., & Jalava, T. (2006). Effects of daily metabolisable energy, calcium, and phosphorus on bone mineralization, leg weakness and performance on broiler chickens. *British Poultry Science*, *47*(1), 301-310.

Williams, B., Waddington, D., Murray, D. H., & Farquharson, C. (2003). Bone strength during growth: Influence of growth rate on cortical porosity and mineralization. *Calcified Tissue International*, *74*(3), 236-245.

Zhang, F., & Adeola, O. (2017). Techniques for evaluating digestibility of energy, amino acids, phosphorus, and calcium in feed ingredients for pigs. *Animal Nutrition*, *3*(4), 344–352.