


# Effects and interaction of dietary calcium and nonphytate phosphorus for slow-growing yellow-feathered broilers between 56 and 84 d of age

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**ABSTRACT** This experiment investigated the effect and interaction of dietary calcium (Ca) and nonphytate phosphorus (NPP) on growth performance, tibial characteristics, carcass traits, and meat quality for slow-growing yellow-feathered broilers during 56 to 84 d of age. A 3 × 3 factorial arrangement was used, and 720 56-day-old broilers were randomly divided into 9 groups and fed with diets containing different levels of Ca (0.70, 0.80, 0.90%) and NPP (0.30, 0.35, 0.40%) for 28 d. The dietary Ca level affected the ADFI of yellow-feathered broilers ( $P < 0.05$ ), and the ADFI of birds fed with 0.90% Ca was increased ( $P < 0.05$ ) compared with that of birds fed with 0.70% Ca. Birds received 0.35 or 0.40% NPP had higher final BW, ADG, and ADFI than those fed with 0.30% NPP ( $P < 0.05$ ). The tibial diameter of birds fed with 0.80% Ca was increased compared with that of other groups ( $P < 0.05$ ). The dietary NPP level did not affect tibial characteristics ( $P > 0.05$ ). The

dietary Ca level did not affect carcass traits ( $P > 0.05$ ). When broilers were fed with 0.30% P, the semieviscerated percentage was increased compared with birds fed with 0.40% NPP ( $P < 0.05$ ). The dietary Ca level had significant effects on the L\* value and shear force of the breast muscle, and the dietary NPP level affected the L\* value and drip loss of the breast muscle ( $P < 0.05$ ). Furthermore, the effect of interaction between the level of Ca and NPP was observed on the L\* and a\* value ( $P < 0.05$ ). In conclusion, dietary Ca had influence on performance, tibial characteristics, and meat quality of yellow-feathered broilers, and dietary NPP affected performance, tibial characteristics, and carcass traits. Furthermore, the effect of interaction between the dietary Ca and NPP level was observed on carcass traits and meat quality. Considering all aforementioned indicators, 0.80% Ca and 0.35% NPP were recommended for slow-growing yellow-feathered broilers aged 57 to 84 d of age.

**Key words:** calcium, slow-growing yellow-feathered broiler, nonphytate phosphorus, performance, tibial characteristic

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## INTRODUCTION

Calcium (Ca) is the most abundant mineral in the body and plays an important role in bone mineralization, blood clotting, intracellular signaling, and muscle contraction (Suttle, 2010). As an essential and critical mineral in broilers' diets, phosphorus (P) performs

critical functions in nucleic acid synthesis, energy metabolism, and bone mineralization (Delezie et al., 2015; Li et al., 2017). Diets with inadequate Ca and P levels can lead to skeletal abnormalities and negatively affect growth performance (Applegate et al., 2003; Gautier et al., 2017). However, excess or imbalance in Ca and P results in a cascade of undesirable changes in broilers (Proszkowiec-Weglarz and Angel, 2013). Excess Ca in the diet interferes with the availability of P and other minerals such as zinc and manganese (Driver et al., 2005). When complexed with lipids, it makes them unavailable, thus decreasing the effective energy provision from feed (Edwards et al., 1960; Majeed et al., 2020). Excessive P intake is thought to disrupt hormonal

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regulation of P, Ca, and vitamin D, contributing to impaired peak bone mass and bone resorption (Calvo and Tucker, 2013). Commercial poultry diets are typically corn and soy based and contain relatively high levels of phytate P. Phytate P has limited availability for poultry (Selle et al., 2011; Bradbury et al., 2014), and nonphytate P (NPP) gives precise estimates of P requirements for poultry (Bradbury et al., 2014). Therefore, research on optimizing dietary levels of Ca and NPP has real importance for broiler production.

Improved yellow-feathered broilers are very important in China and Southeast Asia, with 4 billion marketed annually in China, almost the same as that of introduced white-feathered broilers. The precise nutritional requirements of improved yellow-feathered broilers remain incomplete, and current recommendations for Ca and NPP come from the NRC and are not necessarily appropriate for birds with distinct genetic backgrounds from improved Western commercial lines. The present study has examined the effects of and interactions between dietary Ca and NPP on growth performance, tibial characteristics, carcass traits, and meat quality of yellow-feathered broilers during the latter grower phase, 57 to 84 d. This study provides a rational recommendation for the appropriate dietary nutrient levels and provides a scientific basis for establishing nutritional standards for yellow-feathered broilers.

## MATERIALS AND METHODS

### Chicken Husbandry

The experimental protocol was approved by the Animal Care Committee of the Institute of Animal Science, Guangdong Academy of Agriculture Science, Guangzhou, P.R. China, with the approval number of GAASISA-2015-020. A  $3 \times 3$  factorial arrangement was used to assess the effects of Ca and NPP on slow-growing yellow-feathered female broilers during 56 to 84 d. In detail, 720 56-day-old broilers were randomly divided into 9 groups, which were fed with diets supplemented with different levels of Ca (0.70, 0.80, 0.90%) and NPP (0.30, 0.35, 0.40%), each with 4 replicates of 20 birds per replicate. Before start of the study, birds had received 0.90% Ca and 0.45% NPP from 1 to 28 d and then 0.85% Ca and 0.40% NPP from 29 to 56 d. Broilers were housed in floor pens (stocking density =  $0.40 \text{ m}^2/\text{bird}$ ) with first use of wood shavings litter. Water and mashed diets were provided ad libitum throughout. Daylight was eliminated and replaced with 18-hour lighting from incandescent bulbs. The temperature of the room was maintained at  $26^\circ\text{C}$ .

### Experimental Diets

The basal diets were formulated as per Chinese Feeding Standard of Chicken recommendations (Ministry of Agriculture, PRC, 2004). The details of ingredient composition and calculated nutrient contents

of the experimental diets for broilers are provided in Table 1.

### Measurement of Growth Performance

Feed intake was recorded daily on a per-replicate basis. BW of birds per pen were recorded at day 56 and day 84. Mortality was checked daily, and dead birds were recorded and weighed to adjust estimates of gain, intake, and feed conversion ratio (FCR), as appropriate. The final BW (FBW), ADG, ADFI, and FCR from 56 to 84 d were calculated.

### Analysis of Carcass Traits

At the end of the study, on day 84, 2 birds close to average FBW in each replicate were chosen, deprived of feed overnight, and weighed immediately before slaughter. The head, feet, feathers, and viscera were removed. During the evisceration process, abdominal fat pads were removed and weighed. The left breast muscles and thigh were then dissected and weighed. Dressing percentage, semieviscerated percentage, and eviscerated percentage were expressed as the percentage of whole live bird weight, and parts of yields were expressed as the percentage of postchilled eviscerated weight.

### Measurement of Tibial Characteristics

Two pairs of tibiae from each replicate were collected and cleaned of all adherent tissues for analyses. The right tibia was blotted dry with paper towels, and weight was recorded. The length and diameter (the center of the bone) of the right fresh tibia were immediately measured using a caliper with a minimum scale of 0.01 mm (Ministry of Agriculture and Rural Affairs, 2020). Bone breaking strength of the left tibia was determined using a material tester (Instron 4411; Instron Corporation, Grove City, PA), as described previously by Wang et al., (2014).

### Measurements Related to Meat Quality

Carcasses were dissected, and indices of meat quality including color, shear force, drip loss, and pH of breast muscle were determined, all by standard procedures. In brief, muscle surface color indices, lightness ( $L^*$ ), redness ( $a^*$ ), and yellowness ( $b^*$ ), were measured at 45 min post-mortem using a chroma meter (CR-410; Konica Minolta, Tokyo, Japan). pH was measured at 45 min post-mortem in the right pectoralis major muscle using a portable pH meter equipped with an insertion glass electrode (HI8424; HANA Instrument Science and Technology Co., Ltd., Beijing, PRC). Samples of the pectoralis major were cut at a right angle to the muscle fiber direction and then suspended without contact in a plastic bag filled with air and left at  $4^\circ\text{C}$  for 24 h, and drip loss was determined by weighing to calculate the water-holding capacity. After holding overnight at  $4^\circ\text{C}$ , the breast muscle was cooked to an internal temperature of

**Table 1.** Composition and calculated nutrient contents of diets of broilers from 57 to 84 d of age (as-fed basis).

Diets	Calcium	0.70%	0.70%	0.70%	0.80%	0.80%	0.80%	0.90%	0.90%	0.90%
	NPP	0.30%	0.35%	0.40%	0.30%	0.35%	0.40%	0.30%	0.35%	0.40%
Ingredients, %										
Corn		70.89	70.89	70.89	70.89	70.89	70.89	70.89	70.89	70.89
Soybean meal		18.85	18.85	18.85	18.85	18.85	18.85	18.85	18.85	18.85
Corn gluten meal		1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46
Soybean oil		4.72	4.72	4.72	4.72	4.72	4.72	4.72	4.72	4.72
Limestone		1.07	0.90	0.72	1.35	1.20	1.00	1.63	1.47	1.28
Calcium monohydrogen phosphate		0.80	1.00	1.22	0.80	1.00	1.22	0.80	1.00	1.22
Salt		0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
<i>DL</i> -Met (99%)		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
<i>L</i> -Lysine HCL (78%)		0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Vitamin and mineral premix <sup>1</sup>		0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Zeolite powder		0.63	0.60	0.56	0.35	0.30	0.28	0.07	0.03	0.00
Total		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Nutrient contents <sup>2</sup>										
ME, MJ/kg		13.39	13.39	13.39	13.39	13.39	13.39	13.39	13.39	13.39
CP, %		17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00
Ca, %		0.70	0.70	0.70	0.80	0.80	0.80	0.90	0.90	0.90
Nonphytate phosphorus, %		0.30	0.35	0.40	0.30	0.35	0.40	0.30	0.35	0.40
Lysine, %		0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Methionine, %		0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Met + Cys, %		0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69
Calcium, % (measured)		0.69	0.68	0.68	0.75	0.77	0.75	0.81	0.80	0.80
P, % (measured)		0.53	0.57	0.62	0.53	0.56	0.62	0.52	0.56	0.62

Abbreviation: NPP, nonphytate phosphorus.

<sup>1</sup>Premix provided the following per kilogram of diets: vitamin D<sub>3</sub>, 1,000 IU; vitamin E, 20 IU; vitamin K<sub>3</sub>, 4 mg; vitamin B<sub>1</sub>, 1.8 mg; vitamin B<sub>2</sub>, 8 mg; vitamin B<sub>6</sub>, 3.5 mg; vitamin B<sub>12</sub>, 0.01 mg; chloride, 500 mg; niacin, 44 mg; pantothenic acid, 10 mg; folic acid, 0.55 mg; biotin, 0.15 mg; Fe, 80 mg; Cu, 8 mg; Mn, 80 mg; Zn, 60 mg; I, 0.35 mg; Se, 0.15 mg.

<sup>2</sup>Except where indicated, nutrient levels are all calculated values.

70°C in a digital thermostat water bath. After cooling to room temperature, 10 sections about 3-cm thick were cut parallel to the fiber orientation. Shear force was determined using a Universal Mechanical Machine (Instron model 4411; Instron Corp., Canton, MA).

## Statistical Analysis

Pen or individual bird was taken as the experimental unit. Effects of treatment were examined via multivariate ANOVA using SPSS 16.0 for Windows (SPSS Inc., Chicago, IL), including the main effects (dietary Ca and NPP) and the interactive effect between them. The treatment means were compared using Tukey's multiple range tests at  $P < 0.05$  significance levels. Where appropriate, polynomial regressions were fitted to test for linear and quadratic effects in response to Ca and NPP (Eisemann et al., 2014). When a significant

quadratic component was demonstrated ( $P < 0.05$ ), dietary Ca or NPP was estimated as the lower dietary level achieving 95% of the maximal or minimal response.

## RESULTS

### Growth Performance

The effects of dietary Ca and NPP on growth performance of yellow-feathered broilers between 56 and 84 d are shown in Table 2. The dietary Ca level had significant influence on the ADFI of yellow-feathered broilers, and ADFI increased ( $P < 0.05$ ) in birds fed with 0.90% Ca compared with those fed with 0.70% Ca. FBW, ADG, and ADFI were affected by the dietary NPP level ( $P < 0.05$ ), wherein birds fed with 0.35% or 0.40% NPP had higher FBW, ADG, and ADFI than those fed with 0.30% NPP. The optimal levels of dietary NPP from

the quadratic regressions were 0.36% for ADG and 0.38% for ADFI.

Significant interactions ( $P < 0.05$ ) between dietary Ca and NPP existed for ADFI, and diets providing 0.90% Ca and 0.35% NPP or 0.90% Ca and 0.40% NPP resulted in the highest ADFI (Table 2).

### Tibial Characteristics

As shown in Table 3, for broilers at 84 d, the dietary Ca level affected tibial diameter (quadratically,  $P < 0.05$ ), and the optimal level of dietary Ca from the quadratic regressions was 0.80%. The dietary NPP level did not affect tibial characteristics, and there were no interactions between dietary Ca and NPP.

### Carcass Traits

As presented in Table 4, the dietary Ca level did not affect carcass traits, whereas the NPP level had both linear and quadratic influences ( $P < 0.05$ ) on the semieviscerated percentage and percentage of breast yield. There was a tendency toward abdominal fat being

affected by dietary NPP ( $P = 0.062$ ). When broilers were fed with 0.30% P, increase in semieviscerated percentage and percentage of breast yield was observed compared with that in birds fed with 0.40% NPP and decrease in the percentage of abdominal fat was observed compared with that in birds from the other 2 levels. The optimal levels of dietary NPP from the quadratic regressions were 0.31% for eviscerated percentage and 0.32% for percentage of breast yield.

There were effects of interactions ( $P < 0.05$ ) between the level of Ca and NPP on the dressing percentage and semieviscerated percentage. Birds fed with 0.80% Ca and 0.35% NPP or 0.90% Ca and 0.30% NPP showed in the highest values of dressing percentage and semieviscerated percentage.

### Meat Quality

Effects of dietary Ca and NPP on variables related to meat quality are shown in Table 5. The dietary Ca level had significant effects on the L\* value and shear force (quadratic) of the breast muscle; birds fed with 0.80% Ca had increased L\* values ( $P < 0.05$ ) compared with

**Table 2.** Effects of dietary calcium and nonphytate phosphorus on growth performance of yellow-feathered broilers from 57 to 84 d of age.<sup>1</sup>

Treatment						
Ca, %	NPP, <sup>2</sup> %	IW, <sup>3</sup> g	FBW, <sup>4</sup> g	ADG, g	ADFI, g	FCR <sup>5</sup>
0.70	0.30	705.13	1,206.25	17.28	69.14 <sup>b,c</sup>	0.25
0.70	0.35	704.88	1,202.88	17.17	68.62 <sup>b,c</sup>	0.25
0.70	0.40	704.88	1,193.06	16.83	68.01 <sup>b,c</sup>	0.25
0.80	0.30	705.50	1,158.13	15.61	66.31 <sup>c</sup>	0.24
0.80	0.35	704.63	1,217.43	17.68	69.98 <sup>a,b</sup>	0.25
0.80	0.40	704.38	1,210.00	17.44	70.82 <sup>a,b</sup>	0.25
0.90	0.30	704.63	1,186.88	16.63	67.46 <sup>c</sup>	0.25
0.90	0.35	704.25	1,235.00	18.30	72.80 <sup>a</sup>	0.25
0.90	0.40	705.75	1,223.16	17.84	72.48 <sup>a</sup>	0.24
SEM		0.56	16.35	0.57	1.44	0.01
Main effect means						
0.70		704.96	1,200.73	17.10	68.59 <sup>b</sup>	0.25
0.80		704.83	1,195.19	16.91	69.04 <sup>a,b</sup>	0.24
0.90		704.88	1,215.01	17.59	70.91 <sup>a</sup>	0.25
SEM		0.33	9.44	0.33	0.83	<0.01
	0.30	705.08	1,183.75 <sup>b</sup>	16.51 <sup>b</sup>	67.64 <sup>b</sup>	0.24
	0.35	704.58	1,218.44 <sup>a</sup>	17.72 <sup>a</sup>	70.36 <sup>a</sup>	0.25
	0.40	705.00	1,208.74 <sup>a</sup>	17.37 <sup>a</sup>	70.54 <sup>a</sup>	0.25
	SEM	0.33	9.44	0.33	0.83	<0.01
P-values						
Ca		0.965	0.220	0.223	0.040	0.589
Linear					0.047	
Quadratic					0.111	
NPP		0.538	0.015	0.014	0.006	0.248
Linear			0.061	0.012	0.545	
Quadratic			0.021	0.017	0.226	
Ca × NPP	0.365	0.133	0.131	0.044	0.544	

<sup>a-c</sup>Within a column, means with different superscripts differ significantly ( $P < 0.05$ ).

Quadratic regression equations based on the P level (%): ADG (g) =  $-312.42(\text{NPP})^2 + 227.34(\text{NPP}) - 23.58$ ,  $R^2 = 0.208$ ,  $P = 0.021$ , which yielded the optimized dietary NPP level of 0.36%; ADFI (g) =  $-507.94(\text{NPP})^2 + 384.62(\text{NPP}) - 2.03$ ,  $R^2 = 0.218$ ,  $P = 0.017$ , which yielded the optimized dietary NPP level of 0.38%.

Abbreviation: FBW, final BW.

<sup>1</sup>Data are means of 4 replicates, with 20 birds per replicate for the interaction. For the main effects, data are means of 12 replicates, with 20 birds per replicate.

<sup>2</sup>NPP: nonphytate phosphorus.

<sup>3</sup>IW: initial BW.

<sup>4</sup>FBW: weight at 84 d.

<sup>5</sup>FCR: feed conversion ratio.

**Table 3.** Effects of dietary calcium and nonphytate phosphorus on tibial characteristics of yellow-feathered broilers at 84 d of age.<sup>1</sup>

Treatment		Weight, g	Length, cm	Diameter, mm	Breaking strength, kgf
Ca, %	NPP, <sup>2</sup> %				
0.70	0.30	7.54	10.58	4.80	19.62
0.70	0.35	8.17	10.60	4.77	20.11
0.70	0.40	8.07	10.57	4.75	18.28
0.80	0.30	8.19	10.33	4.90	16.86
0.80	0.35	8.30	10.43	5.10	20.48
0.80	0.40	7.87	10.45	4.92	20.35
0.90	0.30	7.86	10.47	4.77	18.34
0.90	0.35	7.77	10.60	4.65	20.57
0.90	0.40	7.87	10.54	4.83	21.30
SEM		0.18	0.10	0.08	1.12
Main effect means					
0.70		7.93	10.58	4.77 <sup>b</sup>	19.34
0.80		8.12	10.40	4.97 <sup>a</sup>	19.23
0.90		7.83	10.54	4.75 <sup>b</sup>	20.07
SEM		0.10	0.06	0.05	0.65
	0.30	7.86	10.46	4.82	18.27
	0.35	8.08	10.54	4.84	20.39
	0.40	7.94	10.52	4.83	19.98
	SEM	0.10	0.06	0.05	0.65
<i>P</i> -values					
Ca		0.216	0.163	0.004	0.678
Linear				0.774	
Quadratic				0.004	
NPP		0.402	0.693	0.971	0.106
Ca × NPP		0.175	0.980	0.231	0.339

<sup>a,b</sup>Within a column, means with different lowercase superscripts differ significantly ( $P < 0.05$ ).

Quadratic regression equations based on the Ca level (%): perimeter (mm) =  $-21.11(\text{Ca})^2 + 33.67(\text{Ca}) - 8.45$ ,  $R^2 = 0.194$ ,  $P = 0.004$ , which yielded the optimized dietary Ca level value of 0.80%.

<sup>1</sup>Data are means of 4 replicates, with 2 birds per replicate for the interaction. For the main effects, data are means of 12 replicates, with 2 birds per replicate.

<sup>2</sup>NPP: nonphytate phosphorus.

birds fed with 0.90% Ca, and the optimal level of dietary Ca from the quadratic regressions was 0.80%. The dietary NPP level had effect on L\* values and drip loss of the breast muscle ( $P < 0.05$ ); birds fed with 0.30% P had increased L\* values compared with the other levels, and drip loss was increased compared with birds fed with 0.40% NPP. Significant interactions between dietary Ca and NPP existed for L\* and a\* values.

## DISCUSSION

### Effects of Dietary Ca and NPP on Growth Performance

Calcium and P are important elements that are involved in many physiological processes in addition to bone development in poultry and must be adequately supplied in the diet. In the present study, the dietary Ca level had significant influence on the ADFI of yellow-feathered broilers, and FBW, ADG, and ADFI were significantly affected by the dietary NPP level. Half a century ago, [Smith and Taylor \(1961\)](#) had proved that broiler chicks on a lower Ca (0.73%) diet consumed less feed than did birds on a higher Ca (1.3%) diet. Research on Ross 308 broilers showed that the Ca level promoted differences in intake and FBW, and added P increased growth performance ([Hamdi et al., 2015](#)). Final weight and feed efficiency decreased in Cobb 100

broilers fed with suboptimal concentrations of Ca and NPP compared with those fed with the reference diet ([Rama Rao et al., 2006](#)). [Lee et al. \(2019\)](#) also found that dietary Ca influenced feed efficiency, and birds fed with low-Ca diets had poorer FBW and FCR than birds fed with adequate Ca levels. There exists effect of interaction between the level of Ca and NPP on ADFI, and in general, higher ADFI was observed in broilers fed with both higher concentrations of Ca and NPP. The same was found by [Hamdi et al. \(2015\)](#), wherein increasing the level of NPP increased feed intake (FI) in chickens fed with a high-Ca diet. The aforementioned information emphasized the importance of formulating diets to accurately balance the density of Ca and NPP, considering the biological importance of both minerals ([Bradbury et al., 2014](#)). Dietary Ca and NPP had great influence on growth performance of yellow-feathered broilers aged 57 to 84 d, and birds fed with 0.9% Ca and 0.35 or 0.40% NPP showed the best growth; quadratic regressions pinpointed the optimal levels of dietary NPP as 0.36% for ADG and 0.38% for ADFI.

### Effects of Dietary Ca and NPP on Tibial Characteristics

Calcium and P are essential minerals involved in many biological processes including bone development and mineralization ([Proszkowiec-Weglarczyk et al., 2019](#)). The

**Table 4.** Effects of dietary calcium and nonphytate phosphorus on carcass traits of yellow-feathered broilers at 84 d of age.<sup>1</sup>

%							
Treatment							
Ca, %	NPP, <sup>2</sup> %	Dressing <sup>3</sup> percentage	Semieviscerated percentage	Eviscerated percentage	Percentage of breast yield	Percentage of thigh	Percentage of abdominal fat
0.70	0.30						
0.70	0.35	87.46 <sup>b</sup>	80.01 <sup>c</sup>	66.02	10.55	12.45	4.60
0.70	0.40	89.15 <sup>a</sup>	80.98 <sup>a,b,c</sup>	65.46	8.99	12.60	4.42
0.80	0.30	87.91 <sup>b</sup>	80.28 <sup>b,c</sup>	66.11	10.25	13.14	3.32
0.80	0.35	89.20 <sup>a</sup>	82.21 <sup>a</sup>	66.92	10.52	12.86	4.12
0.80	0.40	89.00 <sup>a</sup>	81.44 <sup>a,b</sup>	65.33	9.73	12.70	4.91
0.90	0.30	89.00 <sup>a</sup>	81.77 <sup>a</sup>	67.25	10.91	12.97	3.40
0.90	0.35	88.65 <sup>a</sup>	81.40 <sup>a,b</sup>	66.20	10.31	12.80	4.52
0.90	0.40	89.31 <sup>a</sup>	81.90 <sup>a,b</sup>	66.10	10.06	12.92	5.16
SEM		0.34	0.43	0.47	0.34	0.26	0.34
Main effect means							
0.70		88.53	80.84	65.94	10.05	12.75	4.47
0.80		88.70	81.31	66.12	10.16	12.90	4.12
0.90		88.89	81.54	66.41	10.33	12.85	4.26
SEM		0.20	0.25	0.27	0.20	0.15	0.20
	0.30	88.63	81.20	66.57 <sup>a</sup>	10.59 <sup>a</sup>	13.11	3.71 <sup>b</sup>
	0.35	88.44	81.21	66.38 <sup>a,b</sup>	10.46 <sup>a</sup>	12.70	4.41 <sup>a</sup>
	0.40	89.15	81.44	65.63 <sup>b</sup>	9.59 <sup>b</sup>	12.74	4.83 <sup>a</sup>
	SEM	0.20	0.25	0.27	0.20	0.15	0.20
<i>P</i> -values							
Ca		0.431	0.163	0.503	0.545	0.844	0.431
NPP		0.082	0.954	0.048	0.001	0.188	0.062
Linear				0.020	0.001		
Quadratic				0.048	<0.001		
Ca × NPP		0.019	0.010	0.494	0.349	0.881	0.211

<sup>a-c</sup>Within a column, means with different lowercase superscripts differ significantly ( $P < 0.05$ ).

Quadratic regression equations based on the P level (%): eviscerated percentage (%) =  $-126.40(P)^2 + 78.47(P) + 54.40$ ,  $R^2 = 0.110$ ,  $P = 0.048$ , which yielded the optimized dietary P level value of 0.31%; percentage of breast yield (%) =  $-158.56(P)^2 + 100.51(P) - 5.29$ ,  $R^2 = 0.245$ ,  $P = 0.001$ , which yielded the optimized dietary P level value of 0.32%.

<sup>1</sup>Data are means of 4 replicates, with 20 birds per replicate for the interaction. For the main effects, data are means of 12 replicates, with 20 birds per replicate.

<sup>2</sup>NPP: nonphytate phosphorus.

<sup>3</sup>Dressing percentage, semieviscerated percentage, and eviscerated percentage were expressed as the percentage of whole live bird weight, and parts of yields were expressed as the percentage of postchilled eviscerated weight.

**Table 5.** Effects of dietary calcium and nonphytate phosphorus on indices of meat quality of yellow-feathered broilers at 84 d of age.<sup>1</sup>

Treatment						
Ca, %	NPP, <sup>2</sup> %	L* <sup>3</sup>	a* <sup>4</sup>	b* <sup>5</sup>	Drip loss, %	Shear force, N
0.70	0.30	55.82 <sup>b,c</sup>	14.07 <sup>a</sup>	17.07	2.76	4.07
0.70	0.35	56.63 <sup>b,c</sup>	13.20 <sup>a,b</sup>	16.66	2.50	3.64
0.70	0.40	57.41 <sup>a,b</sup>	13.38 <sup>a,b</sup>	18.30	2.41	4.17
0.80	0.30	59.79 <sup>a</sup>	11.50 <sup>c</sup>	17.85	3.56	3.17
0.80	0.35	56.20 <sup>b,c</sup>	13.49 <sup>a,b</sup>	18.27	2.94	3.19
0.80	0.40	55.87 <sup>b,c</sup>	13.80 <sup>a</sup>	17.99	2.33	3.55
0.90	0.30	56.62 <sup>c</sup>	13.78 <sup>a,b</sup>	17.28	2.51	4.25
0.90	0.35	55.26 <sup>b,c</sup>	13.46 <sup>a,b</sup>	18.18	2.58	3.76
0.90	0.40	56.10 <sup>b,c</sup>	13.25 <sup>b</sup>	18.48	2.34	3.92
SEM		0.67	0.36	0.61	0.24	0.26
Main effect means						
0.70		56.62 <sup>a,b</sup>	13.55	17.34	2.56	3.96 <sup>a</sup>
0.80		57.29 <sup>a</sup>	12.93	18.04	2.94	3.30 <sup>b</sup>
0.90		55.87 <sup>b</sup>	13.36	17.93	2.46	3.93 <sup>a</sup>
SEM		0.39	0.21	0.35	0.14	0.15
	0.30	57.41 <sup>a</sup>	13.12	17.40	2.94 <sup>a</sup>	3.83
	0.35	56.03 <sup>b</sup>	13.38	17.70	2.67 <sup>a,b</sup>	3.53
	0.40	56.46 <sup>b</sup>	13.48	18.26	2.36 <sup>b</sup>	3.88
	SEM	0.39	0.21	0.35	0.14	0.15
P-values						
Ca		0.023	0.058	0.448	0.054	0.008
Linear		0.220				0.932
Quadratic		0.071				0.008
NPP		0.021	0.539	0.393	0.015	0.309
Linear		0.080			0.005	
Quadratic		0.065			0.021	
Ca × NPP		0.001	<0.001	0.671	0.256	0.562

<sup>a-c</sup>Within a column, means with different superscripts differ significantly ( $P < 0.05$ ).

Quadratic regression equations based on the Ca level (%): shear force (N) = 63.89(Ca)<sup>2</sup> - 102.40(Ca) + 44.33,  $R^2 = 0.171$ ,  $P = 0.008$ , which yielded the optimized dietary Ca level value of 0.80%.

<sup>1</sup>Data are means of 4 replicates, with 2 samples per replicate for the interaction. For the main effects, data are means of 12 replicates, with 2 samples per replicate.

<sup>2</sup>NPP: nonphytate phosphorus.

<sup>3</sup>L\*: lightness.

<sup>4</sup>a\*: redness.

<sup>5</sup>b\*: yellowness.

effect of Ca on biomechanical variables of bone has been widely studied (Sun et al., 2018). The present study showed that the dietary Ca level had a quadratic effect on tibial diameter of yellow-feathered broilers, further indicating that impaired bone development resulted from excessive Ca in diet. Some previous studies had similar findings, for example, Gautier et al. (2017) found that tibial size in Ross 308 broilers was influenced by dietary Ca, and tibia length and width were decreased in birds fed with increased levels of Ca. Powell et al. (2011) showed that increasing Ca levels from 0.67 to 1.33% decreased bone breaking strength, bone weight, and tibial ash weight. This might be explained by the high Ca level deteriorating tibia quality (relative weight, mineral composition, and biomechanical property) as a result of decreased duodenal absorption and retention of P (Sun et al., 2018). The present study showed no effect of dietary NPP on tibial characteristics. Bhanja et al. (2007) similarly found that tibial breaking strength of broiler breeders was not influenced by dietary NPP levels, and Dhandu and Angel (2003) showed that there were no differences in tibial stress, modulus of elasticity, or breaking force among dietary NPP levels. Some studies had different results. Sun et al. (2018) showed

that the P-deficient diets negatively affect bone density, breaking strength, and ash content of Arbor Acres male broilers. Liu et al. (2017) found that bone density and breaking strength were affected by the dietary NPP level and increased with higher levels of dietary NPP. Different responses to dietary NPP in these experiments could result from the breeds used, age phases, growth rates, sex, and previous nutrition. Under the conditions of the present experiment with yellow-feathered broilers aged 57 to 84 d, the optimal levels of dietary Ca and NPP were 0.80 and 0.30%, respectively, based on tibial characteristics.

### Effects of Dietary Ca and NPP on Carcass Traits

Carcass traits reflect the growth performance of broilers to some extent, and the BW of broilers affects the dressing percentage and percentage of muscle. Few previous studies have focused on the influence of dietary Ca and NPP on carcass traits. Smith and Taylor (1961) found that there was no significant difference in the percentage of grade A or grade B carcasses from broilers fed with 2 Ca levels. Dressing percentage, percentage of

breast yield, and abdominal fat were also similar when Ross 308 broilers were fed with different concentrations of Ca and NPP (Swiatkiewicz et al., 2011). The present study showed that the dietary Ca level did not affect carcass traits, whereas the NPP level had significant linear and quadratic influences on the semieviscerated percentage and percentage of breast yield. This might indicate that NPP is more important than Ca for growth and muscle deposition of yellow-feathered broilers. The effect of interactions observed between the level of Ca and NPP on the dressing percentage and semieviscerated percentage suggested that it was important to formulate broiler diets to balance the Ca-to-NPP ratio (Gautier et al., 2017; Manangi et al., 2018). Under the present experimental conditions, 0.80% Ca provided good carcass traits in yellow-feathered broilers, and regression analyses indicated that the optimal levels of dietary NPP were 0.31% for eviscerated percentage and 0.32% for percentage of breast yield.

### **Effects of Dietary Ca and NPP on Meat Quality**

Objective indices of meat quality were assessed. Most important for consumer acceptance are appearance, juiciness, flavor, nutritional value, wholesomeness, and texture of meat (Wang et al., 2019). In the latter part of the grower phase studied here, that is, before birds are “finished” for marketing, only objective criteria were considered. The dietary Ca level had significant effects on L\* values and shear force, and the dietary NPP level had effects on L\* values and drip loss of the breast muscle. Shear force is a quantifiable measurement of the tenderness of meat (Lonergan et al., 2003), with lower shear force indicating more tender meat (Li et al., 2016). The present results demonstrated that excessive or inadequate Ca content in diets adversely affected the tenderness of breast meat, with the optimal level of dietary Ca from the quadratic regressions being 0.80%. Drip loss is used to estimate water-holding capacity, and drip loss decreased with increase in dietary NPP levels. There are few studies on the effects of Ca and NPP on meat quality. The present findings are similar to those of the study by Li et al. (2016), showing that different P levels had significant impact on meat color and shear force in breast meat. Wen et al. (2015) also found that water-holding capacity of grass carp meat was significantly elevated, with dietary P at a certain level, and suggested that it may be related to the changes to the gap in the muscle. Commonly, poor meat quality of broilers was accompanied by oxidative impairment (Gao et al., 2010; Zhang et al., 2011). Researches showed that dietary NPP supplementation decreased serum malondialdehyde (MDA) levels in laying hens challenged with lipopolysaccharide (Nie et al., 2018) and MDA contents in the muscle of fish, suggesting that NPP reduced lipid and protein oxidation (Wen et al., 2015), which might explain the improvement of meat quality of

broilers by NPP. In contrast, Ren et al. (2015) found that meat color (L\* value, a\* value, b\* value) and shear force of the thigh meat or breast muscle were not affected by different levels of NPP. The different effects of NPP on meat quality were probably due to differences in supplementation route, dose, animal type, and so on. Further experiments need to be carried out to put forward more accurate suggestions for yellow-feathered broilers. On the basis of these indices of meat quality, the diet with 0.80% Ca and 0.40% NPP achieved the outcome in yellow-feathered broilers.

## **CONCLUSION**

Dietary Ca influenced performance, tibial characteristics, and meat quality of yellow-feathered broilers aged 57 to 84 d, and dietary NPP influenced performance, tibial characteristics, and carcass traits. There were effects of interactions between dietary Ca and NPP levels on carcass traits and meat quality. Considering all of the aforementioned indicators (FBW, ADG, ADFI, diameter of the tibia, semieviscerated percentage, percentage of breast yield, L\* value, shear force, and drip loss of the breast muscle), 0.80% Ca and 0.35% NPP are recommended for yellow-feathered broilers in the later grower phase, between 57 and 84 d of age.

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## **DISCLOSURES**

None.

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