Partial replacement of soybean products with canola meal in indigenous chicken diets: size of internal organs, carcass characteristics and breast meat quality

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ABSTRACT While the use of canola meal (**CM**) as an alternative to soybean meal in broiler diets is well-documented, there is no information on the utility of this valuable by-product for slow-growing indigenous chickens. This study was, therefore, conducted to evaluate the effects of partially replacing soybean products in a chicken grower diet with graded levels of CM on carcass characteristics, relative organ sizes and meat quality in Potchefstroom Koekoek (**PK**) cockerels. A total of 175 PK cockerels (342.6 ± 15.2 g body weight, 5 wk old) were randomly allocated to 25 pens. Five isonitrogenous and isoenergetic grower diets containing 0, 3.75, 6.25, 8.75, and 17.5% of CM were then randomly allocated to the pens (experimental units). After 12 wk of feeding, chickens were slaughtered to measure carcass traits, size of internal organs and meat quality traits. There were no effects of graded levels of CM on carcass weights. Wing weight increased quadratically [$y = 6.27(\pm0.23) + 0.23 (\pm0.063) x$–$0.009 (\pm0.0003) x^2$; $R^2 = 0.28$] in response to incremental levels of dietary CM. Drumstick, vertebrae, liver, and small intestine weights linearly increased ($P < 0.05$) in response to incremental levels of dietary CM. Redness (a*), initial meat pH (pH$_o$), and shear force linearly increased ($P < 0.05$) but lightness (L*) and water holding capacity decreased with an increase in CM inclusion levels. However, there were no significant linear and quadratic trends for yellowness (b*), ultimate pH (pH$_u$), drip loss, and cooking loss in response to incremental levels of CM. There were also significant quadratic trends for mineral contents of the meat with the exception of iron (Fe). It can be concluded that inclusion of CM in place of soybean products had no negative impact on carcass traits, organ size and meat quality traits of indigenous PK chickens.

Key words: canola meal, carcass traits, indigenous chicken, meat quality, soybean meal

INTRODUCTION

Indigenous chickens are a major source of animal protein in resource-poor communities and thus play a critical role in ensuring food and nutrition security (Neggese and Melesse, 2009). The productivity of these chickens is low due to a number of factors that include poor quality feed resources (Teye et al., 2013). This is exacerbated by the high costs of soybean-based commercial feeds, which are unaffordable for most communal households. The market price of soy-based feed ingredients continues to increase due to high usage of soy in both animal and human food. It is, therefore, imperative that alternative protein sources, with no direct food value for humans, be identified and evaluated for their utility as dietary ingredients for the slow-growing indigenous chickens. One such alternative is canola meal (**CM**), a by-product of canola oil, which is not directly used as food for humans and thus is less expensive.

CM has sufficient protein (36 to 39%) as well as an essential amino acid profile that closely matches that of soybean meal (**SBM**). However, the presence of antinutritional factors (**ANF**) such as fibre (12%) and glucosinolates (3.8 μmol/g) (Disetlhe et al., 2018) in CM could hinder growth by interfering with nutrient digestion and absorption (Wickramasuriya et al., 2015) as well as carcass composition and meat quality in indigenous chickens. Indeed, these ANFs have been reported to reduce growth performance in broilers (Payvastegan et al., 2017) and quails (Moraes et al., 2015). Glucosinolates interfere with thyroid hormone synthesis, causing liver damage and appetite depression (Tripathi and Mishra, 2007). CM also contains higher levels of fiber

compared to SBM. Dietary fibre has been reported to reduce protein and energy digestibility resulting in poor growth performance in chickens (Ahmed et al., 2015). Consequently, the potential of CM as a replacement for soybean products in diets of improved poultry species is limited by the negative physiological effects of these ANFs, as reported for quails (Karayagız and Bulbul, 2015; Mnisi and Mlambo, 2017) and broilers (Gopinger et al., 2014; Ahmed et al., 2015). A decline in feed intake and body weight was also observed by Woyengo et al. (2011) in broilers fed on diets containing graded levels (0 to 40%) of CM. However, indigenous chickens are known foragers and thus their digestive system, unlike that of broilers, may be better adapted to handle the higher levels of dietary fibre found in CM. There is no information on anatomical, physiological and meat quality responses of indigenous chickens when offered CM as an alternative dietary protein source. This study was, therefore, conducted to investigate the effect of partially replacing soybean products with graded levels of CM in PK cockerel diets on carcass characteristics, size of internal organs, and meat quality traits. It was hypothesised that replacing soybean products with CM in PK diets would have no negative effects on carcass characteristics, size of internal organs and meat quality traits.

MATERIALS AND METHODS

Study Site

This study was conducted at the North-West University experimental farm (Molelwane) (25.80°S and 25.50°E) in the North-West province of South Africa. The study was conducted between October and December 2017 when ambient temperatures ranged between 3 and 37°C.

Feed Ingredients

All feed ingredients, except for CM, were bought from Optifeeds (PTY) LTD, Lichtenburg, South Africa. The CM was purchased from Southern Oil (PTY) LTD, Western Cape, South Africa. Both SBM and CM were produced via a solvent extraction process without prior heat treatment.

Experimental Diets

Five isonitrogenous and isoenergetic experimental diets (Table 1) in a mash form, were formulated to meet the nutritional requirements for growing chickens by partially replacing soybean products with graded levels of CM. The diets were as follows: 1. CM0 = grower diet without CM, 2. CM1 = a grower diet in which 3.75% of soybean ingredients were replaced with CM, 3. CM2 = a grower diet in which 6.25% of soybean ingredients were replaced with CM, 4. CM3 = a grower diet in which 8.75% of soybean ingredients were replaced with

Table 1. Ingredients and nutrient composition (%) of experimental diets (as-fed basis).

Ingredients	Diets[1]				
	CM0	CM1	CM2	CM3	CM4
Canola oilcake	0	3.76	6.27	8.77	17.50
Yellow Maize	69.90	67.22	65.56	64.75	59.62
Prime Gluten 60	1.18	1.17	1.18	4.40	2.40
Fullfat Soya	5.22	8.80	11.77	12.00	17.40
Soybean Oil cake	19.82	14.93	11.20	7.70	0.00
Limestone powder	1.45	1.40	1.36	0.13	1.22
Mono Calcium	0.72	0.67	0.67	0.65	0.56
Fine Salt	0.32	0.33	0.33	0.32	0.32
Sodium-bicarbonate	0.17	0.16	0.16	0.17	0.16
Choline Powder	0.08	0.08	0.08	0.08	0.08
Lysine	0.28	0.28	0.28	0.30	0.27
L-Threonine	0.41	0.40	0.04	0.00	0.00
Methionine	0.19	0.18	0.17	0.11	0.18
Phytase	0.17	0.17	0.17	0.17	0.17
Olaquindox	0.05	0.40	0.40	0.40	0.04
Coxistac	0.04	0.05	0.05	0.05	0.05
Calculated composition (%)					
Moisture	11.34	11.24	11.13	11.03	10.93
ME(MJ/kg)	12.09	12.09	13.09	12.10	11.90
Protein	18.00	18.02	19.09	19.03	18.93
Crude fats	4.16	5.16	5.60	5.60	6.24
Crude fibre	2.32	2.72	3.03	3.20	4.21
Calcium	0.85	0.85	0.85	0.85	0.85
Sodium	0.18	0.18	0.18	0.18	0.18
Potassium	0.80	0.76	0.76	0.72	0.72
Phosphorus	0.50	0.51	0.52	0.53	0.53
Chlorine	0.30	0.30	0.30	0.30	0.30
Available Phosphorus	3.80	3.80	3.80	3.73	3.73
Lysine	1.07	1.08	1.09	1.90	1.11
Arginine	1.10	1.10	1.10	1.10	1.10
Tryptophan	0.19	0.19	0.19	0.19	0.20
Methionine	0.45	0.43	0.47	0.45	0.52
Threonine	0.71	0.71	0.71	0.71	0.73
Histidine	0.43	1.65	0.48	0	0.53
Leucine	0.34	0.85	1.65	1.92	1.91
Valine	0.84	0.85	0.86	0.92	0.91

[1]Diets: CM0 = a grower diet without CM; CM1 = a grower diet in which 3.75% of soybean ingredients were replaced with CM; CM2 = a grower diet in which 6.25% of soybean ingredients were replaced with CM; CM3 = a grower diet in which 8.75% of soybean ingredients were replaced with CM; CM4 = a grower diet in which 17.5% of soybean ingredients were replaced with CM.

CM, 5. CM4 = a grower diet in which 17.5% of soybean ingredients were replaced with CM. The 17.5% rate was the maximum CM inclusion level that could be used without compromising the objective of meeting the nutrient requirements of growing PK chickens given the physical and non-nutritive limitations of this ingredient.

Animal Management and Statement of ethics

A total of 175 PK cockerels (342.6 ± 15.2 g live weight) were evenly allocated to 25 pens (each measuring 0.131 × 0.128 × 0.98 m and holding 7 birds) to which the five experimental diets were randomly allocated. The rearing of PK cockerels was done according to the ethical guidelines of the North-West University Institutional Research Ethics Regulatory Committee (Ethics Number: NWU 00517–16-A9). The

birds were allowed to adapt to the experimental conditions for a week before measurements commenced. The birds were reared under natural lightning until slaughter after 12 wk of feeding. At the end of the trial all the cockerels (7) were weighed to obtain the slaughter weight before being fasted for 12 h. The birds were then electrically stunned before the jugular vein was cut to allow bleeding for 3 mi. At the abattoir, the birds were scalded at 65°C for 55 s, defeathered in rotary drum picker for 20 s and manually eviscerated. Head, neck, legs, edible viscera, fat, and the first joint from the wing tip were removed leaving the carcass.

Carcass Traits and Internal Organs

Dressing percentage was calculated as a proportion of carcass weight to slaughter weight. After evisceration, the carcasses were weighed to obtain the hot carcass weight (**HCW**). Hot carcass yield (**HCY**) was calculated as a ratio of HCW to slaughter weight. Carcasses were then chilled at 4°C for 24 h and then re-weighed to obtained cold carcass weights (**CCW**). Size of internal organs (gizzard, liver, heart, spleen, and small intestines) were measured using a digital weighing scale (Explorer EX224, OHAUS Corp) and expressed as a proportion of HCW and referred to as an index. The weights of breast muscle, wings, shank, thighs and vertebrae (back) were measured. The carcasses were then packed in polythene bags and stored in a freezer (-4°C) pending meat quality evaluation.

Meat Quality Parameters

Meat colour (L* = luminosity, a* = redness and b* = yellowness) was measured immediately after slaughter and also 24 h post-slaughter using a spectrophotometer (CM 2500c model, Konica Minolta, Inc. Japan) on the dorsal surface of the left breast fillet (bone side) at the 3 distinct points. A portable digital pH meter (CRISON pH25, CRISON Instruments SA, Spain) with a piercing electrode was used to measure the pH of breast muscle, 45 min (initial pH (**pH_o**)) and 24 h post slaughter (ultimate pH (**pH_u**)) (Sanka and Mbanga, 2014). Water holding capacity (**WHC**) was determined according to Delezie et al. (2007) while drip loss was determined according to Mikulski et al. (2012). To determine cooking losses, the breast muscle was weighed (**B_1**), cooked in a water bath at 75°C for 45 min, cooled and re-weighed (**B_2**). Cooking loss was then calculated as:

$$Cooking\,loss(\%) = \frac{B_1 - B_2}{B_1} \times 100$$

Tenderness was assessed by shearing the breast meat sample perpendicular to the fibre direction of the muscle using a Meullenet-Owens Razor Shear Blade (A/MORS) with a diameter of 1.2 cm. The reported value represented the average positive peak force measurement of each sample.

Mineral Contents

The stored breast meat were collected from the freezer and were then analysed for ash and mineral composition. Ash content was determined by ashing the breast meat at 550°C for 6 h (AOAC 1999: method number 924.05). Breast meat calcium (**Ca**), magnesium (**Mg**), potassium (**K**), sodium (**Na**), iron (**Fe**), zinc (**Zn**), manganese (**Mn**), and copper (**Cu**) were analysed using inductive coupled plasma mass spectrometer from Perkin Elmer supplier. Phosphorus (**P**) was determined calorimetrically using sodium phenol and ammonium molybdate plus ascorbic acid method (AOAC 1999: method number 924.05).

Statistical Analyses

Data were evaluated for linear and quadratic effects using polynomial contrasts. Response surface regression analysis (SAS, 2010) was applied to describe the responses of PK chickens to inclusion levels of CM using the following quadratic model: $y = ax^2 + bx + c$, where y = response variable; a and b are the coefficients of the quadratic equation; c is intercept; and x is dietary canola levels (%). Carcass characteristics, size of internal organs and meat quality data were analysed using the general linear model procedure of SAS (2010) for a completely randomized experimental design with pen as the experimental unit.

RESULTS

Carcass Traits and Internal Organs

There were no significant ($P > 0.05$) linear and quadratic trends of all carcass traits with the exception of wing, drumstick and vertebrae weights (Table 2). Wing weight increased quadratically [$y = 6.27\ (\pm0.23) + 0.23\ (\pm0.063)\ x – 0.009\ (\pm0.0003)\ x^2$; $R^2 = 0.28$] in response to incremental levels of dietary CM. Drumstick and vertebrae weights linearly increased in response to incremental levels of dietary CM. Regarding internal organs, liver size linearly decreased ($P < 0.05$) with CM levels (Table 3) while small intestine linearly increased [y = 10.11 (±1.410) + 0.07 (±0.067) x] with the inclusion level of CM. For other internal organs, there were neither linear nor quadratic effects observed.

Meat Quality and Mineral Content

Breast muscle linearly decreased ($P < 0.05$) in lightness (L* value) and WHC with CM levels while the value of redness (a*), pH_o linearly and shear force increased (Table 4). In addition, WHC and linearly decreased ($P < 0.05$) in response to incremental levels

Table 2. Effects of replacing soybean products in chicken grower diets with graded levels of canola meal (CM) on carcass traits in 18-wk old Potchefstroom Koekoek cockerels (mean ± SEM).

Carcass traits	Diets[1]					SEM	Significance	
	CM0	CM1	CM2	CM3	CM4		Linear	Quadratic
Slaughter weight (g)	1789.0	1931.1	1893.0	1882.0	1882.7	49.9	NS	NS
Hot carcass weight (g)	1201.9	1240.9	1312.0	1240.6	1241.9	31.0	NS	NS
Cold carcass weight (g)	1248.6	1232.0	1269.4	1253.2	1221.1	26.8	NS	NS
Hot carcass yield (%)	67.2	64.3	69.3	65.9	66.0	1.7	NS	NS
Cold carcass yield (%)	69.8	63.8	67.1	66.6	64.9	1.4	NS	NS
Shank weight (%)	6.6	6.9	6.6	6.9	6.6	0.2	NS	NS
Wing weight (%)	6.1	7.2	7.5	7.1	7.4	0.2	**	**
Breast muscle weight (%)	12.5	16.8	16.3	14.4	15.6	1.1	NS	NS
Drumstick weight (%)	16.8	18.6	19.2	17.0	19.1	0.5	**	NS
Vertebrae weight (%)	12.1	14.2	15.0	13.6	14.8	0.8	*	NS

NS = not significant; *$P < 0.05$; **$P < 0.01$.
[1]Diets: CM0 = a grower diet without CM; CM1 = a grower diet in which 3.75% of soybean ingredients were replaced with CM; CM2 = a grower diet in which 6.25% of soybean ingredients were replaced with CM; CM3 = a grower diet in which 8.75% of soybean ingredients were replaced with CM; CM4 = a grower diet in which 17.5% of soybean ingredients were replaced with CM.

Table 3. Effects of replacing soybean products in chicken grower diets with graded levels of canola meal (CM) on relative organ weight **(% HCW)** in 18-wk old Potchefstroom Koekoek cockerels.

Organ	Diets[1]					SEM	Significance	
	CM0	CM1	CM2	CM3	CM4		Linear	Quadratic
Heart	0.70	0.73	0.80	0.64	0.73	0.04	NS	NS
Liver	2.11	1.91	1.99	1.85	1.78	0.08	**	NS
Spleen	0.31	0.33	0.34	0.31	0.29	0.02	NS	NS
Proventriculus	0.71	0.76	0.75	0.67	0.66	0.06	NS	NS
Gizzard	2.61	2.78	2.49	2.46	2.71	0.18	NS	NS
Caecum	0.58	0.66	0.70	0.64	0.92	0.11	NS	NS
Small intestines	10.10	10.42	10.44	10.70	10.94	0.26	*	NS

NS = not significant; *$P < 0.05$; **$P < 0.01$
[1]Diets: CM0 = a grower diet without CM; CM1 = a grower diet in which 3.75% of soybean ingredients were replaced with CM; CM2 = a grower diet in which 6.25% of soybean ingredients were replaced with CM; CM3 = a grower diet in which 8.75% of soybean ingredients were replaced with CM; CM4 = a grower diet in which 17.5% of soybean ingredients were replaced with CM.
SEM = Standard error of the mean.

of dietary CM. There were no significant linear and quadratic trends for yellowness (b*), pH$_u$, drip loss, and cooking loss in response to dietary levels of CM. Similarly, there were no significant quadratic trends for all meat quality components. Calcium content of the meat linearly decreased ($P < 0.05$) with CM levels (Table 5). However, P, Mg, and K content of meat quadratically increased with the inclusion levels of CM. There was a linear increase (Table 5) in meat Na content with level of CM. With regarding to meat trace minerals, Mn and Zn contents quadratically increased with CM levels while meat Cu content decreased quadratically (Table 5). No significant linear and quadratic trends for meat Fe contents were detected.

DISCUSSION

Carcass Traits

Carcass yield in poultry is a reliable indicator of diet quality (Tougan et al., 2013). Despite its high fibre

(12%) and glucosinolate (3.8 μmol/g) content, dietary inclusion of CM did not compromise carcass yield, a finding that is supported by Mnisi and Mlambo (2017) who reported no change in HCW of quails fed CM-containing diets. In addition, Ahmed et al. (2015) reported similar results when CM was included in broiler diets at 20% level as a protein source. When put together, findings from this study and previous reports suggest that CM protein is of sufficient quality to replace SBM protein in diets of a variety of poultry species, including indigenous chickens, without compromising carcass traits such as HCW and CCW. Indigenous chickens have been reported (Matshogo et al., 2018) to possess higher capacity to utilise fibrous diets and tolerate anti-nutritional compounds such as glucosinolates (Mcainsh et al., 2004). This may explain why PK cockerels fed canola-containing diets had similar carcass traits compared to those fed the CM0 diet. Indigenous chickens, by nature, are foragers with an ability to extract a considerable amount of nutrients from feedstuffs that are high in fibre (Mcainsh et al.,

Table 4. Effects of replacing soybean products in chicken grower diets with graded levels of canola meal (CM) on breast meat quality parameters of 18-wk old Potchefstroom Koekoek cockerels (mean ± SEM).

Parameters[2]	Diets[1]							Significance	
	CM0	CM1	CM2	CM3	CM4	SEM		Linear	Quadratic
Meat colour									
L* (Lightness)	50.9	51.4	48.9	49.1	48.5	1.0		*	NS
a* (Redness)	3.6	5.1	4.7	4.5	5.2	0.3		*	NS
b* (Yellowness)	9.5	11.0	10.7	10.9	12.0	0.5		NS	NS
pH_o	7.1	7.1	7.1	7.2	7.3	0.1		**	NS
pH_u	6.2	5.1	6.1	6.1	6.2	0.1		NS	NS
WHC (%)	20.2	23.1	20.1	20.9	18.7	2.2		*	NS
Drip loss (%)	5.4	5.7	6.6	6.8	7.7	2.8		NS	NS
Cooking loss (%)	26.5	23.3	30.2	28.9	33.0	3.7		NS	NS
Shear force (N)	12.5	19.9	13.8	18.2	14.3	1.8		**	NS

NS = not significant; *$P < 0.05$; **$P < 0.01$

[1]Diets: CM0 = a grower diet without CM; CM1 = a grower diet in which 3.75% of soybean ingredients were replaced with CM; CM2 = a grower diet in which 6.25% of soybean ingredients were replaced with CM; CM3 = a grower diet in which 8.75% of soybean ingredients were replaced with CM; CM4 = a grower diet in which 17.5% of soybean ingredients were replaced with CM.

[2]Parameters: pH_o = Initial pH; pH_u = Ultimate pH; WHC = Water Holding Capacity.

Table 5. Response of breast meat mineral content to the replacement of soybean products with graded levels of canola meal (CM) in grower diets of Potchefstroom Koekoek cockerels.

	Equation	Significance	R-Square
Macrominerals (mg/g)			
Calcium	$y = 4.04\ (\pm0.38) - 0.74\ (\pm0.11)\ x + 0.038\ (\pm0.006)\ x^2$	**	0.81
Phosphorus	$y = 2.82\ (\pm0.54) - 0.55\ (\pm0.15)\ x + 0.035\ (\pm0.008)\ x^2$	**	0.69
Magnesium	$y = 0.97\ (\pm0.19) - 0.18\ (\pm0.05)\ x + 0.011\ (\pm0.003)\ x^2$	**	0.66
Sodium	$y = 3.56\ (\pm0.79) - 0.62\ (\pm0.21)\ x + 0.041\ (\pm0.011)\ x^2$	**	0.59
Potassium	$y = 8.03\ (\pm1.71) - 1.46\ (\pm0.47)\ x + 0.102\ (\pm0.025)\ x^2$	**	0.68
Trace minerals (μg/g)			
Manganese	$y = 2.20\ (\pm0.27) - 0.32\ (\pm0.077)\ x + 0.024\ (\pm0.004)\ x^2$	**	0.85
Copper	$y = 15.42\ (\pm2.58) - 2.33\ (\pm0.71)\ x + 0.139\ (\pm0.037)\ x^2$	**	0.56
Zinc	$y = 7.8\ (\pm1.10) - 1.21\ (\pm0.30)\ x + 0.091\ (\pm0.016)\ x^2$	**	0.83

2004). These results indicate that dietary inclusion of CM did not reduce the amount of edible meat, as measured by HCW and CCW, in PK cockerels. Canola-containing diets did not affect shank weight in line to Gopinger et al. (2014) who reported similar findings in broilers. Wing, drumsticks and vertebrae weights linearly increased with CM inclusion levels, confirming the findings reported by Mikulski et al. (2012) in turkeys.

Internal Organs

Diets had no effect on the size of heart, spleen, proventriculus, gizzard and caecum, findings that are consistent with earlier reports on the effect of CM-containing diets on size of internal organs in quails (Sarıçiçek et al., 2005; Karayagız and Bulbul, 2015) and in broilers (Naseem et al., 2006). The function of the liver is to detoxify chemicals and metabolize drugs. It is known that the size of the liver increases in response to higher levels of chemical compounds requiring detoxification (Payvastegan et al., 2017). It was expected that higher levels of CM inclusion would induce higher liver activity leading to birds with bigger livers than those reared on the CM0 diet. However, this was not the case

in the current study suggesting that the concentration of ANFs in CM was not high enough to induce toxicity in indigenous PK birds. Despite the higher levels of fibre (12%) in CM, PK cockerels were able to utilise CM-containing diets to the same extent as the CM0 diet. This indicates that the digestive system of PK cockerels has the capacity to utilise CM-containing diets. In poultry, dietary fibre is reported to enlarge and thicken the gastro-intestinal tract (Jorgensen et al., 1996), a possible reason why the size of small intestines in PK cockerels increased with CM inclusion. This is an anatomical adaptation mechanism designed to ensure that the digesta has a longer residence time in the gastro intestinal tract resulting in improved digestion and absorption of digestion products. These results agree with those of Payvastegan et al. (2017) who also reported increased small intestine weight in broiler chickens fed incremental levels of CM.

Meat Quality and Mineral Content

Breast meat colour is known to be influenced by a number of factors that include genotype, diet, and age of the birds (Fletcher, 1999). In the current study,

inclusion of CM was shown to linearly increased the redness (Minolta a*) of PK breast meat. This could be because CM contains minerals such as Fe, Mn and Cu as well as pigments, which may influence meat colour (Wattanachant, 2008). In contrast, Mnisi and Mlambo (2017) and Mnisi et al. (2017) reported no change in redness of meat when CM was fed in place of SBM to Japanese quails. The difference between pH_o and pH_u post-mortem is a result of the decline in pH from the time of slaughter due to post-mortem aging, a function of how rapidly glycogen levels in breast muscle prior to slaughter is converted to lactic acid after slaughter (Dyubele et al., 2010). However, in this study diet had no influence on pH_u, which was observed to be within the normal range (5.5 to 6.5) for chickens (Ao et al., 2008). This implies that inclusion of CM in place of SBM in PK diet does not affect glycogen levels and thus meat pH_u.

CM is known to contain phytic acid, a compound that binds some minerals and thus reduce their bioavailability to chickens (Khajali and Slominski, 2012). It was expected, therefore, that replacing soybean products with CM in PK diets might reduce mineral bioavailability leading to deficiencies. Indeed, our results showed that Ca content of breast meat linearly decreased with CM levels. This suggests that CM inclusion negatively affected Ca bioavailability resulting in meat with lower levels of this mineral. The meat Mn and Zn concentration increased in response to increase in CM inclusion, which could be due to the high concentration of these minerals in CM (Mahan et al., 2005). The copper content of meat was also lower than that reported by Ferreira et al. (2005). It is known that Cu is involved in red blood cell production, iron absorption from the small intestine, iron metabolism, physiological functions of the central nervous system, bone metabolism, and heart function (McDowell, 1985). The reduction in Cu content of breast meat with CM levels could be due to reduced absorption and assimilation from the digestive tract due to ANFs present in CM such as phytic acid and fibre. However, this decrease in Cu levels did not result in hypocupraemia in the cockerels. Similar breast Fe content is a reflection of similar rate of absorption and assimilation of Fe in different dietary treatments. The Fe values reported in the current study were lower than previously reported in free-range chickens (Wei et al., 2016).

CONCLUSIONS

In conclusion, results from the current study showed that carcass characteristics, relative organ sizes, and meat quality in PK cockerels fed CM-containing diets compared well to those fed the CM0 diet. It can be concluded that CM can be used to substitute SBM up to 175.0 g/kg without compromising carcass characteristics, internal quality of the meat from PK cockerels. However, mineral content of meat was negatively in-

fluenced by CM inclusion suggesting a need to take corrective measures, such as supplementation or pre-treatment with exogenous enzymes, when using CM in diets of PK chickens.

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