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REGULAR ARTICLES

Nutrient digestibility, haemo-biochemical parameters and growth performance of an indigenous chicken strain fed canola meal–containing diets

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Abstract

Canola meal (CM) is a potential alternative dietary protein source for indigenous chickens but its utility may be limited by anti-nutrients such as fibre and phytochemical compounds. This study, therefore, explores the effects of replacing soy-based feedstuffs (SB) with graded levels of CM on apparent nutrient digestibility, growth performance and haemo-biochemical parameters in Potchefstroom koekoek (PK) cockerels. Five isonitrogenous and isoenergetic diets were formulated by replacing 0 (CM), 3.75 (CM1), 6.25 (CM2), 8.75 (CM3) and 17.5% (CM4) of SB with CM. One hundred and seventy-five cockerels (342.6 ± 15.2 g live weight, 5 weeks old) were evenly distributed into 25 replicate pens to which experimental diets were randomly allocated. Feed intake, apparent nutrient digestibility, weight gain, feed conversion ratio and protein efficiency ratio (PER) were determined. Blood was collected for serum and haematological analysis at 16 weeks of age. There was a significant quadratic trend [$y = 2.56 (\pm 0.067) + 0.04 (\pm 0.019)x - 0.002 (\pm 0.0010)x^2$] for average weight gain from which an optimum canola inclusion level was calculated to be 7.8%. Neutrophils linearly increased ($P < 0.05$) with CM levels, but there were no significant linear and quadratic trends for serum biochemical components with the exception of total calcium and triglycerides, which decreased linearly in response to incremental levels of CM. However, feed intake, feed utilisation efficiency, growth performance and serum biochemistry parameters were not affected by experimental diets. Based on weight gain response, it was concluded that replacing soy-based dietary ingredients with CM in poultry diets up to 7.8% does not result in adverse effects on diet utilisation, growth performance and health status of PK cockerels.

Keywords Canola meal · Indigenous chickens · Growth performance · Haematology · Serum biochemistry

Introduction

In resource-poor communities of developing countries, slow-growing indigenous chickens remain a critical source of dietary essential amino acids, fatty acids and micronutrients for the general populace. Enhancing the productivity of these chickens is, therefore, imperative for food and nutrition security in these communities. Strategies that enhance productivity of indigenous chickens include semi-intensive production systems whose success is constrained by high costs of feed ingredients (Nga'mbi et al. 2013), especially protein sources. The most common protein source in chicken diets is the commercially available soybean meal whose price on the world market is very high due to high demand, a sum of human food and animal feed requirements. It is, therefore, critical that alternative, relatively inexpensive protein sources with no direct food value to humans be identified and evaluated for indigenous chickens as replacements for soybean feed ingredients. One such example is canola meal (CM), a by-product of oil extraction from *Brassica napus* (rapeseed), which has limited human food and industrial uses and thus is relatively inexpensive.

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Canola meal is reported to be a good source of protein with a balanced essential amino acid profile (Wickramasuriya et al. 2015). However, CM contains anti-nutritional factors (ANFs) such as α-galacto-oligosaccharides, non-starch polysaccharides (NSPs), glucosinolates, phytic acid and fibre (Wiryawan and Dingle 1999). The NSPs are known to increase the viscosity of digesta and decrease nitrogen digestibility and absorption (Khajali and Slominski 2012). Soluble anti-nutritional factors such as glucosinolates and phenolics may cause goitre, haemorrhagic liver and kidney damage (Campbell and Slominski 1991) and reduce voluntary feed intake (Lee and Hill 1983). Fortunately, the level of erucic acid and glucosinolates in CM has been declining over the years due to plant breeding efforts designed to create a better quality feed ingredient. However, ANFs such as phytic acid, phenolics, fibre and trypsin inhibitors can still limit the protein value of CM (Ahmad et al. 2007) for indigenous chickens. In addition, the effects of these ANFs vary greatly depending on poultry species (Tripathi and Mishra 2007). Although the tolerance level of indigenous chickens to fibre and anti-nutritional compounds in CM is largely unknown, there remains a strong possibility that being foraging indigenous chickens, they have better digestive capacity to deal with canola than improved chicken strains. A number of feeding trials with CM have been carried out with poultry species such as broilers (Taraz et al. 2006), Japanese quails (Mnisi and Mlambo 2018) and turkeys (Mikulski et al. 2012) with promising results. However, similar studies with indigenous chickens such as the slow-growing Potchefstroom koekoek (PK) are yet to be done. This study was, therefore, designed to determine nutrient digestibility, protein utilisation efficiency growth performance and haemo-biochemical parameters of PK cockerels fed CM as a partial replacement for soybean-based ingredients (SB). It was hypothesised that partial replacement of the SB with the CM in PK diets would not reduce apparent nutrient digestibility, growth performance and health of the chickens.

Materials and methods

Study site

This study was conducted from October to December 2016 at the North-West University Farm (25.80° S and 25.50° E), in the North-West province of South Africa. During this time, the ambient temperature ranged from between 19 and 25 °C.

Feed ingredients and experimental diets

All feed ingredients, except for CM, were bought from Opti Feeds (PTY) LTD, South Africa. The CM was purchased from Southern Oil (PTY) LTD, South Africa. Soybean meal (SBM) and CM were by-products of solvent extraction of oil from seed. Five isonitrogenous and isoenergetic experimental diets (Table 1) in a mash form were formulated to meet the nutritional requirements of the chicken grower phase (NRC 1994) by replacing soybean ingredients with graded levels of CM as follows. (1) Control = commercial chicken grower diet without CM, (2) CM1 = a commercial chicken grower diet in which 3.75% of soybean ingredients were replaced with CM, (3) CM2 = a commercial chicken grower diet in which 6.25% of soybean ingredients were replaced with CM, (4) CM3 = a commercial chicken grower diet in which 8.75% of

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

	Diets[1]				
	Control	CM1	CM2	CM3	CM4
Ingredients					
Canola oilcake	0	3.76	6.27	8.77	17.50
Yellow maize	69.90	67.82	66.16	63.81	59.50
Prime Gluten 60	1.18	1.17	1.18	4.40	2.40
Full-fat soya	5.10	8.80	11.77	12.00	17.40
Soybean oil cake	19.70	14.93	11.20	7.70	0.00
Limestone powder	1.45	1.40	1.36	0.13	1.22
Monocalcium	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
Nutrient 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 fat	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: Control = commercial chicken grower diet without CM; CM1 = a commercial chicken grower diet in which 3.75% of soybean ingredients were replaced with CM; CM2 = a commercial chicken grower diet in which 6.25% of soybean ingredients were replaced with CM; CM3 = a commercial chicken grower diet in which 8.75% of soybean ingredients were replaced with CM; CM4 = a commercial chicken grower diet in which 17.5% of soybean ingredients were replaced with CM

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

Apparent nutrient digestibility

Thirteen-week-old PK cockerels were randomly placed in 25 cages (0.51 × 0.49 × 0.36 m, 2 birds per cage) to which the five experimental diets were randomly allocated. Feed and water were provided between 0700 and 0800 h. The first 3 days were used to adapt the birds while in the last 3 days, samples (feed offered, feed refused and faeces) were collected, pooled, weighed, oven-dried (55 °C), milled and stored pending chemical analyses. Apparent digestibility values for crude fibre, crude protein and minerals were calculated according to the following formula:

$$Apparent\ nutrient\ digestibility = \frac{Nutrient\ intake - Faecal\ nutrient}{Nutrient\ intake} \times 100$$

Chemical analyses

Formulated diets, feed offered, refusals and faecal samples were analysed, according AOAC (2005), for dry matter (DM; AOAC method number 930.15), organic matter (OM; AOAC method number 924.05), crude protein (CP; AOAC method number 984.13), crude fibre (CF, ANKOM Technology, NY), and minerals (calcium, phosphorus, sodium, chlorine and potassium) (AgriLasa 1998).

Growth performance

A total of 175, 36-day-old PK cockerels (342.6 ± 15.2 g live weight) were allocated to 25 pens (0.131 × 0.128 × 0.98 m) to which the five experimental diets were randomly allocated. Each diet was represented in 5 replicate pens with each pen holding seven birds. Feed offered and refusals were quantified daily and birds were weighed weekly. Feed intake (FI), average body weight gain (AWG) and feed conversion ratio (FCR) were calculated (Mnisi and Mlambo 2018). Protein intake (PI) was determined as a product of crude protein concentration in the diet and feed intake. Protein efficiency ratio (PER) was calculated as a proportion of body weight gain to protein intake (Table 2).

Blood analyses

One week before slaughter, three birds from each pen were randomly selected and blood was aspirated from the wing vein using 21 gauge needles. For haematological parameters (total erythrocyte count (TEC), haemoglobin (Hb), haematocrit (HCT) and different leukocyte counts), ethylene diamine tetra-acetic acid (EDTA)–coated vacutainer tubes were used while for serum biochemical parameters (bilirubin, alanine aminotransferase (ALT), aspartate aminotransferase (AST), total protein (TP), albumin (ALB), urea, creatinine, triglycerides (TG), serum sodium (Na), potassium (K), chloride (Cl), calcium (Ca) and magnesium (Mg)), anti-coagulant-free vacutainer tubes were used. Haematological parameters were measured using an automated Idexx Laser Cyte Haematology analyser (IDEXX Laboratories, Inc.) while serum biochemical parameters were determined using an automated Idexx Vex Test Chemistry Analyser (IDEXX Laboratories, Inc.).

Table 2 Feed intake and growth performance of Potchefstroom koekoek cockerels fed diets containing graded levels of canola meal as substitution for soybean meal (mean ± SE)

Parameters	Diets[1]					Significance	
	Control	CM1	CM2	CM3	CM4	Linear	Quadratic
Final weight	1788.9 ± 48.9	1931.85 ± 48.9	1892.6 ± 48.9	1919.3 ± 54.7	1857.7 ± 44.7	NS	NS
Average feed intake	78.36 ± 3.24	84.86 ± 3.24	80.15 ± 3.62	81.47 ± 3.62	78.31 ± 2.96	NS	NS
Average weight gain	2.53 ± 0.07	2.74 ± 0.07	2.66 ± 0.07	2.70 ± 0.08	2.57 ± 0.06	NS	*
Feed conversion ratio	5.30 ± 0.26	2.74 ± 0.26	2.66 ± 0.26	2.70 ± 0.08	2.57 ± 0.24	NS	NS
Protein consumed	15.27 ± 0.69	15.29 ± 0.69	15.30 ± 0.69	15.50 ± 0.77	14.83 ± 0.63	NS	NS
Protein efficiency ratio	0.18 ± 0.01	0.19 ± 0.01	0.19 ± 0.01	0.19 ± 0.01	0.19 ± 0.01	NS	NS

NS not significant

*$P < 0.05$

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

Statistical analysis

Data were evaluated for linear and quadratic effects using polynomial contrasts. Response surface regression analysis (Proc RSREG; SAS 2010) was applied to estimate the optimum inclusion level of canola meal for PK chickens according to the following quadratic model: $y = ax^2 + bx + c$, where y is the response variable; a and b are the coefficients of the quadratic equation; c is the intercept; x is the dietary canola levels (%) and $-b/2a$ is the x value for optimal response. Weekly feed intake, weight gain and feed conversion efficiency data were analysed using the repeated measures procedure of SAS (2010). Apparent digestibility values, overall feed intake, weight gain, feed conversion efficiency and blood parameters data were analysed using the general linear model procedure of SAS (2010) for a completely randomised experimental design with each pen as the experimental unit.

Results

Apparent nutrient digestibility and growth performance

There were no significant linear and quadratic trends for DM and CF digestibility while CP digestibility linearly decreased ($y = 78.19\ (\pm 1.410) - 0.52\ (\pm 0.389)x$) in response to incremental levels of CM in the diet (Table 3). However, there were no quadratic effects ($P > 0.05$) of CM on CP digestibility. Regarding mineral bioavailability, K digestibility linearly decreased ($P < 0.05$) with CM levels (Table 4). For the digestibility of all other minerals, there were neither linear nor quadratic effects. There were no significant linear and quadratic effects of dietary levels of CM on FI, FCR, PI and PER (Table 2). However, there was a significant quadratic trend for AWG ($y = 2.56\ (\pm 0.067) + 0.04\ (\pm 0.019)x - 0.002\ (\pm 0.0010)x^2$) from which an optimum canola inclusion level was calculated to be 7.8%.

Haematology and serum biochemistry

There were no significant linear and quadratic trends of erythrocytes, haemoglobin, haematocrit, leucocytes, lymphocytes, monocytes, eosinophils and basophils except for neutrophils in response to dietary levels of CM (Table 5). However, neutrophils linearly increased ($P < 0.05$) with CM levels. There were no significant linear and quadratic trends of serum biochemical components with the exception of total calcium and triglycerides (Table 6). Total calcium and triglycerides linearly decreased in response to incremental levels of dietary CM.

Discussion

Apparent nutrient digestibility

In the current study, low CP digestibility in chickens offered CM4 diet might be attributed to intestinal viscosity caused by fibre and non-starch polysaccharides (NSPs) contained in CM (Bell 1993). Indeed, cellulose, β-glucans, arabinoxylans and pectins have been reported to suppress nutrient digestibility in chickens (Madzimure et al. 2017). In addition, Landero et al. (2012) reported a decline in CP digestibility when CM inclusion levels were increased in diets of piglets. However, Gopinger et al. (2014) reported no effects on CP digestibility when up to 20% CM was used to substitute SBM to broiler chickens. Indigenous chickens have greater digestive capacity to handle fibrous diets than broilers and hence may digest CM more efficiently (Sebola et al. 2015).

Table 3 Effects of replacing soybean meal with canola meal in Potchefstroom koekoek cockerel diets on apparent digestibility (%) of dry matter, crude protein and fibre

Parameters	Diets[1]					Significance	
	Control	CM1	CM2	CM3	CM4	Linear	Quadratic
Dry matter	80.34 ± 7.14	75.03 ± 6.77	78.61 ± 6.77	80.79 ± 6.77	81.81 ± 6.55	NS	NS
Crude protein	78.33 ± 1.57	76.34 ± 1.57	74.67 ± 1.57	75.09 ± 1.57	72.42 ± 1.57	*	NS
Cruder fibre	15.85 ± 2.24	20.79 ± 2.24	11.56 ± 2.24	16.56 ± 2.24	17.29 ± 2.39	NS	NS

NS not significant

*$P < 0.05$

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

Table 4 Effects of dietary inclusion of canola meal on apparent digestibility (%) of minerals in Potchefstroom koekoek cockerels

Diets[1]							Significance	
Minerals	Control	CM1	CM2	CM3	CM4	SEM	Linear	Quadratic
Macro								
Calcium	48.73	50.93	50.7	30.92	37.78	8.83	NS	NS
Phosphorus	63.92	55.37	55.37	47.71	48.10	9.10	NS	NS
Magnesium	66.58	59.63	63.96	50.67	50.00	6.67	NS	NS
Potassium	50.42	71.36	40.7	63.26	64.86	7.46	NS	NS
Sodium	46.06	45.39	41.90	41.15	31.78	5.53	*	NS
Trace								
Copper	49.07	48.81	50.39	31.68	53.45	8.44	NS	NS
Iron	50.38	49.43	33.30	42.38	49.79	7.82	NS	NS
Manganese	51.80	50.43	36.54	53.98	56.87	7.77	NS	NS
Zinc	58.80	64.00	61.95	61.32	58.56	8.30	NS	NS

NS not significant

*$P < 0.05$

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

Inclusion of CM in chicken diets had no influence on digestibility of calcium, phosphorus, magnesium and other trace minerals suggesting that the indigenous PK chickens have the capacity to extract minerals from these diets despite the presence of phytic acid. Indeed, phytic acid has a high density of negatively charged phosphate ions that have the capacity to form stable complexes with minerals, thus making them unavailable for intestinal absorption (Lopez et al. 2002).

Feed intake and growth performance

Replacing soybean ingredients with CM did not depress feed intake and FCR in PK cockerels. Similar results have been reported in broilers chickens (Disetlhe et al. 2018) and Japanese quails (Mnisi and Mlambo 2018) when 17.5% CM was included in the diets of these birds. This suggests that inclusion of CM did not alter the physicochemical parameters

Table 5 Haematological parameters in 18-week-old Potchefstroom koekoek cockerels fed graded levels of canola meals as partial replacements for soybean meal (mean ± SE)

	Diets[1]					Significance	
Parameters	Control	CM1	CM2	CM3	CM4	Linear	Quadratic
Erythrocytes ($\times 10^{12}$/L)	2.67 ± 0.18	2.61 ± 0.26	2.97 ± 0.26	2.93 ± 0.18	3.06 ± 0.21	NS	NS
Haemoglobin (g/dL)	10.11 ± 0.43	10.38 ± 0.46	10.70 ± 0.51	10.93 ± 0.41	10.78 ± 0.43	NS	NS
Haematocrit (L/L)	0.39 ± 0.01	0.38 ± 0.01	0.39 ± 0.02	0.39 ± 0.02	0.39 ± 0.02	NS	NS
Leucocytes (10^9/L)	22.65 ± 2.33	16.81 ± 2.52	19.67 ± 2.77	14.33 ± 2.19	16.73 ± 2.33	NS	NS
Neutrophils (%)	5.71 ± 2.23	9.33 ± 2.42	2.40 ± 2.65	5.00 ± 2.10	13.70 ± 2.24	*	NS
Lymphocytes (%)	84.57 ± 2.78	78.67 ± 3.01	90.40 ± 3.27	86.50 ± 2.60	78.29 ± 2.78	NS	NS
Monocytes (%)	7.42 ± 1.86	9.33 ± 2.00	4.80 ± 2.20	5.00 ± 1.74	5.71 ± 1.90	NS	NS
Eosinophils (%)	0.5 ± 0.70	1.33 ± 0.80	0.80 ± 0.82	1.00 ± 0.82	1.14 ± 0.70	NS	NS
Basophils (%)	1.71 ± 1.05	1.33 ± 1.14	1.60 ± 1.24	2.50 ± 0.98	1.14 ± 1.05	NS	NS

NS not significant

*$P < 0.05$

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

Table 6 Serum biochemical parameters in 18-week-old Potchefstroom koekoek cockerels fed graded levels of canola meal as partial replacements for soybean meal

Parameters	Diets[1]						Significance	
	Control	CM1	CM2	CM3	CM4	SEM	Linear	Quadratic
Bilirubin (μmol/L)	0.71	0.63	0.60	0.60	0.67	0.16	NS	NS
ALT (IU/L)	0.40	0.60	0.40	0.40	0.40	0.28	NS	NS
AST(IU/L)	182.8	196.8	193.4	187.8	199.8	7.60	NS	NS
Total protein (g/L)	40.80	43.20	43.60	39.60	43.80	1.85	NS	NS
Sodium (mmol/L)	153.6	152.2	154.0	152.8	153.2	1.12	NS	NS
Potassium (mmol/L)	4.57	4.93	3.85	4.40	4.20	0.49	NS	NS
Albumin (g/L)	15.80	15.60	17.20	15.80	16.20	0.67	NS	NS
Creatinine (μmol/L)	18.00	18.00	18.00	18.00	18.00	0.00	NS	NS
Calcium total (mmol/L)	2.93	2.84	2.79	2.75	2.79	0.69	**	NS
Magnesium (mmol/L)	1.12	1.11	1.20	1.13	1.09	0.04	NS	NS
Triglycerides (mmol/L)	0.97	0.75	0.73	0.72	0.67	0.10	*	NS

NS not significant

*$P < 0.05$; **$P < 0.01$

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

of the diet and thus did not affect its palatability and functional properties. Protein efficiency ratio (PER) depends on protein content, digestibility and the level of essential amino acids (first limiting amino acids) (Maina et al. 2007). The tendency of PER to decline with age is explained by an increase in protein intake, which is not matched by an increase in weight gain. Indeed, Kamran et al. (2008) reported a linear reduction in PER for the broilers during the grower to finisher stages. In older birds, less protein is required resulting in large amounts of protein being excreted and thus contributing to low PER. In this study, it is clear that CM can be used to replace soybean meal in indigenous chicken diets at levels up to 78 g/kg without any detrimental effects on PER. It may be deduced that CM-containing diets supplied the required amino acids to support growth of the PK cockerels despite the relatively higher fibre and other anti-nutrients, which are regarded as growth suppressants.

Haematology and serum biochemistry

Most of the haematological parameters measured fell within the normal range for healthy chickens (Jain 1986). Similar findings were reported in broilers fed diets containing CM (Disetlhe et al. 2018). However, the neutrophils linearly increased with CM inclusion levels suggesting that the immune systems of cockerels were challenged when a high level of CM was incorporated in the diet, which could be due to the presence of glucosinolate compounds. It is well known that the intake of glucosinolates may cause haemorrhaging of the liver (Campbell and Slominski 1991) and that neutrophils participate in the resolution of the resultant inflammatory responses (Selders et al. 2017). The biomarkers ALT, AST and bilirubin, which are indicators of the integrity of some vital organs (Gowda et al. 2010), were similar ($P > 0.05$) across all diets suggesting that the health of PK cockerels was not negatively affected by inclusion of CM in the diets. Contrary to expectations, triglyceride levels linearly decreased with increasing CM inclusion levels. Similar total protein and albumin content observed in this study is a reflection of similar protein nutritional status of the birds in different dietary treatments. This indicates that the less expensive CM can be included in PK diets without compromising the protein nutrition of the birds. Similar finding have been reported by Ahmed et al. (2015) in broiler chickens when 20% CM was included in their diets. Concentration of serum minerals in the present study, with the exception of calcium, was similar between PK cockerels fed CM-based diets and those on the control diet despite the expectation that bioavailability of minerals would be lower in CM-containing diets due to the presence of phytic acid. This finding is also a reflection of the similar mineral digestibility results reported above. This reveals that partial replacement of SBM with CM in PK diets does not compromise mineral nutrition of the birds. The serum calcium concentration decreased linearly with an increase in CM inclusion, which could be due to the low concentration of this mineral in canola (Mahan et al. 2005). However, this decline in calcium levels did not result in hypocalcemia in the cockerels.

Conclusions

The study revealed that CM can safely be used to partially substitute SBM as it did not cause any physiopathological abnormalities in PK cockerels. Haematopoiesis and organ integrity were also not compromised. Weight gain data revealed that CM could be used to replace up to 7.8% of soybean ingredients in indigenous PK diets without compromising growth performance.

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Compliance with ethical standards

The management and care of PK cockerels were performed following the ethical guidelines of the North-West University Institution Research Ethics Regulatory Committee that approved the protocol used herein.

Conflict of interest The authors declare that they have no competing interests.

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