Brazilian Journal of Poultry Science
Revista Brasileira de Ciência Avícola

ISSN 1516-635X 2023 / v.25 / n.1 / 001-008

http://dx.doi.org/10.1590/1806-9061-2021-1546

Original Article

Commercial Feed Diluted with Different Fiber Sources and Enzyme Product for Broilers: Growth Performance, Carcass and Gut Health

■Author(s)

Diarra SS[I] https://orcid.org/0000-0002-6579-8709
Anand S[I] https://orcid.org/0000-0002-0050-6971
Lemuelu T[I] https://orcid.org/0000-0003-2078-7448
Areta F[I] https://orcid.org/0000-0002-9838-0691
Mathew E[I] https://orcid.org/0000-0003-0234-7246
Lehi E[I] https://orcid.org/0000-0002-1492-2474
Hoponoa S[I] https://orcid.org/0000-0002-5582-1522
Kava F[I] https://orcid.org/0000-0001-9479-9324
Mafi J[I] https://orcid.org/0000-0003-0174-2885
Taliauli F[I] https://orcid.org/0000-0002-4166-7333

[I] School of Agriculture and Food Technology, Alafua campus Samoa, the University of the South Pacific, Alafua, Samoa.

■Mail Address

Corresponding author e-mail address
Siaka Seriba Diarra
Agriculture and Food Technology Discipline, Samoa campus, the University of the South Pacific - Animal Science, University of the South Pacific, Samoa Campus PMBAG Alafua, Samoa.
Email: diarra_s@usp.ac.fj

■Keywords

Alternative ingredients; broiler production; feed enzymes; feed processing.

Submitted: 19/July/2022
Approved: 13/September/2022

ABSTRACT

The dilution of commercial broiler feed with copra meal (CM), palm kernel meal (PKM) and cassava leaf meal (CLM) and enzyme supplementation was investigated. Two hundred and eighty 7-day old Cobb 500 broilers were fed commercial feed alone or diluted with the test ingredients with and without enzyme. There were no interaction effects ($p>0.05$) on feed intake (FI) and weight gain (WG). Poorer ($p<0.05$) feed conversion ratio (FCR) was observed on the diet diluted diets from 22-42 d, but this was restored ($p>0.05$) by enzyme supplementation. There was no interaction effect on final body weight (FBW). Diet dilution depressed FBW ($p<0.05$) but enzyme supplementation restored ($p>0.05$) this weight depression. Abdominal fat was lighter ($p<0.05$) on CLM compared to CM. There were no interaction effects ($p>0.05$) on the weight of gut segments and *E. coli* count. Heavier ($p<0.05$) liver, gizzard and intestine were observed on the test diets. Commercial feed dilution with CM, CLM and PKM at 100 g/kg for starter and 200 g/kg for finisher would be a viable option for smallholder broiler production. More research is needed into dilution levels and enzyme concentrations.

INTRODUCTION

Globally, poultry meat consumption is increasing at a faster rate in developing countries (Ravindran, 2012; OECD, 2018) where feed availability is a major production constraint (Ravindran, 2012). High feed cost due to unavailability of conventional ingredients such as maize and soybean meal, is the single most important factor affecting poultry production. Copra meal (CM), palm kernel meal (PKM) and cassava leaf meal (CLM) are moderate sources of protein but high in fiber and low in essential amino acids. There are reports of feeding CM, PKM and cassava leaf meal (CLM) (Eruvbetine *et al.*, 2003; Sundu *et al.*, 2006; Abdollahi *et al.*, 2016; Devi & Diarra, 2017) to poultry but recommendations are generally low. There is the need for research in feed technologies to optimize the inclusion of CM, PKM and CLM in poultry diets. Dilution of commercial feed with CM at 200 g/kg significantly reduced cost without compromising performance of Hubbard broilers grown to 53 days (Pandi, 2005). However, report on feed dilution in modern broilers with higher nutrient requirements is still scanty. Recently, Mael *et al.* (2020) observed that the dilution of commercial feed at 100 g/kg maintained performance and reduced the cost of producing Cobb 500 broilers, but at 200 g/kg dilution, enzyme supplementation was required. Diarra & Anand (2020) also found that both CM and CLM have potential to dilute commercial broiler feed with cost benefit. Although PKM is similar to CM and CLM in nutritional characteristics there are no reports on its use in commercial feed dilution for broilers.

Several enzyme products have been found to improve the utilization of fibrous ingredients by poultry and reduce feed cost (Berwanger *et al.*, 2017; Alagawany *et al.*, 2018; Dayal *et al.*, 2018; Rehman *et al.*, 2018). Dietary fiber may also improve bird performance through enhanced gut health (Iji *et al.*, 2001; Jha *et al.*, 2019).

This study evaluated the performance of Cobb500 broilers fed commercial feed alone or diluted with CM, PKM and CLM. The hypotheses were (i) feed dilution will not affect bird performance, (ii) enzyme supplementation of the diluted feed will be beneficial, and (iii) birds fed the diluted feeds will have lower *E. coli* count compared to the control.

MATERIALS AND METHODS

The study was conducted at the Teaching and Research Farm of the Agriculture and Food Technology Discipline of the University of the South Pacific. The Animal Ethics Committee of the University approved the experimental protocol.

Experimental ingredients and diets

Expeller extracted CM and PKM, major by-products of coconut and palm oils extraction were obtained from Pacific Oil Samoa and Guadalcanal Plains Palm Oil Limited Solomon Islands, respectively. Cassava leaf harvested from 8-month-old sweet cultivar was sun-dried for 5 days and ground in a hammer mill from Golden Machinery Equipment Co. Limited (Zhengzhou Runxiang, China) to pass through a 4 mm sieve. The composition of the test ingredients in selected constituents is presented in Table 1. The test ingredients could not be analyzed for amino acid composition due to lack of analytical facilities in the study area and difficulties to send samples overseas during the lockdown to Covid-19.

Table 1 – Composition of the experimental fibre sources.

Constituents (g/kg)	CM	CLM	PKM
Dry matter	907	884	899
Crude protein	208	205	201
Ether extract	120	66	97
Crude fiber	164	168	154
Ash	62	97	44

CM: copra meal, CLM: cassava leaf meal; PKM: palm kernel meal; NDF: neutral detergent fiber; ADF: acid detergent fiber.

A commercial broiler feed based on wheat, maize and soybean meal from the Pacific Feed, Fiji served as the control. The crude protein and metabolizable energy contents of the control feed were 205 and 190 g/kg; 12 and 12.5 MJ/kg in the starter and finisher, respectively. The control feed supplied 12 and 5 g; 10.4 and 4.3 g of lysine and methionine/kg in the starter and finisher, respectively. The control feed contained 40 g crude fiber/kg in both the starter and finisher.

The experimental diets consisted of the commercial feed diluted with CM, PKM and CLMat 100 g/kg in the starter and 200 g/kg in the finisher without or with enzyme (Table 2). Challenzyme 1309A with eight enzyme activities (U/g): β-glucanase800; xylanase15,000; β-mannanase100; α-galactosidase100; protease 800; amylase 500; pectinase 500 and cellulase300) was used at 300 g/tonne. Challenzyme1309A has the following matrix values:crude protein (3,000%), lysine (270%), methionine (64%), tryptophan (90%), threonine (120%) and metabolizable energy (1,000 Mcal/kg). Dilution was done on protein basis to keep al diets isonitrogenous.

Experimental birds and management

Two hundred and eighty 7 d-old Cobb 500 male broiler chicks (185 ± 5.3 g) were allotted in groups of 10 to 28 open-sided floor pens (2.59 m^2) in a factorial arrangement (4 fiber sources x 2 enzyme levels). Each diet was fed to four replicate pens in a completely randomized design. The starter diet was fed from 8-21 d and the finisher from 22-42 d. Feed and drinking water were available *ad libitum* throughout the experimental period. The birds received 24 h light up to 14 d, and 15 h thereafter until the end of the experiment.

Data collection

Data were collected on feed intake, BWG, FCR, carcass and gut measurements and *E. coli* count. Feed intake was calculated by difference between the quantities supplied and left over. The birds were individually weighed at the start of the experiment, d 21 and d 42 and weight gain during each growth phase calculated by difference. Feed conversion ratio was derived as the ratio of feed consumed to weight gain and corrected for mortality.

On d 42, two birds weighing closer to the pen mean were fasted overnight for carcass studies and gut measurements. The birds were killed by cervical dislocation, scalded at 50 ºC for 30 seconds, manually plucked and eviscerated. Carcasses and different cuts were weighed and expressed as percentages of the liveweight. Gut segments (proventriculus, gizzard, intestine, caeca and liver) were also weighed on a portable digital scale (JadeverJKH-500 series, Smartfox, Auckland, New Zealand) sensitive at 0.1 g and expressed as relative to the live weight. Small intestine length was taken, from the duodenum to the ileo-caecal joint, using a measuring tape and expressed as

Table 2 – Composition of the basal diets (as fed basis) and calculated analyses based on the nutrient content of the commercial feed, CM, CLM and PKM.

Ingredients (g/kg)	Starter diets				Finisher diets			
	Control	CM	CLM	PKM	Control	CM	CLM	PKM
Commercial feed	1,000	901.4	900	898	1,000	817.3	814.6	811
CM	-	98.6	-	-	-	182.7	-	-
CLM	-		100	-			185.4	-
PKC	-			102				189
HCl Lysine	-	7.3	7	8	-	1.08	1.3	1.1
DL Methionine	-	0.3	0.2	0.4	-	0.3	0.1	0.3
Calculated values								
Crude protein	205	205	205	205	190	190	190	190
Crude fibre	40	52	55	51	40	69	73	67
Lysine	12	12	12	12	10.4	10.4	10.4	10.4
Methionine	5	5	5	5	4.3	4.3	4.3	4.3
Ca	8.0	7.8	7.9	7.8	7.5	7.3	7.4	7.4
Avail.P	4.0	3.7	3.7	3.6	3.3	3.4	3.4	3.3
Ca: Avail. P	2.0	2.1	2.1	2.2	2.3	2.1	2.2	2.2
ME (MJ/kg)	12	12	11.7	12.1	12.5	12.4	11.8	12.6

CM: copra meal, CLM: cassava leaf meal, PKM: palm kernel cake, ME: Metabolisable energy.

cm/kg body weight. The caeca were placed in labelled sterile sample bottles with ice and sent immediately to the microbiology laboratory for *E. coli* count following the procedure described by Wang *et al.* (2017).

Chemical analysis

The fiber sources were analysed for dry matter, nitrogen, total fat, crude fiber and ash according to standard procedures (AOAC, 1995). Crude protein (CP) was calculated as nitrogen × 6.25 (feed factor).

Statistical analysis

Data collected were subjected to one-way analysis of variance (ANOVA) (Steel *et al.*, 1997) of the GLM in SPSS (SPSS for Windows 2013, version 22.0; IBM Corporation, Armonk, NY, USA) with pen as the experimental unit. Treatment means were compared using the Duncan Multiple Range test and differences considered significant at $p<0.05$.

RESULTS

Growth performance

The growth performance results are presented in Table 3. With the exception of FCR during the finisher phase, there were no interaction effects ($p>0.05$) on the growth parameters observed. The best F/G

Table 3 – Growth performance of broilers fed commercial diet alone or diluted with different fibre sources and enzyme supplementation.

Treatment	7-21 d			22-35 d			Final body weight (g/bird)
	FI (g/bird)	WG (g/bird)	F/G	FI (g/bird)	WG (g/bird)	F/G	
Control	1045	860	1.22	2607	1682	1.51[b]	2733
Control + CM	928	710	1.31	2785	1537	1.81[a]	2433
Control + CM with enzyme	1030	708	1.45	3095	1748	1.77[ab]	2643
Control + CLM	985	648	1.52	2957	1390	2.13[a]	2225
Control + CLM with enzyme	975	675	1.44	2923	1778	1.64[ab]	2635
Control + PKM	955	700	1.36	2872	1430	2.03[a]	2313
Control + PKM with enzyme	1005	710	1.42	3010	1452	1.98[a]	2418
SEM	28	24	0.05	215	68	0.09	80
Main effects							
Control	1045	860[a]	1.22	2607	1682	1.51[b]	2733[a]
CM	979	709[ab]	1.38	2940	1643	1.80[a]	2588[ab]
CLM	980	661[b]	1.49	2940	1584	1.90[a]	2430[b]
PKM	980	705[ab]	1.39	2941	1476	2.00[a]	2365[b]
Enzyme, no	978	698	1.40	2806	1510	1.87[a]	2426[b]
Enzyme, yes	1003	729	1.37	3009	1682	1.79[b]	2565[a]
Probabilities							
Diet	0.234	0.001	0.051	0.570	0.276	0.001	0.007
Enzyme	0.052	0.557	0.361	0.442	0.009	0.015	0.001
Diet * enzyme	0.161	0.822	0.127	0.728	0.336	0.026	0.178

Values are means of 4 replications (n = 4); means in the column bearing different letters (a, b, c) are different ($p<0.05$),CM: copra meal, CLM: cassava leaf meal, PKM: palm kernel cake, ME: Metabolisable energy; SEM: standard error of the mean.

($p<0.05$) was recorded on the control. Enzyme supplementation of the CM and CLM-based diets improved ($p<0.05$) FCR comparable to the control but enzyme supplementation of the PKM diet had no effect ($p>0.5$) on FCR.

In the main effects, birds fed the control gained more ($p<0.05$) weight than those fed the CLM-diluted diet during the starter phase. Weight gain was not different ($p>0.05$) between the control, CM and PKM as well as among the test diets. During the finisher phase, the best FCR ($p<0.05$) was recorded on the control. Feed conversion ratio gain did not differ ($p>0.05$) among the test diets. Enzyme supplementation improved ($p<0.05$) F/G. Final body weight was heavier ($p<0.05$) on the control compared to CLM and PKM. Final body weight did not differ ($p>0.05$) between the control and CM and among the test diets. Enzyme supplementation improved ($p<0.05$) FBW.

Carcass measurements

Results of carcass measurements (Table 4) showed no interaction effects ($p>0.05$) on any of the parameters studied. Similarly, there were no main effects ($p>0.05$) on the relative weights of carcass, breast, thigh and drumstick. Birds fed the CLM dilution diet had lighter ($p<0.05$) abdominal fat than the control group. There was no difference ($p>0.05$) in abdominal fat weight between the control, CM and PKM diets. Enzyme supplementation did not affect ($p>0.05$) carcass measurements.

Table 4 – Relative weight of carcass and cuts (percentage) of broilers fed commercial diet alone or diluted with different fibre sources and enzyme supplementation.

Treatment	Carcass	Breast	Thigh	Drumstick	Abdominal fat
Control	67.8	25.9	11.0	10.5	1.1
Control + CM	69.3	26.1	13.4	11.2	1.3
Control + CM with enzyme	72.7	26.5	12.9	10.2	1.7
Control + CLM	70.8	25.8	11.8	10.9	1.0
Control + CLM with enzyme	69.8	25.1	12.2	11.1	1.0
Control + PKM	68.7	26.1	11.7	9.8	1.1
Control + PKM with enzyme	70.5	26.4	13.3	10.7	1.3
SEM	6.91	2.67	1.30	1.07	0.16
Main effects					
Control	67.8	25.9	11.0	10.5	1.1^{ab}
CM	71.0	26.3	13.1	10.7	1.5^{a}
CLM	70.3	25.4	12.0	11.0	0.9^{b}
PKM	69.6	26.2	12.5	10.2	1.2^{ab}
Enzyme, no	68.0	24.7	11.7	10.1	1.1
Enzyme, yes	71.0	26.0	12.8	10.7	1.2
Probabilities					
Diet	0.253	0.389	0.250	0.240	0.013
Enzyme	0.806	0.997	0.657	0.970	0.374
Diet * enzyme	0.948	0.971	0.746	0.679	0.274

Values are means of 4 replications (n = 4); means in the column bearing different letters (a, b) are different ($p<0.05$), CM: copra meal, CLM: cassava leaf meal, PKM: palm kernel cake, ME: Metabolisable energy; SEM: standard error of the mean.

Gut measurements and E. coli count

Results of organ measurements and *E. coli* count are presented in Table 5. There were no interaction effects ($p>0.05$) on the relative weight of gut segments/ glands (liver, gizzard, proventriculus, caeca and intestine), intestine length and *E. coli* count. In the main effects, lighter ($p<0.05$) liver and gizzard were recorded on the control compared to the test diets. The weight of intestine increased ($p<0.05$) on CLM and PKM compared to the control. Intestine weight did not differ ($p>0.05$) between the control and Cm and among the test diets. Enzyme supplementation had no marked ($p>0.05$) effects on gut segments measured and *E. coli* count.

DISCUSSION

Growth performance

Currently, there are very few studies on dilution of commercial feed with fiber sources on broiler performance. The growth performance pattern observed suggests that this level of dilution (100 and 200 g/kg in the starter and finisher, respectively) can maintain broiler performance. Enzyme supplementation of the diluted diets was shown to be beneficial probably due

Table 5 – Relative weight of gut segments (percentage), intestine length ((cm/kg weight)) and caeca *E. coli* count (log10 CFU/g) of broilers fed commercial diet alone or diluted with different fibre sources and enzyme supplementation.

Treatment	Liver	Gizzard	Proventriculus	Caeca	Intestine	Intestine length	*E. coli* count
Control	2.22	1.51	0.60	0.61	2.87	1.71	7.73
Control + CM	3.34	2.22	0.40	0.68	4.00	1.75	7.35
Control + CM with enzyme	3.23	2.07	0.40	0.70	3.84	1.86	7.56
Control + CLM	3.64	2.40	0.40	0.77	4.64	1.82	7.33
Control + CLM with enzyme	3.80	2.43	0.40	0.88	5.07	1.93	7.40
Control + PKM	3.51	2.41	0.37	0.72	4.19	1.78	7.83
Control + PKM with enzyme	3.64	2.33	0.38	0.55	4.22	1.79	7.45
SEM	0.28	0.15	0.07	0.10	0.49	0.10	0.49
Main effects							
Control	2.22[b]	1.51[b]	0.60	0.61	2.87[b]	1.71	7.73
CM	3.24[a]	2.11[a]	0.44	0.67	3.88[ab]	1.82	7.46
CLM	3.71[a]	2.40[a]	0.49	0.77	4.87[a]	1.89	7.37
PKM	3.63[a]	2.41[a]	0.40	0.61	4.16[a]	1.78	7.93
Enzyme, no	3.20	2.11	0.43	0.69	3.92	1.81	7.54
Enzyme, yes	3.51	2.30	0.44	0.70	4.40	1.88	7.69
Probabilities							
Diet	0.002	0.001	0.122	0.172	0.028	0.633	0.663
Enzyme	0.944	0.512	0.590	0.775	0.809	0.398	0.597
Diet * enzyme	0.875	0.728	0.828	0.113	0.835	0.861	0.953

Values are means of 4 replications (n = 4); means in the column bearing different letters (a, b) are different ($p<0.05$), CM: copra meal, CLM: cassava leaf meal, PKM: palm kernel cake, ME: Metabolisable energy; SEM: standard error of the mean.

to increased fiber hydrolysis. The beneficial effect of enzymes products on transit time in broilers fed fibrous CM (Diarra, S. S. *et al.*, 2015; Devi & Diarra, 2017), rye (Lázaro *et al.*, 2003), soybean (Adeyemi *et al.*, 2013) and de-oiled rice bran (Anuradha & Roy, 2015) diets has been reported. Similar studies on commercial diet dilution with CM (Mael *et al.*, 2020) and CM or CLM (Diarra, S. & Anand, 2020) also reported improvement in broilers with enzyme supplementation. The pattern of WG and F/G in the main effects was not clear but this suggests the need for more studies on enzyme concentration.

Carcass measurements

There were no interaction effects on the relative weights of carcass and cuts (breast muscle, thigh, drumstick and abdominal fat). The reason for reduced abdominal fat on CLM in the main effects was not clear but probably due to compositional differences among the fiber sources, especially in micronutrients. In the present study, the fiber sources were not analyzed for micronutrients but cassava leaf is known for its good profile in lysine (Morgan & Choct, 2016). Several studies (Ojano-Dirain & Waldroup, 2002; Adeyemi *et al.*, 2013; Fouad & El-Senousey, 2014; Mendes *et al.*, 2014) have confirmed the role of dietary lysine in reducing abdominal fat in broilers. Although all diluted diets were supplemented with lysine and methionine, possible beneficial effect of additional lysine from CLM may be postulated. The mode of action of dietary lysine on abdominal fat has mainly been attributed to its lipogenesis inhibitory activity (Fouad & El-Senousey, 2014).

Organ weight and *E. coli* count

The heavier liver and gizzard on the test diets is suggestive of increased activities of these segments on the test diets. Increased gizzard weight on high-fiber diets due to fiber accumulation and grinding activity in this organ is well reported (Hetland *et al.*, 2004; Jiménez-Moreno *et al.*, 2009). Increased biliary secretion for digestion and release of nutrients sequestered in the fiber fraction may also be implicated in the pattern of liver weight. Diarra & Anand (2020) also observed similar trends in gizzard and liver weights of broilers fed commercial diet diluted with CM or CLM. The pattern of full intestine weight in this study may be attributed to digesta weight on the test diets at the time of slaughter due to slower transit. The effect of dietary fiber on digesta transit time is well documented (Jiménez-Moreno *et al.*, 2009; Rougière & Carré, 2010; Mateos *et al.*, 2012).

Short-chain-fatty-acids (SCFAs) mainly acetic, propionic and butyric acids, produced from fiber fermentation in the caeca (Iji *et al.*, 2001; Mateos *et al.*, 2012), suppress pathogenic and encourage the multiplication of beneficial bacteria (Abazari *et al.*, 2016; Khan & Iqbal, 2016; Jha *et al.*, 2019). In the present study, there was no effect of diet on *E. coli* count suggesting low rate of fermentation probably due to lower substrate in the caeca. This can further explain the lack of significant difference in caeca weight among the treatments.

CONCLUSIONS

The results of this preliminary investigation suggest that dilution of commercial feed with copra, cassava leaf or palm kernel meals (100 and 200 g/kg in the starter and finisher diets, respectively) maintains broiler growth and carcass cuts. Supplementation of diets with Challenzyme1309A at g/tonne may have beneficial effects. The high cost of conventional ingredients justifies the use of these by-products in diet dilution for smallholder broiler production.

ACKNOWLEDGMENTS

The study was funded by the University of the South Pacific (Grant F4341-FBE16-71502-001). Authors are grateful to the staff of the Livestock Farm for assisting during feed processing and management of the lighting programme. We are grateful to Beijing Challenge Group for donating the enzyme product.

CONFLICT OF INTEREST STATEMENT

Authors declare no conflict of interest.

REFERENCES

Abazari A, Navidshad B, Mirzaei Aghjehgheshlagh F, Nikbin S. The effect of rice husk as an insoluble dietary fiber source on intestinal morphology and Lactobacilli and Escherichia coli populations in broilers. Iranian Journal of Veterinary Medicine 2016;10(3):217–24.

Abdollahi MR, Hosking BJ, Ning D, Ravindran V. Influence of palm kernel meal inclusion and exogenous enzyme supplementation on growth performance, energy utilization, and nutrient digestibility in young broilers. Asian-Australasian Journal Animal Science 2016;29(4):539–48.

Adeyemi OA, Jimoh B, Olufade OO. Soybean meal replacement with cassava leaf: blood meal mix with or without enzyme in broiler diets. Archivos de Zootecnia 2013;62(238):275–85.

Alagawany M, Elnesr ShS, Farag MR. The role of exogenous enzymes in promoting growth and improving nutrient digestibility in poultry. Iranian Journal of Veterinary Research 2018;19(3):157–64.

Anuradha P, Roy B. Effect of supplementation of fiber degrading enzymes on performance of broiler chickens fed diets containing de-oiled rice bran. Asian Journal of Animal and Veterinary Advances 2015;10:179–84.

AOAC - Association of Official Analytical Chemists. Official methods of analysis of AOAC international. Washington; 1995.

Berwanger E, Nunes RV, Pasquetti TJ, Murakami AE, Oliveira TMM de, Bayerle DF, *et al.* Sunflower cake with or without enzymatic complex for broiler chickens feeding. Asian-Australasian Journal Animal Science 2017;30(3):410–6.

Dayal AD, Diarra SS, Lameta S, Devi A, Amosa F. High cassava peel meal-based diets with animal fat and enzyme for broilers. Livestock Research for Rural Development 2018;30(6):99.

Devi A, Diarra SS. Influence of dietary protein source and utilisation of copra meal in finishing broiler chicken. Indian Journal of Animal Nutrition 2017;34(2):193–200.

Diarra S, Anand S. Impact of commercial feed dilution with copra meal or cassava leaf meal and enzyme supplementation on broiler performance. Poultry Science 2020;99(11):5867–73.

Diarra SS, Sandakabatu D, Perera D, Tabuaciri P, Mohammed U. Growth performance and carcass yield of broiler chickens fed commercial finisher and cassava copra meal-based diets. Journal of Applied Animal Research 2015;43(3):352–6.

Eruvbetine D, Tajudeen ID, Adeosun AT, Olojede AA. Cassava (Manihot esculenta) leaf and tuber concentrate in diets for broiler chickens. Bioresource Technology 2003;86(3):277–81.

Fouad AM, El-Senousey HK. Nutritional factors affecting abdominal fat deposition in poultry: a review. Asian-Australasian Journal Animal Science 2014;27(7):1057–68.

Hetland H, Choct M, Svihus B. Role of insoluble non-starch polysaccharides in poultry nutrition. World's Poultry Science Journal 2004;60(4):415–22.

Iji PA, Saki AA, Tivey DR. Intestinal development and body growth of broiler chicks on diets supplemented with non-starch polysaccharides. Animal Feed Science and Technology 2001;89(3):175–88.

Jha R, Fouhse JM, Tiwari UP, Li L, Willing BP. Dietary fibre and intestinal health of monogastric animals. Frontiere in Veterinary Science 2019;6(48).

Jiménez-Moreno E, González-Alvarado JM, Coca-Sinova A de, Lázaro R, Mateos GG. Effects of source of fibre on the development and pH of the gastrointestinal tract of broilers. Animal Feed Science and Technology 2009;154(1):93–101.

Khan SH, Iqbal J. Recent advances in the role of organic acids in poultry nutrition. Journal of Applied Animal Research 2016;44(1):359–69.

Lázaro R, García M, Medel P, Mateos GG. Influence of enzymes on performance and digestive parameters of broilers fed rye-based diets. Poultry Science 2003;82(1):132–40.

Mael SH, Diarra SS, Devi A. Maintenance of broiler performance on commercial diets diluted with copra meal and supplemented with feed enzymes. Animal Production Science 2020;60(12):1514–20.

Mateos GG, Jiménez-Moreno E, Serrano MP, Lázaro RP. Poultry response to high levels of dietary fiber sources varying in physical and chemical characteristics. Journal of Applied Poultry Research 2012;21(1):156–74.

Mendes AS, Api I, Silva L, Silva RTL, Sausen L, Menezes LFG, *et al.* Effects of dietary lysine on broiler performance and carcass yield - meta-analysis. Brazilian Journal of Poultry Science 2014;16(4):425–30.

Morgan NK, Choct M. Cassava: nutrient composition and nutritive value in poultry diets. Animal Nutrition 2016;2(4):253–61.

OECD - Organization for Economic Co-operation and Developmen. Agriculture Statistics. OECD-FAO Agricultural Outlook; 2018. Available from: https://www.oecd-ilibrary.org/agriculture-and-food/oecd-fao-agricultural-outlook-2018-2027_agr_outlook-2018-en

Ojano-Dirain CP, Waldroup PW. Evaluation of lysine, methionine and threonine needs of broilers three to six week of age under moderate temperature stress. International Journal of Poultry Science 2002;1(123):16–21.

Pandi J. Dilution of broiler finisher feed with copra meal. PNG Journal of Agriculture, Forestry and Fisheries 2005;48:3–6.

Ravindran V. Advances and future directions in poultry nutrition: an overview. Korean Journal of Poultry Science 2012;39(1):53–62.

Rehman ZU, Kamran J, El-Hack MEA, Alagawany M, Bhatti SA, Ahmad G, *et al.* Influence of low-protein and low-amino acid diets with different sources of protease on performance, carcasses and nitrogen retention of broiler chickens. Animal Production Science 2018;58(9):1625–31.

Rougière N, Carré B. Comparison of gastrointestinal transit times between chickens from D+ and D− genetic lines selected for divergent digestion efficiency. Animal 2010;4(11):1861–72.

Steel RGD, Torrie JH, Dickey DA. Principles and procedures of statistics: a biometrical approach. New York: McGraw-Hill; 1997. 698 p.

Sundu B, Kumar A, Dingle J. Palm kernel meal in broiler diets: effect on chicken performance and health. World's Poultry Science Journal 2006;62(2):316–25.

Wang S, Peng Q, Jia HM, Zeng XF, Zhu JL, Hou CL, *et al.* Prevention of Escherichia coli infection in broiler chickens with Lactobacillus plantarum B1. Poultry Science3 2017;96(8):2576–86.