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Short communication

Macadamia nut cake as an alternative feedstuff for broilers: Effect on growth performance

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ABSTRACT

Corn, wheat, and soybean meal (SBM) have been primarily used as feedstuffs in animal feeding programs. However, it is necessary to explore and evaluate alternative feedstuffs to deal with variable costs and the supply of these conventional feedstuffs. This study determined the nutrient composition of macadamia nut cake (MNC) and its effect on the growth performance of broiler chickens fed at graded levels. A total of 180 d-old chicks were randomly and equally assigned to one of the treatment diets: 0 g/kg (control), 50, 100, 150, and 200 g/kg MNC included in corn-soybean meal-based diets. Body weight (BW) and feed intake were recorded to calculate average daily feed intake (ADFI), average daily gain (ADG), and feed conversion rate (FCR). Dietary inclusion of different levels of MNC during both starter (0–21 days) and finisher (22–42 days) period had similar average BW and ADG to control diet ($P > 0.05$). ADFI and FCR increased linearly with increasing concentration of MNC with significance at 200 g/kg during starter, and 150 g/kg MNC during finisher and overall study period compared to control ($P < 0.05$). Although MNC is high in fiber content, there was no retardation in growth. It could be due to the richness of essential nutrients, high lipid residue, and the beneficial role of fiber on gut health. Thus, MNC can be included up to 150 g/kg in broilers diets without compromising the growth performance and can serve as a potential alternative feedstuff to partially replace corn and SBM.

1. Introduction

It is becoming more challenging to meet the food demand for the ever-growing human population, especially from animal sources, as humans and animals compete for common ingredients such as corn, wheat, and soybean (Henchion et al., 2017). Because of this, not only the price of these conventional ingredients but also their availability in the marketplace is inconstant (Yadav et al., 2019). In poultry feed, energy and protein yielding feed sources are the most expensive components. Thus the increase in the cost of such feedstuffs also increases the cost of poultry production (Ahiwe et al., 2018). Hence, exploring and evaluating alternative energy and protein sources that are inexpensive, efficient, and locally available would benefit the poultry industry. Several alternative feedstuffs, including cassava root chips (Yadav et al., 2019), tropical fruits, leaves, tubers, and agro-industrial coproducts (Tiwari and Jha, 2016), distiller's dried grains with solubles (Świątkiewicz and Koreleski, 2008), oilseed cakes (Seneviratne et al., 2010), and wheat millrun

Abbreviations: ADFI, average daily feed intake; ADG, average daily gain; AME, apparent metabolizable energy; BW, Body weight; FCR, feed conversion rate; MNC, Macadamia nut cake.

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(Jha et al., 2012) have been evaluated and used successfully in monogastric animals' diets.

Macadamia nut cake (MNC), a byproduct of macadamia nut oil extraction process, is available in Hawaii (USA), Australia, New Zealand, Kenya, Brazil, Israel, and elsewhere in the world. MNC, like other coproducts, is high in fiber, fat residue, and gross energy and fair to high in protein. MNC is expected to affect the growth performance, gut microbiota, fermentation metabolites produced from those microbiota in animals (Acheampong-Boateng et al., 2008; Skenjana et al., 2006; Tiwari and Jha, 2017). It has reasonably high apparent metabolizable energy (AME) content (Berrocoso et al., 2017). Thus, MNC has the potential to be used in poultry diets as a source of both energy and protein. There is limited information on its optimum inclusion level and its effect on the growth performance of broiler chickens. However, several factors, including agro-climatic conditions, farming systems, and processing techniques influence the nutritional value of feedstuffs for the animals. Therefore, the study was conducted to determine the nutrient profile of MNC in Hawaii and evaluate the effects of its dietary inclusion on the growth performance of broiler chickens.

2. Materials and methods

2.1. Source and nutrient analysis of MNC

The MNC sample was sourced from a local macadamia nut processing plant (Oils of Aloha, Kunia, HI, USA). Before diet formulation, MNC was ground and analyzed for the proximate composition of MNC (Table 1). The nitrogen corrected AME (AME_n) value was estimated to be 12.13 MJ/kg on a DM basis as determined previously in our lab (Berrocoso et al., 2017), and the same batch of MNC was used in this study. The diets used in the present study were corn-soybean meal-based fed in mash form. The diets were formulated for two phases- starter (0–21d) and finisher (22–42 d) to meet or exceed the nutrients requirements of broilers (NRC, 1994). The diets were formulated to have five different inclusion levels of MNC: 0 g/kg MNC as control, and 50, 100, 150, and 200 g/kg. These treatments were allotted to chickens in a completely randomized design. The diets formulation and their nutrient profile are presented in Table 2. All feed samples, including starter and finisher as well as MNC sample, were analyzed for crude protein (CP), crude fat (CF), and fiber components (ADF, NDF, Lignin) using standard procedures of AOAC (AOAC, 2006).

2.2. Experimental animals, diets, and design

The Institutional Animal Care and Use Committee of the University of Hawaii approved the animal study protocol. A total of 180 day-old unsexed broiler chicks (Cobb 500) was obtained from a local hatchery used in the growth performance study at the Small Animal Facility, University of Hawaii at Manoa. Birds were raised in floor pen with a standard commercial broiler rearing environment (temperature, humidity, light, and built up litters). On day one, all chicks were weighed individually, wing tagged, and placed randomly in one of 30 pens (six birds/ pen). Out of 30 pens, birds in each pen were allotted with one of five diets where the individual pen was the experimental unit. All the birds had *ad libitum* access to feed and water.

2.3. Growth performance

The body weight of individual birds was taken on day 1 and weekly thereafter until day 42. Feed was offered to each pen daily and were recorded. Any leftover fed was weighed back and recorded weekly adjusted while calculating ADFI and FCR. The data generated were corrected for mortality and used to calculate ADG, ADFI, and FCR. Birds were monitored daily for any abnormal health or mortality and recorded.

2.4. Statistical analysis

All the data were analyzed by ANOVA using the Mixed procedure of SAS (SAS 9.2, SAS Institute Inc., Cary, NC). Significant differences among treatments were assessed by Tukey's test. The effect of increasing levels of MNC in diets was partitioned into linear and

Table 1
Nutrient profile of MNC used in this study, g/kg, as fed basis*.

Item	Value
Dry matter	946.0
Gross energy (MJ/kg)	18.8
Crude protein	176.0
Ether extract	90.1
Crude fiber	217.6
Acid detergent fiber	391.0
Neutral detergent fiber	500.4
Starch	105.0
Total ash	33.0

* Details are avaialable in Berrocosso et al. (2017); Same batch of MNC was used in present study.

Table 2
Ingredient used and nutrient composition of different treatment diets (g/kg unless otherwise indicated).

	Starter					Finisher				
Ingredients	MNC 0	MNC 50	MNC 100	MNC 150	MNC 200	MNC 0	MNC 50	MNC 100	MNC 150	MNC 200
Corn	553.8	523.4	483.6	448.7	413.8	603.9	566.8	532.5	502.5	471.4
SBM	370.0	350.0	340.0	330.0	315.0	312.5	300.0	285.0	275.0	255.0
MNC	0.0	50.0	100.0	150.0	200.0	0.0	50.0	100.0	150.0	200.0
Soybean oil	25.0	25.0	25.0	20.0	20.0	40.0	40.0	40.0	30.0	30.0
Limestone	14.0	14.0	14.0	14.0	14.0	13.0	13.0	13.0	13.0	13.0
Mono-cal Phosphate	15.0	15.0	15.0	15.0	15.0	12.0	12.0	12.0	12.0	12.0
Lysine	3.1	3.0	2.8	2.7	3.1	1.5	1.3	1.1	1.1	1.5
Methionine	3.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0	2.0
Threonine	2.0	2.0	2.0	2.0	2.0	1.0	1.0	0.5	0.5	1.0
Tryptophan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Choline Cl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nacl	4.0	4.5	4.5	4.5	4.0	4.0	3.8	3.8	3.8	4.0
Vitamin mix[1]	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Mineral mix[1]	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Phytase	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Calculated content, g/kg										
MEn, MJ/kg	12.2	12.2	12.2	12.0	12.0	13.0	12.9	12.9	12.6	12.6
CP	213.8	211.1	212.1	213.6	213.2	187.1	187.2	185.9	187.7	185.8
Ca	9.3	9.3	9.3	9.3	9.3	8.2	8.2	8.2	8.2	8.2
Total P	7.1	7.1	7.1	7.1	7.1	6.2	6.2	6.2	6.3	6.3
Available P	4.4	4.4	4.3	4.2	4.2	3.7	3.7	3.6	3.5	3.5
Lysine	13.8	13.5	13.3	13.2	13.3	11.2	10.9	10.6	10.6	10.6
Methionine	6.2	6.2	6.1	6.1	6.1	5.0	5.0	4.9	4.9	4.8
Cysteine	4.1	4.1	4.0	4.0	4.0	3.9	3.9	3.8	3.8	3.8
Threonine	9.9	9.7	9.7	9.7	9.5	8.1	8.0	7.4	7.4	7.7
Tryptophan	3.1	3.0	2.9	2.9	2.8	2.7	2.6	2.6	2.5	2.4
Methionine + Cysteine	10.3	10.2	10.2	10.2	10.1	8.9	8.8	8.7	8.7	8.6
Arginine	15.2	15.2	15.5	15.7	15.8	13.5	13.7	13.8	14.1	14.1
Valine	11.6	11.3	11.2	11.1	10.9	10.5	10.3	10.1	10.1	9.7
Isoleucine	8.9	8.6	8.6	8.5	8.4	7.9	7.8	7.6	7.6	7.3
Leucine	18.1	17.5	17.2	17.0	16.6	16.6	16.3	15.9	15.7	15.1
NDF	89.1	102.1	115.4	129.2	142.4	87.2	100.5	113.8	127.9	140.9
CF	38.1	42.6	47.6	52.8	57.6	35.2	40.1	44.9	50.1	54.6
Na	1.7	1.9	1.9	1.9	1.7	1.7	1.7	1.7	1.7	1.7
Cl	2.8	3.1	3.1	3.1	2.7	2.8	2.7	2.6	2.6	2.7
Choline (mg/kg)	1354	1280	1228	1179	1117	1228	1171	1108	1063	989
Analyzed content, g/kg										
Crude protein	209.0	211.3	205.1	215.1	201.0	180.7	190.3	182.6	182.5	187.5
Crude fat	23.0	30.8	41.2	41.4	46.2	46.8	53.3	54.7	44.5	49.7
ADF	39.2	61.8	68.2	96.6	98.2	38.5	49.8	66.2	93.7	94.0
NDF	64.8	91.8	93.1	137.0	141.8	72.2	85.3	113.7	134.9	162.1
Lignin	7.0	20.8	25.3	43.7	31.7	7.8	16.7	24.0	35.9	37.0

[1] Provided the following (per kg of diet): vitamin A (trans-retinyl acetate), 10,000 IU; vitamin D_3 (cholecalciferol), 3000 IU; vitamin E (all-*rac*-tocopherol-acetate), 30 mg; vitamin B_1, 2 mg; vitamin B_2, 8 mg; vitamin B_6, 4 mg; vitamin B_{12} (cyanocobalamin), 0.025 mg; vitamin K_3 (bisulphatemenadione complex), 3 mg; choline (choline chloride), 250 mg; nicotinic acid, 60 mg; pantothenic acid (D-calcium pantothenate), 15 mg; folic acid, 1.5 mg; betaíne anhydrous, 80 mg; D-biotin, 0.15 mg; zinc (ZnO), 80 mg; manganese (MnO), 70 mg iron ($FeCO_3$), 60 mg; copper ($CuSO_4 \cdot 5H_2O$), 8 mg; iodine (KI), 2 mg; selenium (Na_2SeO_3), 0.2 mg.

quadratic components using polynomial trend analysis. Statistical significance was considered at $P < 0.05$. Results are presented as group means and standard error of mean (SEM).

3. Results and discussion

3.1. Nutrient profile

Nutrient contents of different diets used in the study are presented in Table 2. As expected, the fiber component increased with the increasing level of MNC in the diets. The 200 g/kg MNC inclusion had 98.2 g/kg W/W of ADF compared to 39.2 g/kg in the control group in the starter phase and had a proportionately similar difference in the finisher phase. Also, NDF was 141.8, and 162.1 g/kg in 200 MNC included diet, whereas it was 64.8 and 72.2 g/kg for the control group in the starter and finisher phases, respectively. Similarly, lignin increased from 7 g/kg in control to 31.7 g/kg in 200 MNC groups in the starter phase and 7.8–37 g/kg in control and 200 MNC groups, respectively, in the finisher stage. The essential amino acid content of MNC used in this study was found to be similar, as reported in a previous study from our lab (Tiwari and Jha, 2017). The difference was accounted for different batches and sources of macadamia nut and change in its processing conditions in the oil mill.

This study found higher fiber content including ADF, NDF, and lignin in the MNC included feed as well as MNC itself being rich in fiber along with higher crude fat compared to that of corn and SBM. These results are consistent with the findings of Tiwari and Jha (2017). They found total NSP and soluble NSP contents of MNC to be 322 and 118 g/kg, respectively. Tiwari and Jha (2017) evaluated MNC as a potential feed ingredient for swine diets and found that MNC was rich in energy with relatively high *in vitro* nutrient digestibility. Using the same batch of MNC used in the present study, Berrocoso et al. (2017) determined the basic nutrient profile and AMEn content of MNC for broiler chicken to be 12.13 MJ/kg on a DM basis, which is comparable to the AME of conventional feedstuffs used in chicken diets. The present study found the gross energy of MNC to be 18.8 MJ/kg, whereas the study of Tiwari and Jha (2017) found it to be 23.35 MJ/kg on a DM basis, although both studies obtained MNC from the same source. This might be due to the variation in the source of macadamia nuts and the processing techniques applied in the extraction of oil from the nuts, resulting in the difference in the nutrient profile of MNC.

3.2. Growth performance

Growth performance results are presented in Table 3. The broiler chickens fed with different levels of MNC did not differ for BW and ADG from the control group ($P > 0.05$) during both the starter and finisher periods. The ADFI and FCR linearly increased ($P < 0.05$) with an increasing level of MNC. The insignificant differences in BW and ADG among treatments were probably due to higher feed consumption. During the starter phase, ADFI was insignificant up to the inclusion of 150 g/kg MNC and FCR up to 100 g/kg MNC compared to the control diet. In the finisher phase and overall period, ADFI was not different ($P > 0.05$) up to 100 g/kg inclusion level. The FCR in the overall period increased significantly ($P < 0.05$), which was not desirable, but comparing with the control diet in the starter and finisher phase, FCR was not different ($P > 0.05$) up to 100 and 150 g/kg MNC inclusion, respectively. This could be due to an increase in insoluble fiber component of MNC when included in the higher amount that caused an increase in feed intake whereas, when MNC was included in a lower dose, birds consumed a similar amount of feed and gain similar weight as the control group.

Macadamia nut cake being a byproduct of the macadamia nut oil industry is moderately high in protein, energy, and fiber content. Macadamia nut cake mostly contains insoluble fiber, which passes through the small intestine undigested, causes an increase in bulkiness and passage rate (Jha et al., 2019). A previous study had shown that the performance of birds is not affected when insoluble fiber was included in moderate concentration, rather there is a decrease in the nutrient concentration of the diet (Hetland et al., 2002). Van Ryssen et al. (2014) reported that the growth of chickens was not compromised with 100 g/kg MNC inclusion in diets, which is in agreement with this study. Acheampong-Boateng et al. (2016) reported that MNC could substitute SBM up to 25 % as the abdominal fat increases with 50 % MNC inclusion and the growth parameters such as feed intake, final body weight, and weight gain significantly reduced with 100 % substitution of SBM with MNC. A study done with MNC (Sherrod and Ishizaki, 1967) to replace conventional grains with MNC in the ruminant rations can be done up to 90−100 g/kg, whereas increasing beyond that showed a decrease in feed intake. In contrast, the present study found an increase in feed intake with an increase in MNC inclusion in diets. This increase in feed intake could be due to high fiber content that causes relatively high energy demand of the gut to meet the high cell turnover rate (Jha and Berrocoso, 2015). It also increases the passage rate and inhibits digestion and absorption (Jha and Berrocoso, 2015). So, birds might consume more feed to compensate for the nutrient required to maintain body weight gain. As MNC is a relatively inexpensive

Table 3
Growth performance of broiler chickens fed different levels of macadamia nut cake.

Items	MNC 0	MNC 50	MNC 100	MNC 150	MNC 200	SEM	*P* – value	
							Linear	Quadratic
BW, g								
Starter[1]	757	822.67	785	783.33	788.17	23.292	0.757	0.335
Finisher[2]	1759.33	1721.83	1762.33	1755.17	1704.17	40.221	0.550	0.624
Overall[3]	2516	2544.5	2547.5	2538.33	2492.33	48.231	0.729	0.380
ADFI, g								
Starter	48.83^{b}	52.50^{ab}	51.33^{ab}	52.50^{ab}	53.33^{a}	1.072	0.014	0.414
Finisher	126.17^{b}	134.50^{ab}	132.33^{ab}	140.83^{a}	144.50^{a}	3.523	0.001	0.920
Overall	94.33^{b}	101.17^{ab}	100.67^{ab}	106.33^{a}	107.83^{a}	2.221	0.001	0.593
ADG, g								
Starter	35.83	39.17	38.33	37.17	37.83	0.874	0.476	0.096
Finisher	83.67	82	83	83.5	81.17	1.956	0.577	0.804
Overall	60.00	60.83	60.67	60.33	59.33	1.163	0.622	0.387
FCR								
Starter	1.35^{b}	1.34^{b}	1.34^{b}	1.41^{a}	1.41^{a}	0.022	0.014	0.204
Finisher	1.51^{b}	1.64^{ab}	1.60^{b}	1.69^{ab}	1.79^{a}	0.045	0.001	0.657
Overall	1.58^{c}	1.67^{abc}	1.66^{bc}	1.77^{ab}	1.82^{a}	0.036	0.001	0.846

[a,b,c]Means in the same row with different superscripts differ significantly ($P < 0.05$). Starter[1] refers to age of birds from day 1–21, Finisher[2] refers to age of birds from day 22 to 42, and Overall[3] refers to age of birds from day 1 to 42. Overall mortality was <5% throughout the study.

replacement to corn and soybean, it would still be beneficial to include up to 150 g/kg without compromising the growth performance and up to 200 g/kg with a small decrease in growth performance. Although MNC is high in fiber content, there was still no retardation in growth, probably due to the development of well-balanced gut microbiota as a function of fiber fermentation (Jha et al., 2019) and energy provided from their metabolites and high lipid content (Tiwari and Jha, 2017).

4. Conclusions

This study revealed that MNC could be successfully included in the diet to replace conventional feedstuffs like corn and SBM partially. Also, the price and availability of conventional feedstuffs are very fluctuating in the marketplace. The nutrient profile of MNC indicates that it is rich in protein, carbohydrates, lipids, along with minerals and vitamins. Although inclusion at a higher level has some negative effect on the growth performance parameter, including 150 g/kg MNC in the chicken diet can provide appropriate nutrients. Along with growth, the fiber component of MNC could be beneficial from a gut health perspective by influencing the gut microbiota and volatile fatty acid production. Further studies using MNC could provide more insight into this area and help to optimize the inclusion level of MNC for chicken diets.

Author statement

The animal study protocol was approved by the Institutional Animal Care and Use Committee of the University of Hawaii.

Declaration of Competing Interest

None.

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