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Growth performance, serum biochemistry and meat quality traits of Jumbo quails fed with mopane worm (*Imbrasia belina*) meal-containing diets

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ABSTRACT

Alternative protein sources such as mopane worm (*Imbrasia belina*) meal (MWM) are essential for sustainable poultry production. To date, no studies have attempted to investigate the effect of replacing soybean products with MWM in Jumbo quail diets. Thus, this study was designed to investigate the optimum inclusion level of MWM in place of soybean products on feed intake, physiological and meat quality responses of Jumbo quails. A total of 384 two-week-old mixed-gender quails (71.2 ± 5.40 g live-weight) were allotted to four isoproteic and isocaloric dietary treatments formulated by replacing soybean products with MWM at 0 (MWM0), 50 (MWM5), 100 (MWM10), and 150 (MWM15) g/kg. Neither linear nor quadratic effects ($P > 0.05$) were observed for feed intake, physiological responses, carcass traits and internal organs except for large intestines, which linearly decreased ($P < 0.05$) with MWM levels. There were significant quadratic trends for meat redness (a^*), yellowness (b^*) and chroma values in response to MWM levels. No dietary influences ($P > 0.05$) were observed on feed intake, physiological responses, internal organ weights, and carcass and meat quality parameters, except on b^*, chroma and shear force. Diets MWM5 and MWM10 promoted higher ($P < 0.05$) b^* and chroma values than MWM0. Whereas diet MWM5 promoted the highest ($P < 0.05$) shear force (2.39 N) than diets MWM0 and MWM10. We concluded that MWM has the potential to replace soybean products in quail diets without compromising their performance, health and meat quality. An optimum MWM inclusion level could not be determined suggesting that higher levels of MWM should be further investigated.

Introduction

Novel bird species such as the Jumbo quail (*Coturnix coturnix*) has great potential for use in the alleviation of food and nutrition insecurity, particularly in the most disadvantaged parts of the world. Currently, quails are gaining worldwide popularity as a source of high-quality protein in the form of meat and eggs (Genchev, Ribarski, Afanasjev, & Blohin, 2005; Priti & Satish, 2014), and are steadily cementing their place in the poultry industry (Mnisi & Mlambo, 2018a). This could be attributed to their fast growth rates, early sexual maturity, short generation intervals, lower feed and space requirements, high egg production rates, and resistance to several poultry diseases (Huss, Poynter, & Lansford, 2008; Mnisi & Mlambo, 2018b). For optimal performance, quails require a high energy and protein diet with highly digestible essential amino acids (Altine, Sabo, Muhammad, Abubakar, & Saulawa, 2016). Indeed, as with any intensive bird production system, the contribution towards sustainable food and nutrition security depends on innovative and low-cost feeding strategies. For many decades, soybean has been used as a source of high-quality protein in animal diets (Beski, Swick, & Iji, 2015). However, due to its high market prices, the continued use of soybean in animal feeds may reduce the contribution of Jumbo quails to food and nutrition security. The demand for soybean by the animal, food and biofuel industries has increased tremendously in such a way that its production has doubled (Castanheira & Freire, 2013). From an environmental and economic viewpoint, soybean production incurs high variable costs and is highly dependent on the use of fuel, machinery, pesticides and chemical fertilizers (Sharma, 2016; Arrieta, Cuchietti, Cabrol, & González, 2018; Ishiwata & Furuya, 2020). According to Brandão, Clift, Milà, and Basson (2010), the emission of nitrogen oxide from nitrogen fertilizers and mineralization of organic matter is the major contributor of greenhouse gases in soybean production. Indeed, the production of soybean has a larger carbon footprint due to deforestation and other land preparation activities as well as transportation (Castanheira & Freire, 2013). Thus, the

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use of insects as alternative protein sources provide an opportunity to sustainably intensify the production of Jumbo quails with lower environmental footprint (Yen, 2009). Mopane worm (*Imbrasia belina*) is a caterpillar of mopane month (*Lepidoptera*) that grows on mopane trees (*Colophospermum mopane*) in Southern Africa (Gondo, Frost, Kozanayi, Stack, & Mushongahand, 2010). This worm is locally available, accessible and acceptable as source of food and feed (Moyo, Masika, & Muchenje, 2019), and can be used as a source of high-quality protein (55%) (Moreki, Tiroesele, & Chiripasi, 2012). Mopane worm (MW) is a rich source of carbohydrates, lipids, vitamins and minerals (Potgieter, Makhado, & Potgieter, 2012; Chiripasi, Moreki, Nsoso, & Letso, 2013; Kwiri et al., 2014). In addition, the amino acid profile of MWM is high in lysine, methionine, threonine, valine, phenylalanine and tryptophan than soybean (Madibela, Mokwena, Nsoso, & Thema, 2009). Rapatsa and Moyo (2019) reported that MW contain unsaturated oil acids rather than typically fat, which are a good source of fatty acids (oleic linoleic and α-linolenic). Although the occurrence of MW is seasonally, mass rearing methods are currently under investigation (Rapatsa & Moyo, 2019) in order to increase their production under controlled environments or in captivity (Stack et al., 2003). Nonetheless, the use of MW as a sustainable protein source of high biological value in Jumbo quails provide an opportunity to directly or indirectly increase the supply of dietary protein for human consumption. According to Mbhele, Mnisi, and Mlambo, (2019), there is no information on the use of insect meals in Jumbo quail diets, probably because these birds are relatively new entrants into the commercial poultry production sector. Likewise, no studies have attempted to determine the optimal inclusion level of mopane worm meal (MWM) in Jumbo quail diets. This study, therefore, investigated the optimum inclusion level of MWM to partially replace soybean products using physiological and meat quality parameters of Jumbo quails as response indicators. We hypothesized that the inclusion of incremental levels of MWM in place of soybean products would follow a quadratic response in terms of feed intake, growth performance, serum biochemistry, internal organs and carcass and meat quality of Jumbo quails.

Material and methods

Description of study site and ingredients

The study was conducted at Molelwane Research Farm (25°40.459′S, 26°10.563′E) of the North-West University (North West, South Africa). The feeding trial was carried out during summer where ambient temperatures around the area range from 17°C to 37°C. Degutted and dried mopane worms were purchased from street vendors (Gaborone, Botswana). The worms were degutted by pushing the head towards the anus in-between two fingers to remove the undigested material in the gut, and thereafter roasted in a brine for 20 minutes to remove the spines and prevent spoilage. The degutted worms were subsequently sun-dried for a period of four days and thereafter packaged in paper bags. The worms were milled (2 mm; Polymix PX-MFC 90 D) to produce the meal (MWM) prior blending to the other ingredients. Soybean products (soya oilcake and oil crude soya) and all the other feed ingredients were purchased from Nutroteq (Gauteng, South Africa).

Diet formulations

Four isocaloric and isoproteic dietary treatments were formulated by partially replacing soybean products in a commercial grower diet as follows: 1) MWM0 = a commercial grower diet without mopane worm meal, 2) MWM5 = a commercial grower diet in which 50 g/kg of soybean products was replaced with mopane worm meal, 3) MWM10 = a commercial grower diet in which 100 g/kg of soybean products was replaced with mopane worm meal, and 4) MWM15 = a commercial grower diet in which 150 g/kg of soybean products was replaced with mopane worm meal, as shown in Table 1.

Table 1
Ingredient and nutrient profile (g/kg as fed basis, unless stated otherwise) of dietary treatments.

	[1]Diets MWM0	MWM5	MWM10	MWM15
Mopane worm meal	0	50.0	100.0	150.0
Yellow maize	605.5	635.0	664.6	659.0
Soya oil cake 47%	322.8	260.9	199.1	143.3
Oil Crude Soya (Degummed)	29.03	15.04	1.05	0
Di-calcium phosphate	24.51	14.92	5.33	0
Limestone	3.20	9.98	16.77	20.35
Salt-fine	4.39	3.76	3.13	2.51
Kaoline	5.00	5.00	5.00	5.00
Methionine (Dl 98%)	2.18	1.82	1.46	1.14
Lysine (Sint 78%)	0.95	1.18	1.41	1.52
Threonine (98%)	0.25	0.12	0	0
Br Starter	1.00	1.00	1.00	1.00
Choline Cl (60%)	0.70	0.70	0.70	0.70
Coxistac 12	0.50	0.50	0.50	0.50
Sand	0	0	0	14.99
Chemical composition				
Dry matter	879.8	880.4	881.1	885.2
[2]ME (MJ/kg)	12.27	12.25	12.23	12.21
Crude protein	200.0	200.0	200.0	200.0
Crude fat	58.04	50.53	43.01	47.15
Crude fibre	26.76	25.27	23.78	21.63
Calcium	8.0	8.0	8.0	8.0
Phosphorus	8.42	7.38	6.34	6.10
Sodium	1.80	1.80	1.80	1.80
Chlorine	3.32	3.14	2.96	2.74
Potassium	9.26	8.57	7.87	7.19
Methionine	5.24	4.87	4.50	4.14
Cysteine	3.30	3.56	3.82	4.07
Threonine	7.81	7.66	7.52	7.51
Tryptophan	2.28	2.17	2.07	1.98

[1] Diets: MWM0 = a commercial grower diet with no mopane worm meal inclusion, MWM5 = a commercial grower diet in which 50 g/kg of soybean products was replaced with mopane worm meal, MWM10 = a commercial grower diet in which 100 g/kg of soybean products was replaced with mopane worm meal, and MWM15 = a commercial grower diet in which 150 g/kg of soybean products was replaced with mopane worm meal.
[2] ME = metabolisable energy.

Chemical analyses

The MWM was subjected to preliminary analysis for proximate composition using the Official Analytical Chemists International methods (AOAC, 2005) before diet formulations. After formulations, subsamples of the experimental diets (MWM0, MWM5, MWM10 and MWM15) were analyzed using the AOAC methods (AOAC, 2005) for dry matter (method no. 930.15), organic matter (method no. 924.05) and crude protein (method no. 984.13), crude fibre (method no. 978.10) and crude fat (method no. 920.39). The concentrations of calcium, phosphorus, sodium, chlorine and potassium were determined following the Agri Laboratory Association of Southern Africa guidelines (AgriLASA, 1998). Metabolisable energy (ME) and amino acids (lysine, methionine, cysteine, threonine and tryptophan) were predicted using the near-infrared reflectance spectroscopy SpectaStar XL (Unity Scientific, Emu Heights, Australia).

Experimental design and feeding trial

A total of 384, one-week old, unsexed Jumbo quails were purchased from T/A R&G Poultry in Welkom (Gauteng, South Africa). The quails were randomly allocated to 32 replicate pens (experimental unit) made of wire mesh floor without any bedding, with each pen carrying 12 birds that were replicated eight times per dietary treatment. In their replicate pens (100 cm long × 60 cm wide × 30 cm high), the quails were adapted to the dietary treatments and infrared lamps were used to provide warmth until two weeks of age. The average temperature (30°C) and humidity (40%) of the quail house was regularly monitored using a multi-meter device. Fresh, clean water and dietary treatments were offered *ad libitum* during the experimental period, and rearing was conducted under natural lighting (12 h of daylight).

At two weeks of age, initial live-weights were measured and subsequently measured weekly by weighing all the birds in a pen until six weeks of age to determine average weekly body weight gain (ABWG). Average weekly feed intake (AWFI) was measured by subtracting the weight of the feed refusals from that of the feed offered from week 2 to week 6. The ABWG and AWFI were used to determine weekly gain-to-feed ratio (G:F).

Slaughter procedures and serum biochemical analysis

At six weeks of age, the birds were transported to Rooigrond abattoir (North West, South Africa) where they were electrically stunned and slaughtered by cutting the jugular vein with a sharp knife. While bleeding, 2 mL of blood was collected from two randomly selected birds per replicate into sterilized tubes. Clotted blood in the tubes was then centrifuged to generate serum, which was used to determine total protein, glucose, urea, creatinine, calcium, albumin, globulin, phosphorus, bilirubin, serum symmetric dimethylarginine (SDMA), albumin/globulin ratio (ALB/GLOB), alanine transaminase (ALT) and alkaline phosphate (ALKP) using an automated IDEXX Vet Test Chemistry Analyzer (IDEXX Laboratories Inc. Maine, US).

Carcass characteristics and internal organ weights

Hot carcass weight (HCW) was immediately recorded after slaughter and then the carcasses were chilled in a cold-room for 24 h, and thereafter re-weighed to obtain cold carcass weights (CCW). The dressing percentage was calculated as the proportion of HCW on final body weight. Weights of carcass parts (breast, wing, drumstick and thigh) and internal organs (liver, gizzard, proventriculus, small intestine and large intestine) were measured using a digital weighing scale (Explorer® EX224, OHAUS Corp, US) and expressed as proportion of the HCW (g/100 g HCW).

Meat pH, temperature and colour measurements

A portable Corning Model 4 pH-temp meter (Corning Glass Works, Medfield, MA) equipped with an Ingold spear-type electrode (Ingold Messtechnik AG, Udorf, Switzerland) was used to measure pH and temperature 24 h post slaughter around the breast muscle. According to the Commission Internationale de l'Eclairage guidelines (CIE, 1976), color indicators (L^* = lightness, b^* = yellowness, and a^* = redness) were measured 24 h post-mortem on breast muscle using a calibrated Minolta color-guide (BYK-Gardener GmbH, Geretsried, Germany), with a 20 mm diameter measurement area and illuminant D65-day light, 10° observation angle. The color indicators were subsequently used to calculate hue angle and chroma values as described by Priolo, Micol, Agabriel, Prache, and Dransfield (2002).

Cooking loss and shear force

To measure cooking loss, breast meat samples were pre-weighed and thereafter cooked by oven-boiling at 140°C for 20 min (Honikel, 1998). After cooking, the samples were cooled and re-weighed. The loss in weight was expressed as a proportion of the initial sample weight. The cooked breast samples were then mounted on a Texture Analyzer (TA XT plus, Stable Micro Systems, Surrey, UK) and sheared perpendicular to the fibre direction using a Meullenet-Owens Razor Shear Blade (A/MORS) to measure shear force (N).

Water Holding Capacity (WHC) and thawing loss

The WHC was measured as described by Grau and Hamm (1957), where freshly cut slices of breast meat samples (~ 10 g) were placed between a pre-weighed 18 Whatman filter-paper and pressed under a pressure of 60 kg for 5 min using dumbbell weights. The water from the fresh meat samples was absorbed by the filter-paper and calculated as the proportion of the initial breast sample weight. For thawing loss, frozen breast meat samples were weighed and thereafter allowed to thaw by hanging in a vertical chiller for 12 h as described by Ali, Rajput, Li, Zhang, and Zhou (2016). Thawing loss was calculated as a proportion of weight loss on the weight of the breast meat sample before thawing.

Statistical analysis

Data on feed intake, growth performance, serum biochemistry, internal organs, carcass traits, and meat quality were evaluated for linear and quadratic effects using polynomial contrast. A response surface regression analysis (SAS, 2010) was employed to estimate the optimum dietary inclusion level of MWM. Repeated measures procedure of SAS (2010) was used to analyze weekly measured data (AWFI, ABWG, and G:F). Overall feed intake, body weight gain, gain-to-feed ratio, serum biochemical parameters, internal organs, carcass characteristics and meat quality data were analyzed using the general linear model procedure of SAS (2010) in a completely randomized design, with diet as the only main factor. For all statistical tests, significance was declared at $P < 0.05$ and least squares means were compared using the probability of difference.

Results

Repeated measures analysis showed no significant week × diet interaction effect on AWFI, ABWG and average weekly G:F. Neither linear nor quadratic effects ($P > 0.05$) were observed for overall feed intake, overall BWG, overall G:F and final body weight (Table 2). Similarly, no significant dietary effects were observed on overall feed intake and growth performance parameters.

There were no linear or quadratic trends ($P > 0.05$) for serum biochemical parameters in response to incremental levels of MWM (Table 3). Likewise, no dietary influences ($P > 0.05$) were observed on serum biochemistry of Jumbo quails.

Table 4 shows that there were neither linear nor quadratic responses ($P > 0.05$) for internal organ weights and carcass traits, with the exception of large intestines ($P < 0.05$). There were significant linear trends for weights of large intestine [y = 1.089 (± 0.082) - 0.023

Table 2
Effect of partially replacing soybean products with mopane worm meal on overall feed intake (g/bird), overall body weight gain (g/bird), overall gain-to-feed ratio (g:g) and final body weight (g/bird) of Jumbo quails.

	[1]Dietary treatments					Significance	
	MWM0	MWM5	MWM10	MWM15	[2]SEM	Linear	Quadratic
Overall FI	654.9	625.2	645.8	628.0	14.01	0.353	0.680
Overall BWG	171.9	169.0	167.3	161.7	4.510	0.115	0.755
Overall G:F	0.262	0.270	0.260	0.258	0.007	0.447	0.455
Final body weight	247.6	237.6	235.3	234.2	5.009	0.064	0.374

[1] Dietary treatments: MWM0 = a commercial grower diet with no mopane worm meal inclusion, MWM5 = a commercial grower diet in which 50 g/kg of soybean products was replaced with mopane worm meal, MWM10 = a commercial grower diet in which 100 g/kg of soybean products was replaced with mopane worm meal, and MWM15 = a commercial grower diet in which 150 g/kg of soybean products was replaced with mopane worm meal.
[2] SEM = standard error of the mean.

Table 3
Serum biochemical parameters of six-week-old Jumbo quails fed diets containing mopane worm meal in place of soybean products.

[2]Parameters	[1]Dietary treatments				[3]SEM	Significance	
	MWM0	MWM5	MWM10	MWM15		Linear	Quadratic
Glucose (mmol/L)	5.34	4.68	5.37	4.98	1.538	0.959	0.712
Urea (mmol/L)	1.19	1.01	0.98	1.46	0.300	0.612	0.954
Calcium (mmol/L)	3.53	2.99	6.11	3.21	1.473	0.903	0.834
Total protein (g/L)	52.26	49.38	53.31	55.31	3.481	0.417	0.367
Albumin (g/L)	21.31	15.56	19.75	16.69	3.187	0.544	0.702
Globulin (g/L)	37.13	34.31	33.53	38.75	2.082	0.389	0.284
SDMA (µg/dL)	21.13	17.69	17.21	21.56	2.918	0.753	0.071
Creatinine (µmol/L)	12.56	10.81	11.44	9.14	1.549	0.740	0.215
Phosphorus (mmol/L)	6.11	5.16	4.94	5.08	0.559	0.837	0.706
ALB/GLOB	0.44	0.45	0.44	0.44	0.015	1.000	0.461
ALT (U/L)	35.83	50.57	43.00	44.33	12.54	0.967	0.639
ALKP (U/L)	211.1	215.1	219.7	172.9	18.40	0.840	0.072
Bilirubin (µmol/L)	9.14	11.25	10.79	13.29	3.135	0.506	0.982

[1] Dietary treatments: MWM0 = a commercial grower diet with no mopane worm meal inclusion, MWM5 = a commercial grower diet in which 50 g/kg of soybean products was replaced with mopane worm meal, MWM10 = a commercial grower diet in which 100 g/kg of soybean products was replaced with mopane worm meal, and MWM15 = a commercial grower diet in which 150 g/kg of soybean products was replaced with mopane worm meal

[2] Parameters: ALB/GLOB = albumin/globulin ratio, ALKP = alkaline phosphatase, ALT = alanine aminotransferase, SDMA = serum symmetric dimethylarginine.

[3] SEM = standard error of the mean.

(± 0.026) x; R^2 = 0.1379; P = 0.040] in response to MWM level. There were no significant dietary effects on carcass characteristics and internal organ weights of Jumbo quails.

No linear or quadratic effects ($P > 0.05$) were observed for breast meat pH, temperature, lightness and hue angle with MWM levels (Table 5). Quadratic trends ($P < 0.05$) were observed for a^* [$y = 4.66$ (± 0.185) + 0.151 (± 0.059) x - 0.008 (± 0.004) x^2; R^2 = 0.118], b^* [y = 8.83 (± 0.236) + 0.306 (± 0.0758) x - 0.017 (± 0.005) x^2; R^2 = 0.094] and chroma [y = 0.343 (± 0.075) x + 10.0 (± 0.234) - 0.019 (± 0.005) x^2; R^2 = 0.312] in response to increasing levels of MWM. Dietary treatments had no significant effect on pH, temperature, L^*, a^* and hue angle, but had influenced ($P < 0.05$) b^* and chroma. Quails on diets MWM5 and MWM10 had higher ($P < 0.05$) b^* and chroma values than those fed the control treatment MWM0. There were no differences ($P > 0.05$) among quails fed the MWM-containing diets in terms of b^* and chroma values. However, quails on diet MWM0 had similar ($P > 0.05$) b^* and chroma values than those on diet MWM15.

Likewise, no linear or quadratic effects ($P > 0.05$) were observed for cooking loss, shear force, thawing loss and WHC. With the exception of shear force ($P < 0.05$), no significant dietary influences were observed on cooking loss, thawing loss and WHC. Diet MWM5 promoted the highest ($P < 0.05$) shear force (2.39 N) than diets MWM0 and MW10, which did not differ ($P > 0.05$). Quails on the control treatment MWM0 had the same ($P > 0.05$) shear force as those on diets MWM10 and MWM15. Diet MWM5 promoted similar ($P > 0.05$) shear force as diet MWM15.

Discussion

To this end, soybean meal has been criticized for high market prices, generation of high land-use competition and significant environmental deterioration (Arru, Furesi, Gasco, Madau, & Pulina, 2019). In other reports, the continued use of soybean as a protein source in poultry diets would be a major setback for sustainable intensification (Mnisi & Mlambo, 2018b) and economic sustainability (Arru, Furesi, Gasco, Madau, & Pulina, 2019). Thus, insect meals are proposed alternatives to soybean meal because their production requires less water and land occupation, with lower greenhouse gas emissions. According to Gasco et al. (2018), insect-derived products have a higher biological value than soybean, and are characterized by a higher protein content

Table 4
Carcass characteristics and internal organ weights (g/100 g HCW, unless stated otherwise) of Jumbo quails fed diets containing mopane worm meal in place of soybean products.

	[1]Dietary treatments				[4]SEM	Significance	
	MWM0	MWM5	MWM10	MWM15		Linear	Quadratic
Dressing (%)	65.30	68.05	65.25	67.24	1.259	0.609	0.777
[2]HCW (g)	161.2	161.7	153.2	157.7	3.670	0.265	0.593
[3]CCW (g)	159.8	161.4	153.2	154.3	3.340	0.113	0.955
Thigh	6.26	6.20	6.20	5.86	0.186	0.157	0.453
Wing	4.38	4.38	4.21	4.24	0.138	0.343	0.931
Drumstick	4.01	4.10	3.90	3.98	0.097	0.491	0.947
Breast	21.78	21.77	20.95	20.96	1.095	0.503	0.990
Liver	3.23	3.01	3.68	3.36	0.198	0.267	0.831
Gizzard	2.30	2.13	2.38	2.25	0.089	0.824	0.854
Proventriculus	0.56	0.56	0.46	0.52	0.045	0.270	0.496
Small intestine	4.29	4.50	4.30	4.21	0.276	0.728	0.596
Large intestine	1.11	0.92	0.97	0.82	0.084	0.040	0.808

[1] Dietary treatments: MWM0 = a commercial grower diet with no mopane worm meal inclusion, MWM5 = a commercial grower diet in which 50 g/kg of soybean products was replaced with mopane worm meal, MWM10 = a commercial grower diet in which 100 g/kg of soybean products was replaced with mopane worm meal, and MWM15 = a commercial grower diet in which 150 g/kg of soybean products was replaced with mopane worm meal.

[2] HCW = hot carcass weight

[3] CCW = cold carcass weight

[4] SEM = standard error of the mean.

Table 5
Meat quality parameters of Jumbo quails fed diets containing mopane worm meal in place of soybean products.

	[1]Dietary treatments				[3]SEM	Significance	
	MWM0	MWM5	MWM10	MWM15		Linear	Quadratic
pH	5.32	5.49	5.42	5.60	0.084	0.055	0.913
Temperature (°C)	15.18	16.80	14.65	14.77	0.911	0.425	0.428
*L** (lightness)	51.32	51.87	50.77	50.86	0.743	0.462	0.762
*a**(redness)	4.70	5.10	5.50	5.10	0.190	0.070	0.046
*b** (yellowness)	8.74[a]	10.20[b]	9.89[b]	9.60[ab]	0.235	0.046	0.001
Chroma	9.94[a]	11.41[b]	11.33[b]	10.87[ab]	0.239	0.018	0.000
Hue angle	1.08	1.11	1.06	1.08	0.017	0.695	0.781
Cooking loss (%)	16.60	17.84	16.02	16.34	1.131	0.614	0.684
Shear force (N)	2.18[a]	2.39[b]	2.14[a]	2.23[ab]	0.048	0.732	0.318
Thawing loss (%)	3.42	3.38	3.29	3.30	0.170	0.547	0.879
[2]WHC (%)	6.30	5.63	5.72	5.50	0.307	0.103	0.470

[1]Dietary treatments: MWM0 = a commercial grower diet with no mopane worm meal inclusion, MWM5 = a commercial grower diet in which 50 g/kg of soybean products was replaced with mopane worm meal, MWM10 = a commercial grower diet in which 100 g/kg of soybean products was replaced with mopane worm meal, and MWM15 = a commercial grower diet in which 150 g/kg of soybean products was replaced with mopane worm meal.
[2]HCW = water holding capacity
[3]SEM = standard error of the mean.

(45 – 70%) and a well-balanced amino acid profile. Still, the use of MWM has not been investigated in Jumbo quail diets, with too much attention directed to the use of houseflies (*Musca domestica L.*), yellow mealworm (*Tenebrio molitor L.*) and black soldier fly (*Hermetia illucens L.*) in broiler chickens (Hwangbo et al., 2009; Bovera et al., 2015; Biasato et al., 2017) and, to a limited degree, in quails (Zadeh, Kheiri, & Faghani, 2019; Mbhele, Mnisi, & Mlambo, 2019). In this study, repeated measures analysis revealed no significant diet and week interaction effects on weekly measured parameters (feed intake, body weight gain, and gain-to-feed ratio), demonstrating that the inclusion of MWM had no influence on the performance of the birds as they grew older. Similarly, no linear and quadratic trends were observed for overall feed intake and growth responses indicating that MWM promotes similar performance as the soybean control diet without compromising the performance of the birds. Indeed, no dietary influences were observed on overall feed intake and growth traits. These findings were in line with those of many authors who reported a lack of differences on growth performance of various poultry species when soybean meal was replaced with various insect meals (Maurer et al., 2016; Biasato et al., 2016; Cullere et al., 2018; Elahi et al., 2020). Contrary to our findings, several studies have reported that the inclusion of insect meals improves the bird performance (Mareko, Nsoso, Mosweu, Mokate, & Madibela, 2010; Mbhele, Mnisi, & Mlambo, 2019; Zadeh, Kheiri, & Faghani, 2019). Nonetheless, it is worth noting that the nutritive value of these meals vary by species, life stage and rearing condition, which could explain the wide variability of the reported results (Zadeh, Kheiri, & Faghani, 2019). Serum biochemical indices serve as indicators that are used to clinically monitor the pathophysiological status of animals. In this study, adding MWM in place of soybean products did not alter the pathophysiology of the birds. In addition, the serum biochemical values fell within the normal range reported for healthy quails (Mnisi & Mlambo, 2018a; Mbhele, Mnisi, & Mlambo, 2019). Indeed, no differences were observed particularly on serum total protein as well as the liver enzymes (ALT and ALKP), further verifying that the inclusion of MWM did not compromise the health status of the birds. Weight of large intestines linearly decreased with incremental levels of MWM inclusion, which was surprising as it was expected that the birds would have enlarged large intestines as an anatomical adaptation mechanism to utilize chitin, a fibrous substance, present in insect meals (Bovera et al., 2015). Nonetheless, dietary treatments had no influence on carcass characteristics and internal organ weights of Jumbo quails. These findings were consistent with those of other authors who found that inclusion of insect meals in place of soybean meal had no effect on relative weights of internal organs (Zadeh, Kheiri, & Faghani, 2019) and carcass traits (Elahi et al., 2020). Despite the nutritional properties of MW, its effect on quail meat quality has not been investigated. We found that inclusion of MWM had no effect on meat pH, temperature, water retention, cooking and thawing losses, which was in agreement with the findings of Mbhele, Mnisi, and Mlambo (2019) and Elahi et al. (2020), who reported a lack of dietary effect on meat quality. Replacing soybean products with MWM had effect on meat yellowness, chroma and shear force values. Although mopane worms are rich in carotenoids, which may have influenced the pigmentation thus altering the color of the meat, we are unable to explain why quails in the control group had the same yellowness and chroma values as those in treatment MWM15. Thus, further research is required to fully understand the effect of MWM in quail meat. It is not clear why quails fed diet MWM5 had a higher shear force value than those fed with diets MWM0 and MW10, given that diet MWM5 promoted the same shear force as diet MWM15, which was also similar to the control treatment MWM0. This could have been a measurement error because birds in the control diet had similar shear force as those in diets MWM10 and MWM15.

Conclusion

Results from this study showed that partial replacement of soybean products with mopane worm meal had no effect on the physiological response of Jumbo quails, but influenced some meat quality attributes. We concluded that MWM has the potential to replace soybean meal in quail diets without compromising their performance and health status. An optimum MWM inclusion level could not be determined suggesting a need to further investigate the effect of MWM at higher inclusion levels. Further studies can also be designed to investigate economical evaluation for replacing soybean products with MWM.

Ethical approval

The procedures used to conduct the feeding trial and slaughter the birds were approved by the Animal Research Ethics Committee of the North-West University (approval no: NWU-01885-19-S5).

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Declaration of Competing Interest

The authors declare no conflicts of interest.

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