ISSN 1682-8356
ansinet.org/ijps

INTERNATIONAL JOURNAL OF POULTRY SCIENCE

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International Journal of Poultry Science 12 (1): 19-28, 2013
ISSN 1682-8356

Effect of Feeding *Mopane* Worm Meal on Mineral Intake, Retention and Utilization in Guinea Fowl under Intensive System

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Abstract: This study investigated the mineral intake, utilization and retention of guinea fowl fed varying levels of *mopane* worm meal as a protein source under intensive system up to 13 weeks of age. Ninety-six day old keets were randomly assigned to four dietary treatments each having four replicates (n = 6/replicate). The four treatments were 3% fishmeal (control), 4.5% *mopane* worm meal, 9% *mopane* worm meal and 13.5% *mopane* worm meal. At 7 and 13 weeks of age, blood and faecal samples were collected from three randomly selected birds from each replicate and analyzed for minerals. At 13 weeks of age, all birds were sacrificed and left tibiae collected for determination of bone physical dimensions and mineral composition. Meat samples were collected from the thighs and decomposed by microwave digestion and analyzed for various minerals. Data were regarded as a split plot design with four dietary treatments and analyzed using the General Linear Model Procedures in Statistical Analysis System. Dietary treatment had no significant ($P>0.05$) effect on bone length. Bone weights for birds fed 9% *mopane* worm meal and bone widths for birds fed 4.5% *mopane* worm meal had lower weights (5.96 g) and widths (5.79 mm) than the other three treatments which did not differ significantly from each other. Bone mineral composition of guinea fowl fed diets with 4.5% *mopane* meal had significantly higher P (353.62 mg/l), Na (1332.96 mg/l) and K (1841 mg/l) contents than other treatment diets where the control and 13.5% *mopane* worm meal diets did not differ significantly. Generally, meat and blood mineral compositions of guinea fowl fed 4.5% *mopane* worm meal were higher than those fed on 13.5% *mopane* worm meal diet whilst control and 9% *mopane* worm meal were the same. Dietary treatments and age had a significant ($P<0.05$) effect on the daily mineral intake, faecal excretions and retention as percentage of mineral intake. Blood mineral composition and mineral retention increased with age as more minerals were required to support growth. Diets containing 3% fishmeal, 4.5% *mopane* meal and 9% *mopane* meal generally promote higher mineral intakes, bone physical development, bone and meat mineral compositions and retentions compared to 13.5% *mopane* worm meal. Results from the present study suggest that *mopane* worm meal can replace fishmeal up to 9% without negatively affecting mineral intake, retention and utilization.

Key words: Bone dimensions, mineral intake, mineral retention, *mopane* meal, utilization

INTRODUCTION

Mopane worms (*Imbrasia belina*) are caterpillars of the *mopane* moth which is commonly found in the warmer parts of southern Africa (Botswana, Namibia, South Africa and Zimbabwe). The caterpillars feed on leaves of the *mopane* trees (*Colophospermum mopane*) which are abundant in these areas (Gondo *et al*., 2010). The moth can also survive on other indigenous trees found in the *mopane* woodlands including leaves of a mango tree.

Mopane worm production is seasonal and mostly occurs during the rainy season, i.e., from December to January and April to May (Hope *et al*., 2009). As a result, the availability of the *mopane* worms relies mainly on the amount of rainfall which will promote the vegetative production of *mopane* trees. Seasonal and climatic changes are a major threat to the availability of *mopane* worms. *Mopane* worms face a threat of over exploitation due to minimal restrictions in collection and trade of the worms coupled with increasing incidence of poverty in countries where the worms are found (Akpalu *et al*., 2007; Gondo *et al*., 2010). Therefore, policies and resource management frameworks for the sustainable use of *mopane* worms that incorporate both conservation and livelihood objectives of *mopane* worm resource users have to be put in place in order to overcome over exploitation of *mopane* worms.

Mopane meal is *mopane* worms harvested at larval stage, sun dried and then milled to be incorporated in animal diets. Madibela *et al*. (2009) stated that the chemical composition of *mopane* worms has to be documented to fully utilize the resource. The nutritive significance of *mopane* worms as feed for livestock including guinea fowl in Botswana could be cost

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effective compared to the conventional fishmeal which is imported from South Africa and Namibia at exorbitant prices. This study was carried out to determine the mineral intake, utilization and retention of varying levels of *mopane* worm meal fed to guinea fowl reared under the intensive rearing system.

MATERIALS AND METHODS

The experiment was carried out at the Guinea Fowl Unit of the Botswana College of Agriculture (BCA), Sebele from February to May 2011. The site is located on 24° 33' S, 24° 54' E and is at an altitude of 994 m above sea level. The average annual rainfall is 450 mm and the mean daily temperature is 30°C (Aganga and Omphile, 2000).

Animal management: A total of 96 day old keets were obtained from BCA hatchery unit and randomly assigned to four dietary treatments, each having four replicates (6 birds/replicate). The four treatments were 3% fishmeal (control), 4.5% *mopane* meal, 9% *mopane* meal and 13.5% *mopane* meal. The initial weights of birds were determined by weighing 20% of the birds at placement (i.e., at day old) and the coefficient of variation of the flock determined. Keets were reared in a closed room with air conditioning from day old to four weeks of age. Each treatment was placed in 1×0.7×1.2 m wooden pen with wood shavings as litter material. The brooder was maintained at a temperature of 36°C and lighting provided for 24 hours a day for one week. Thereafter, lighting was reduced to 23 hours a day and temperatures reduced gradually until 25°C. At two weeks of age, keets were vaccinated against Gumburo and Newcastle disease. Keets were individually tagged at four weeks of age and transferred to an open-sided house. Each replicate was housed in a 1.8×1.6 m wire mesh fenced pen with wood shavings used as litter on concrete floors. Each pen was equipped with a 20 liter drinker and a 10 kg feeder. Vitamin and mineral supplement (Phenix stresspac) was added to drinking water during the first five days of age and during placement. The house curtains were raised during the day for natural lighting and closed at night for protection against cold conditions.

Diets: Birds were fed two diets during the two feeding phases namely starter with 24% crude protein from 0 to 7 weeks and finisher with 17% crude protein from 8 to 13 weeks of age. Diets were formulated according to the Botswana standard for guinea fowl (BOS 234:2006). Experimental diets were analyzed for energy, protein and minerals to ensure accurate diet formulation. Diets for each feeding phase were isocaloric and isonitrogenous (Table 1 and 2). Keets were provided with feed and water *ad libitum* throughout the experimental period.

Data collection: Feed intake was measured by giving pre-weighed feed allocations to each replicate group throughout the week and unconsumed feed weighed back at the end of the week. Pen Body Weights (BW) were also recorded on weekly basis. Bird's mineral intake was calculated by multiplying percentage of minerals in the feed by feed intake (Moreki *et al*., 2011b). Feed samples were collected and oven dried at 60°C for 24 hours to determine dry matter content. After drying, the feeds were digested using the Ethos 1 Advanced Microwave digestion System. The digesta was then analyzed for minerals as described by Association of Official Analytical Chemists (A.O.A.C., 1996).

At 7 and 13 weeks of age, blood samples were collected from the radial vein of three randomly selected birds from each replicate (i.e., 12 birds/treatment) using 21 gauge needles. The radial vein was raised by pressing the interior side of the wing with a thumb then inserting the needle into the vein. About 10 ml of blood was collected into plain vacutainer tubes and the serum separated immediately after clotting. The serum was stored at -20°C until further analysis (Onyeanusi, 2007). Thereafter, stored serum samples were thawed and 1 ml of the serum was digested in a microwave with 5 ml of 70% nitric acid and 2 ml of deionized water. After digestion the volume was made to 100 ml with deionized water. The mixture was then used for mineral analysis.

Faecal samples from the randomly selected birds were collected at 7 and 13 weeks of age. Birds were individually caged where lighting was reduced for approximately 15 minutes until sufficient excreta were collected in metal trays (minimum of 5 g per bird). Following faecal collection, birds were returned to their original pens. Faecal matter was dried in the oven at 100°C for 24 hours and air cooled and thereafter dry matter was determined. The faecal matter was then pulverized using laboratory mill with a 1 mm sieve and homogenized by thoroughly mixing before taking a representative sample for determination of minerals. Approximately 1 g sample of faecal material was then ashed in a muffle furnace at 550°C for 8 hours until a white or grey ash residue was obtained. The ash sample was cooled in a desiccator. The residue was dissolved in 5 ml of 25% nitric acid and when necessary, the mixture was heated slowly to dissolve the residue. The solution was transferred to a 100 ml volumetric flask and made up to volume with deionized water before mineral analysis (Moreki *et al*., 2011b). Mineral retention was calculated by subtracting faecal mineral content from the guinea fowl mineral intake. Mineral retention was expressed as a percentage of each mineral intake. At 13 weeks of age, all the birds were slaughtered by stunning at the BCA slaughter house and carcasses stored at 0°C in the cold room and the tibiae removed the next day. The bones were excised and defleshed

Table 1: Nutrient composition of guinea fowl starter diet fed from 0 to 7 weeks of age reared under the intensive system

	0 to 7 weeks			
Age of birds	24	24	24	24
Crude protein (%)	Fishmeal	*Mopane*	Worm	meal
Treatments	Control	1	2	3
Inclusion levels (%)	3%	4.5%	9%	13.5%
Ingredients				
Yellow maize (9% CP)	46.29	46.64	49.29	51.91
Soy bean meal (38% CP)	46.61	44.76	37.61	30.49
Fishmeal (60% CP)	3.0	-	-	-
Phane meal (55% CP)	-	4.5	9.0	13.5
Dehydrated alfalfa (16% CP)	2.0	2.0	2.0	2.0
Dicalcium phosphate (%)	0.35	0.35	0.35	0.35
Vitamin/ mineral premix (%)	1.5	1.5	1.5	1.5
Iodized salt (%)	0.25	0.25	0.25	0.25
Antibiotics and coccidiostat (%)	+	+	+	+
Total	100	100	100	100
Calculated Composition				
Metabolizable Energy (MJ/kg)	12.97	12.97	12.97	12.97
Crude protein (%)	24	24	24	24
Calcium (%)	0.90	0.90	0.90	0.90
Total phosphorus (%)	0.70	0.70	0.70	0.70
Available phosphorus (%)	0.55	0.55	0.55	0.55

Table 2: Nutrient composition of guinea fowl finisher diet fed from 8 to 13 weeks of age reared under the intensive system

	8 to 13 weeks			
Age of birds	17	17	17	17
Crude protein (%)	Fishmeal	*Mopane*	worm	meal
Treatments	Control	1	2	3
Inclusion levels (%)	3%	4.5%	9%	13.5%
Ingredients				
Yellow maize (9% CP)	70.41	70.79	73.41	76.06
Soy bean meal (38% CP)	22.49	20.26	13.49	6.34
Fishmeal (60% CP)	3.0	-	-	-
Phane meal (55% CP)	-	4.5	9.0	13.5
Dehydrated alfalfa (16% CP)	2.0	2.0	2.0	2.0
Dicalcium phosphate (%)	0.35	0.35	0.35	0.35
Vitamin/ mineral premix (%)	1.5	1.5	1.5	1.5
Iodized salt (%)	0.25	0.25	0.25	0.25
Antibiotics and coccidiostat (%)	+	+	+	+
Total	100	100	100	100
Calculated Composition				
Metabolizable Energy (MJ/kg)	12.97	12.97	12.97	12.97
Crude protein (%)	17	17	17	17
Calcium (%)	0.90	0.90	0.90	0.90
Total phosphorus (%)	0.70	0.70	0.70	0.70
Available phosphorus (%)	0.55	0.55	0.55	0.55

without boiling. Thereafter, bones were weighed using an electronic balance with accuracy 0.001 grams. The bones were analyzed for physical bone characteristics (weight, length and bone shaft width) using an electronic calliper with an accuracy of 0.001 cm (Moreki, 2005). Thereafter, bone samples were then ashed in a muffle furnace at 550°C for 8 hours. Approximately 1 g of ash samples was then dissolved in 10 ml of 3M hydrochloric acid and boiled for 10 minutes. The samples were allowed to cool and filtered into a 100 ml volumetric flask. Thereafter, the volume was topped to 100 ml with deionized water and analyzed for minerals (Bao *et al.*, 2007).

Meat samples were collected from the thighs of the carcasses and decomposed by microwave digestion method for the analysis of various minerals. A known quantity, approximately 1 g of each sample was digested with 5 ml of concentrated HNO_3 and 2 ml of deionized water for 30 minutes in a microwave digestion system. The digesta was allowed to cool and filtered into a

100 ml volumetric flask. The volume was topped to 100 ml with deionized water and analyzed for minerals.
A Perkin Elmer ICP-Optical Emission Spectrometer Optima 7300 DV Series was used to determine Ca, Mg, Cu, Fe, Mn, K, Na and Zn and UV flame photometer was used to estimate P (AOAC, 1996).

Statistical analyses: Data were analyzed using the General Linear Model Procedures in Statistical Analysis System (SAS, 2003). In this analysis, data were regarded as a split plot design with four dietary treatments being the main plots and age as sub plots. The following model was used:

$$Y_{ijkl} = \mu + A_i + A_{ij} + B_k + (AB)_{jk} + E_{ijkl}$$

where, Y_{ijkl} = response variables (bone width, bone weight, bone length, bone mineral composition, blood mineral composition, meat mineral composition and mineral retention); μ = general mean; A_i = effect of treatment diet; A_{ij} = treatment error; B_k = effect of age; $(AB)_{jk}$ = interaction between treatment and age; E_{ijkl} = residual error.
The reported Least Squares Means were separated using the Dunnett's mean separation test (Dunnett, 1955). Significance was declared at $P<0.05$.

RESULTS AND DISCUSSIONS

Bone physical dimensions: Dietary treatment had no significant ($P>0.05$) effect on bone length (Table 3). Birds fed 4.5% *mopane* worm meal had lower bone width (5.79 mm) compared to other treatment diets. In addition, bone widths for birds fed control diet, 9% and 13.5% *mopane* worm meal did not differ significantly. Bone weights were significantly influenced by dietary treatments with birds fed 9% *mopane* worm meal having the lowest weight of 5.96 g than the other three treatments which were not significantly different from each other (Table 3). This result suggested that the diet containing 4.5% *mopane* worm meal promoted more bone mineral deposition resulting in heavier weights than the other treatment diets. The bone dimensions in this study are considerably lower than those reported by Moreki and Kelemogile (2012). The authors reported bone length, width and weight of 109.00 mm, 6.57 mm and 9.07 g, respectively at 12 weeks. The difference in the results of the current study and that of Moreki and Kelemogile (2012) may be attributable to differences in dietary treatments. The study of Moreki and Kelemogile (2012) used different cereal grains (millet, sorghum and maize) as sources of energy and fishmeal as a protein source. Millet and sorghum contain more Ca, P, K, Mg, Cu and Zn (NRC, 1994) thus resulting in higher mineral intakes and bone mineral deposition than maize based diets.

Bone mineral composition: No significant difference in Ca and Mn levels between treatments was observed (Table 4). Bone mineral composition of guinea fowl fed diets with 4.5% *mopane* worm meal had significantly higher P (35362 mg/l), Na (1332.96 mg/l) and K (1841 mg/l) than other treatment diets. However, the bone P, Na and K concentrations in guinea fowl fed the control and 13.5% *mopane* worm meal diets did not differ significantly. Bones from guinea fowl fed control diets contained more Cu (13.45 mg/l) compared to other three treatments. In addition, bones from birds fed 13.5% *mopane* worm meal diet had the lowest Cu (6.47 mg/l) content whilst 4.5% *mopane* worm meal and 9% *mopane* worm meal diets did not differ significantly. Magnesium bone content for birds fed control, 9% and 13.5% *mopane* worm meal diets did not differ significantly and were significantly higher than the 4.5% *mopane* worm meal (603.57 mg/l). The bone Fe content was highest (204.64 mg/l) in birds fed 13.5% *mopane* worm meal probably due to the relatively higher daily mineral intakes (0.1577 to 0.2347 g/day) in the treatment diet. The current results are inconsistent with Moreki *et al*. (2011a) who found 28.92% and 16.75% bone Ca and P, respectively in broiler breeder pullets at 12 weeks. The higher mineral values in the bones reported by the authors may be due to higher daily mineral intakes and differences in bird species. In the present study, birds fed 13.5% *mopane* worm meal generally had no significant difference in bone mineral composition compared to other treatment diets indicating that there are no positive benefits in bone mineralization realized by increasing *mopane* worm meal concentration to 13.5% in guinea fowl diets. *Mopane* worm meal is high in chitin making it highly unpalatable and poorly digestible (Madibela *et al*., 2007) leading to reduced feed intake and reduced bone mineralization at high concentration. Calcium, P and Mg are required as structural components of the skeleton (McDonald *et al*., 2002) hence high concentrations of these elements in this study.

Meat mineral composition: Potassium, Cu and Fe contents of the meat did not differ significantly between treatments (Table 5). The meat of guinea fowl fed a diet containing 4.5% *mopane* worm meal had significantly higher Ca (154.81 mg/l) than other treatments whilst the 9 and 13.5% *mopane* worm meal Ca contents did not differ. The Ca mean value (102.92 mg/l) obtained in this study compared favourably with the value obtained by Tlhong (2008) who reported Ca value of 15.87 mg/100 g. Values for other elements in the current study were higher than those reported by Tlhong (2008). The differences in results may be due to the differences in treatment diets used in both studies. Mareko *et al*. (2008) reported Ca and P values ranging from 0.14 to 0.16% and 1.81 to 2.55%, respectively in guinea fowl

Table 3: Effect of dietary treatments on bone dimensions of guinea fowl at 13 weeks reared under the intensive system

			Significance of effect (P)		
Variable	Treatment	Means	General mean	Treatment	CV
Length (mm)	Control	78.574^{a}±0.6830	77.42	0.1249	3.18
	4.5% *Mopane* worm meal	77.445^{a}±0.7425			
	9.0% *Mopane* worm meal	77.316^{a}±0.8208			
	13.5% *Mopane* worm meal	76.020^{a}±0.7787			
Width (mm)	Control	6.858^{a}±0.1127	6.691	0.0001	6.077
	4.5% *Mopane* worm meal	5.791^{b}±0.1225			
	9.0% *Mopane* worm meal	6.996^{a}±0.1355			
	13.5% *Mopane* worm meal	7.189^{a}±0.1285			
Weights (g)	Control	6.963^{a}±0.2176	6.743	0.0178	11.63
	4.5% *Mopane* worm meal	7.021^{a}±0.2365			
	9.0% *Mopane* worm meal	5.968^{b}±0.2615			
	13.5% *Mopane* worm meal	6.848^{a}±0.2481			

^{ab}Means in the same column within a parameter with different superscripts differ significantly; p<0.05; CV: Coefficient of variation

Table 4: Effect of dietary treatments on bone chemical composition of guinea fowl at 13 weeks of age reared under the intensive system

					Significance of effect (P)		
Mineral (mg/l)	Treatments Control	4.5% *Mopane* worm meal	9.0 % *Mopane* worm meal	13.5 % *Mopane* worm meal	Means	Treatment	CV
Ca	148700^{a}±5637.01	146018^{a}±6128.00	165067^{a}±6774.84	159855^{a}±6427.19	154033.7	0.1261	13.19
P	30892^{ab}±14.36	35362^{a}±15.62	27907^{b}±17.26	30693^{ab}±16.38	31364	0.0215	16.51
Na	16.79^{c}±15.10	1332.96^{a}±16.42	239.95^{b}±18.15	23.79^{c}±17.22	401.82	0.0001	13.55
Mg	659.60^{a}±7.20	603.57^{b}±7.83	658.84^{a}±8.66	655.82^{a}±8.21	644.22	0.0001	4.03
K	99.51^{c}±55.31	1841.00^{a}±60.13	536.39^{b}±66.48	224.30^{c}±63.07	665.46	0.0001	19.96
Zn	251.32^{ab}±16.83	127.37^{c}±18.29	201.11^{b}±20.22	291.01^{a}±19.18	218.33	0.0001	17.78
Mn	17.15^{a}±1.25	17.44^{a}±1.36	18.58^{a}±1.50	20.54^{a}±1.43	18.31	0.3057	14.67
Cu	13.45^{a}±0.70	9.04^{b}±0.76	9.24^{b}±0.84	6.47^{c}±0.79	9.82	0.0001	15.76
Fe	145.80^{b}±8.29	169.69^{b}±9.00	154.47^{b}±9.99	204.64^{a}±9.43	167.4	0.0003	17.83

^{ab}Means in the same row with different superscripts in a row differ significantly; p<0.05; CV: Coefficient of variation

Table 5: Effect of dietary treatments on meat mineral composition of guinea fowl at 13 weeks reared under the intensive system

					Significance of effect (P)		
Mineral (mg/l)	Treatments Control	4.5% *Mopane* worm meal	9.0 % *Mopane* worm meal	13.5 % *Mopane* worm meal	Means	Treatment	CV
Ca	114.30^{b}±11.03	154.81^{a}±11.03	68.25^{c}±11.03	74.32^{c}±11.03	102.92	0.0001	17.12
P	33.00^{a}±0.092	25.50^{b}±0.092	32.00^{a}±0.092	31.10^{a}±0.092	30.40	0.0001	10.42
Na	590.32^{b}±35.82	676.79^{b}±35.82	60.17^{c}±35.82	884.82^{a}±35.82	553	0.0001	12.43
Mg	19.62^{c}±14.95	239.99^{a}±14.95	240.77^{a}±14.95	132.24^{b}±14.95	158.15	0.0001	12.74
K	2423.57^{a}±40.33	2368.16^{a}±40.33	2361.47^{a}±40.33	2415.52^{a}±40.33	2392.18	0.6026	5.84
Zn	22.02^{b}±2.33	23.05^{b}±2.33	23.59^{b}±2.33	32.87^{a}±2.33	25.38	0.0064	21.78
Mn	4.41^{a}±0.45	2.62^{b}±0.45	2.62^{b}±0.45	4.11^{a}±0.45	3.43	0.009	25.93
Cu	9.36^{a}±0.64	8.13^{a}±0.64	9.16^{a}±0.64	8.03^{a}±0.64	8.67	0.332	15.24
Fe	23.41^{a}±2.35	25.47^{a}±2.35	19.39^{a}±2.35	21.94^{a}±2.35	22.55	0.3248	16.04

^{ab}Means in the same row with different superscripts in a row differ significantly; p<0.05; CV: Coefficient of variation

raised on concrete and earth floors from 16 to 24 weeks. Both Ca and P are the major structural elements with 99% of the Ca in the body found in the skeleton (Church and Pond, 1978). This explains why the Ca content in guinea fowl meat was lower than in the bone. Magnesium content was also highest (239.99 mg/l) in the meat of guinea fowl fed 4.5% *mopane* worm meal and lowest (19.62 mg/l) in the control diet. On the other hand, the meat of guinea fowl fed 4.5% *mopane* worm meal had the lowest P (25.50 mg/l) compared to other treatments which did not differ significantly. No significant differences were noted in the Mn contents in meat between birds fed control (4.41 mg/l) and 13.5% *mopane* worm meal (4.11 mg/l) diets which were also higher than 2.62 mg/l in both 4.5% and 13.5% *mopane* meal diets. Guinea fowl meat contained an average of 22.55 mg/l Fe which was considerably higher than other trace minerals. The high Fe content in this study may be due to freezing meat prior to analyses resulting in the release of haemoglobin from red blood cells of the bone marrow and also high myoglobin levels in the muscle of guinea fowl (Lombardi-Boccia *et al*., 2005). Significant differences in Na level between the treatment diets were noted. Birds fed 13.5% *mopane* worm meal had significantly higher Na (884.82) and Zn (32.87 mg/l) content in the meat than other treatments which did not differ significantly (Table 5). Sodium is contributed to the meat by consumption of feed high in Na. The diet

Table 6: Effect of dietary treatments on blood mineral composition of guinea fowl at 7 and 13 weeks reared under the intensive system

	Treatments	4.5%		9.0% *Mopane*			13.5% *Mopane*		Significance of effect (P)			
Mineral	Control	*Mopane* meal	worm	worm meal			worm meal		--			
(mg/L)	7 weeks	13 weeks	7 weeks	13 weeks	7 weeks	13 weeks	7 weeks	13 weeks	Treatments	Age	Interaction	CV
Ca	99.40^{a}±2.76	260.05^{a}±2.73	67.29^{b}±2.76	102.43^{b}±2.73	60.50^{b}±2.76	115.73^{b}±2.73	65.70^{b}±2.76	104.82^{b}±2.73	0.0001	0.0001	0.0001	17.49
P	93.40^{a}±0.016	99.40^{a}±0.015	92.80^{a}±0.016	97.40^{a}±0.015	92.90^{a}±0.016	96.00^{a}±0.015	100.10^{a}±0.016	100.50^{a}±0.015	0.2724	0.1217	0.8476	11.54
Na	8058.7^{a}±170.43	10514.42^{a}±168.78	9053.3^{a}±170.43	9978.38^{b}±168.78	6441.8^{b}±170.43	10662.83^{c}±168.78	8610.8^{a}±170.43	10553.22^{a}±168.78	0.0120	0.0001	0.0001	12.76
Mg	31.38^{ab}±1.19	83.52^{a}±1.17	27.07^{ab}±1.19	27.28^{c}±1.17	22.95^{b}±1.19	36.15^{b}±1.17	35.56^{a}±1.19	34.27^{b}±1.17	0.0001	0.0001	0.0001	22.05
K	165.02^{ab}±5.44	337.54^{a}±5.39	147.71^{b}±5.44	199.25^{a}±5.39	79.71^{c}±5.44	311.08^{a}±5.39	187.57^{a}±5.44	311.59^{a}±5.39	0.0001	0.0001	0.0001	17.27
Zn	4.74^{b}±0.86	33.35^{a}±0.86	1.67^{c}±0.86	3.79^{b}±0.86	6.95^{a}±0.86	6.11^{b}±0.86	4.93^{b}±0.86	3.15^{b}±0.86	0.0001	0.0001	0.0001	14.88
Mn	6.32^{c}±0.48	9.36^{a}±0.52	8.36^{ab}±0.48	10.26^{a}±0.52	7.58^{bc}±0.48	10.09^{a}±0.52	9.23^{a}±0.48	8.70^{a}±0.52	0.0256	0.0001	0.0029	19.91
Cu	20.55^{a}±0.79	13.75^{a}±0.64	11.41^{bc}±0.79	11.54^{b}±0.64	13.14^{b}±0.79	12.55^{ab}±0.64	9.78^{c}±0.79	12.49^{c}±0.64	0.0001	0.0027	0.0001	16.31
Fe	20.25^{b}±0.80	23.19^{a}±0.64	20.80^{ab}±0.80	20.93^{bc}±0.64	23.11^{a}±0.80	22.02^{ab}±0.64	20.85^{ab}±0.80	19.39^{c}±0.64	0.0066	0.8074	0.0123	11.73

^{ab}Means in the same row with different superscripts in a row differ significantly; $p<0.05$. CV: Coefficient of variation

containing 13.5% *mopane* worm meal contained a high level of Na (1255 mg/l) which explains the high Na level in the meat. Sodium and K play a primary role in maintaining the acid-base balance, membrane permeability and the osmotic control of water distribution within the body (McDonald *et al.*, 2002).

Blood mineral composition: Generally, blood mineral compositions of guinea fowl fed 4.5% *mopane* worm meal were higher than other three treatments at both 7 and 13 weeks of age (Table 6). The plasma Ca for birds fed the control diet was significantly higher than the other three treatments which did not differ significantly at 7 and 13 weeks of age. Blood Mg and K concentrations were higher (35.56 and 187.57 mg/l, respectively) in birds fed 13.5% *mopane* worm meal at 7 weeks compared to other treatment diets. At 13 weeks of age, K concentration (199.25 mg/l) was lowest in blood of birds fed 4.5% *mopane* worm meal diet and other treatments did not differ significantly between each other whilst Mg was highest (83.52 mg/l) in the control diet. Plasma Cu concentrations (20.55 mg/l) were highest in the control diet and lowest in the 13.5% *mopane* worm meal (9.78 mg/l) compared to other treatments at 7 weeks of age. The mean blood Ca and P values reported in this study were 144.92 and 98.30 mg/l, respectively at 13 weeks of age. Onyeanusi (2007) reported lower mean plasma Ca and P contents of 9.72 and 6.59 mg/100 ml in Nigerian guinea fowl fed commercial broiler diets. The differences in the mineral concentrations may be due to differences in dietary treatments. Bao *et al.* (2007) observed that when dietary contents for Mn, Fe, Cu and Zn were higher than the requirement for growth, there was an increase in plasma and tibia concentration. The authors stated that chickens give priority to their mineral requirement for vital functions in compromise of body growth resulting in normal mineral concentrations in the plasma of chicken fed diets deficient in trace mineral. At 13 weeks of age, the plasma trace mineral concentrations were significantly higher in guinea fowl on control diet and 4.5% *mopane* worm meal than other two treatment diets. Zinc and Mn concentrations were 6.95 and 9.23 mg/l in the 9 and 13.5% *mopane* worm meal diets, respectively at 7 weeks of age. Blood mineral composition increased significantly with age except for Fe and P (Table 6) showing that there is rapid tissue growth between 7 and 13 weeks of age in guinea fowl. Nsoso *et al.* (2006) reported significant increase in body weights from 0.27 to 1.29 kg from 5 to 12 weeks of age under the intensive system. Similar observations were also noted by Saina *et al.* (2005) and Nobo *et al.* (2012). A significant dietary treatment x age interaction for Fe concentration occurred whilst the age effect was insignificant showing that the significance in interaction was mainly due to dietary effect.

Table 7: Daily macro mineral intake, faecal excretion and mineral retention of guinea fowl at 7 and 13 weeks of age reared under the intensive system

Mineral (mg/L)	Variable	Treatment Control 7 weeks	13 weeks	4.5% *Mopane* worm meal 7 weeks	13 weeks	9.0 % *Mopane* worm meal 7 weeks	13 weeks	13.5 % *Mopane* worm meal 7 weeks	13 weeks	Significance of effect (P) Treatment	Age	Interaction	CV
Ca	Daily Intake (g)	0.3992^{a}±0.0024	0.3632^{a}±0.0025	0.3345^{b}±0.0024	0.2032^{c}±0.0025	0.2600^{c}±0.0024	0.2632^{b}±0.0025	0.1370^{d}±0.0024	0.1780^{d}±0.0025	0.0001	0.0001	0.0001	1.88
	Faecal excretion (g)	0.1327^{a}±0.0052	0.0915^{a}±0.0032	0.0045^{d}±0.0052	0.0375^{c}±0.0032	0.0687^{b}±0.0052	0.0560^{b}±0.0032	0.0217^{c}±0.0052	0.0417^{c}±0.0032	0.0001	0.6473	0.0001	15.6
	Retention (g)	0.2665^{b}±0.0041	0.2712^{a}±0.0035	0.3295^{a}±0.0041	0.1705^{c}±0.0035	0.1912^{c}±0.0041	0.2072^{b}±0.0035	0.1150^{d}±0.0041	0.1362^{d}±0.0035	0.0001	0.0001	0.0001	3.64
	% Retention	66.84^{d}±1.50	76.80^{b}±1.31	98.65^{a}±1.50	83.98^{a}±1.31	73.61^{c}±1.50	78.73^{b}±1.31	84.15^{b}±1.50	76.66^{b}±1.31	0.0001	0.0329	0.0001	3.54
P	Daily Intake (g)	0.2838^{a}±0.0027	0.5012^{b}±0.0056	0.2510^{c}±0.0027	0.4852^{b}±0.0056	0.2710^{b}±0.0027	0.5437^{a}±0.0056	0.2365^{d}±0.0027	0.4895^{b}±0.0056	0.0001	0.0001	0.0001	2.25
	Faecal excretion (g)	0.0183^{a}±0.0007	0.0915^{a}±0.0032	0.0045^{b}±0.0007	0.0375^{c}±0.0032	0.0058^{b}±0.0007	0.0566^{b}±0.0032	0.0035^{d}±0.0007	0.0417^{c}±0.0032	0.0490	0.0009	0.0001	18.44
	Retention (g)	0.2652^{a}±0.0020	0.4992^{b}±0.0055	0.2470^{b}±0.0020	0.4745^{c}±0.0055	0.2652^{a}±0.0020	0.5300^{a}±0.0055	0.2327^{c}±0.0020	0.4742^{c}±0.0055	0.0001	0.0001	0.0011	2.25
	% Retention	93.56^{b}±0.2314	99.70^{a}±0.16	98.20^{a}±0.2314	97.75^{b}±0.16	97.86^{a}±0.2314	97.46^{b}±0.16	98.54^{a}±0.2314	96.89^{c}±0.16	0.0001	0.0001	0.0001	0.4
Na	Daily Intake (g)	0.0445^{d}±0.00045	0.0522^{d}±0.0010	0.0475^{c}±0.00045	0.0815^{c}±0.0010	0.0495^{b}±0.00045	0.8825^{b}±0.0010	0.6055^{a}±0.00045	0.1142^{a}±0.0010	0.0001	0.0001	0.0001	20.35
	Faecal excretion (g)	0.0398^{a}±0.0012	0.0370^{c}±0.0027	0.0125^{b}±0.0012	0.0705^{b}±0.0027	0.0382^{a}±0.0012	0.0707^{b}±0.0027	0.0120^{b}±0.0012	0.0892^{a}±0.0027	0.0001	0.0001	0.0001	12.75
	Retention (g)	0.0045^{d}±0.0012	0.2150^{ab}±0.0036	0.0355^{b}±0.0012	0.0110^{b}±0.0036	0.0110^{c}±0.0012	0.0170^{ab}±0.0036	0.0437^{a}±0.0012	0.0247^{a}±0.0036	0.0001	0.0139	0.0001	25.86
	% Retention	10.42^{c}±2.33	41.15^{a}±3.78	73.83^{a}±2.33	13.56^{b}±3.78	22.35^{b}±2.33	19.44^{b}±3.78	78.52^{a}±2.33	21.72^{b}±3.78	0.0001	0.0001	0.0001	17.89
Mg	Daily Intake (g)	0.6425^{a}±0.0295	0.7440^{a}±0.0134	0.4600^{b}±0.0295	0.7320^{a}±0.0134	0.4483^{b}±0.0295	0.6207^{b}±0.0134	0.4083^{b}±0.0295	0.6422^{b}±0.0134	0.0001	0.0001	0.0022	7.04
	Faecal excretion (g)	0.4500^{a}±0.0170	0.5995^{a}±0.0171	0.2870^{b}±0.0170	0.3805^{c}±0.0171	0.4142^{a}±0.0170	0.5565^{ab}±0.0171	0.2867^{b}±0.0170	0.4825^{b}±0.0171	0.0001	0.0001	0.2122	10.77
	Retention (g)	0.1925^{a}±0.0284	0.1452^{b}±0.0258	0.1730^{a}±0.0284	0.3525^{a}±0.0258	0.0340^{b}±0.0284	0.0645^{c}±0.0258	0.1215^{d}±0.0284	0.1595^{b}±0.0258	0.0001	0.0154	0.0033	24.19
	% Retention	29.92^{a}±4.89	19.52^{bc}±3.91	37.61^{a}±4.89	48.21^{a}±3.91	7.03^{b}±4.89	10.21^{c}±3.91	29.87^{a}±4.89	24.77^{b}±3.91	0.0001	0.9573	0.1393	24.37
K	Daily Intake (g)	0.1877^{a}±0.0014	0.2840^{a}±0.0025	0.1765^{b}±0.0014	0.2675^{b}±0.0025	0.1677^{c}±0.0014	0.2485^{c}±0.0025	0.1575^{d}±0.0014	0.2285^{d}±0.0025	0.0001	0.0001	0.0001	2.2
	Faecal excretion (g)	0.1675^{a}±0.0071	0.1327^{b}±0.0082	0.0365^{c}±0.0071	0.0940^{c}±0.0082	0.1185^{b}±0.0071	0.1592^{a}±0.0082	0.0377^{c}±0.0071	0.1195^{b}±0.0082	0.0001	0.0001	0.0001	14.19
	Retention (g)	0.0218^{d}±0.0059	0.1512^{a}±0.0080	0.1400^{a}±0.0059	0.1735^{a}±0.0080	0.0495^{c}±0.0059	0.0890^{b}±0.0080	0.1200^{b}±0.0059	0.1090^{b}±0.0080	0.0001	0.0001	0.0001	13.28
	% Retention	10.83^{c}±3.59	53.26^{b}±3.25	79.51^{a}±3.59	64.91^{a}±3.25	29.55^{b}±3.59	35.77^{c}±3.25	76.15^{a}±3.59	47.64^{d}±3.25	0.0001	0.0001	0.0001	13.79

^{ab}Means in the same row with different superscripts in a row differ significantly; $p<0.05$.

Table 8: Daily micro mineral intake, faecal excretion and mineral retention of guinea fowl at 7 and 13 weeks of age reared under the intensive system

Mineral (mg/L)	Variable	Treatment Control 7 weeks	13 weeks	4.5% *Mopane* worm meal 7 weeks	13 weeks	9.0 % *Mopane* worm meal 7 weeks	13 weeks	13.5 % *Mopane* worm meal 7 weeks	13 weeks	Significance of effect (P) Treatment	Age	Interaction	CV
Zn	Daily Intake (g)	0.1382^{d}±0.0024	0.2620^{a}±0.0052	0.2215^{b}±0.0024	0.0922^{d}±0.0052	0.7132^{a}±0.0024	0.1387^{c}±0.0052	0.1935^{c}±0.0024	0.1567^{b}±0.0052	0.0001	0.0001	0.0001	3.41
	Faecal excretion (g)	0.1027^{b}±0.0026	0.0932^{b}±0.0025	0.0695^{c}±0.0026	0.0775^{c}±0.0025	0.0317^{d}±0.0026	0.1195^{a}±0.0025	0.1702^{a}±0.0026	0.9800^{b}±0.0025	0.0001	0.2357	0.0001	8.53
	Retention (g)	0.0352^{c}±0.0053	0.1687^{a}±0.0056	0.1520^{b}±0.0053	0.1500^{c}±0.0056	0.6815^{a}±0.0053	0.0192^{c}±0.0056	0.0232^{c}±0.0053	0.0590^{b}±0.0056	0.0001	0.0001	0.0001	7.62
	% Retention	25.66^{c}±0.0030	64.42^{a}±2.70	68.60^{b}±0.0030	16.19^{c}±2.70	95.57^{a}±0.0030	14.01^{c}±2.70	12.03^{d}±0.0030	36.83^{b}±2.70	0.0001	0.2357	0.0001	14.02
Mn	Daily Intake (g)	0.1395^{b}±0.0001	0.0274^{a}±0.0003	0.0165^{a}±0.0001	0.0296^{b}±0.0003	0.1617^{a}±0.0001	0.0203^{c}±0.0003	0.0137^{b}±0.0001	0.0238^{d}±0.0003	0.0001	0.0001	0.0001	2.24
	Faecal excretion (g)	0.0066^{b}±0.0004	0.0081^{b}±0.0006	0.0051^{c}±0.0004	0.0115^{a}±0.0006	0.0109^{a}±0.0004	0.0109^{a}±0.0006	0.0023^{d}±0.0004	0.0060^{b}±0.0006	0.0001	0.0001	0.0001	14.53
	Retention (g)	0.0073^{b}±0.0003	0.1932^{a}±0.0006	0.0115^{a}±0.0003	0.0181^{a}±0.0006	0.0053^{c}±0.0003	0.0094^{b}±0.0006	0.0115^{a}±0.0003	0.0178^{a}±0.0006	0.0001	0.0001	0.0001	7.93
	% Retention	52.96^{c}±2.41	70.51^{a}±2.57	69.61^{b}±2.41	61.33^{b}±2.57	32.82^{d}±2.41	45.93^{c}±2.57	83.81^{a}±2.41	74.78^{a}±2.57	0.0001	0.0704	0.0001	8.11
Cu	Daily Intake (g)	0.0010^{b}±0.00008	0.0020^{c}±0.00007	0.0011^{b}±0.00008	0.0062^{b}±0.00007	0.0012^{a}±0.00008	0.0086^{a}±0.00007	0.0009^{c}±0.00008	0.0019^{c}±0.00007	0.0001	0.0001	0.0001	3.46
	Faecal excretion (g)	0.0009^{a}±0.00004	0.0005^{c}±0.00005	0.0002^{c}±0.00004	0.0004^{c}±0.00005	0.0005^{b}±0.00004	0.0013^{a}±0.00005	0.0003^{c}±0.00004	0.0006^{b}±0.00005	0.0001	0.0001	0.0001	14.9
	Retention (g)	0.0009^{c}±0.0028	0.0015^{c}±0.00008	0.0008^{a}±0.0028	0.0056^{b}±0.00008	0.0006^{b}±0.0028	0.0072^{a}±0.00008	0.0006^{b}±0.0028	0.0011^{d}±0.00008	0.0001	0.0001	0.0001	5.68
	% Retention	9.53^{c}±3.51	75.29^{c}±1.45	77.22^{a}±3.51	92.13^{a}±1.45	54.34^{b}±3.51	84.53^{b}±1.45	72.15^{a}±3.51	63.19^{d}±1.45	0.0001	0.0001	0.0001	7.43
Fe	Daily Intake (g)	0.1405^{d}±0.0024	0.2620^{b}±0.0038	0.1775^{b}±0.0024	0.3485^{a}±0.0038	0.1842^{a}±0.0024	0.3505^{a}±0.0038	0.1577^{c}±0.0024	0.2347^{c}±0.0038	0.0001	0.0001	0.0001	2.48
	Faecal excretion (g)	0.0255^{b}±0.0034	0.0238^{b}±0.0017	0.0495^{a}±0.0034	0.0230^{b}±0.0017	0.0220^{b}±0.0034	0.0325^{a}±0.0017	0.0560^{a}±0.0034	0.0260^{b}±0.0017	0.0001	0.0001	0.0001	16.84
	Retention (g)	0.1152^{c}±0.0034	0.2382^{b}±0.0029	0.1285^{b}±0.0034	0.3255^{a}±0.0029	0.1625^{a}±0.0034	0.3182^{a}±0.0029	0.1015^{d}±0.0034	0.2087^{c}±0.0029	0.0001	0.0001	0.0001	3.34
	% Retention	81.93^{a}±2.03	90.86^{b}±0.57	72.26^{b}±2.03	93.46^{a}±0.57	88.15^{a}±2.03	90.78^{b}±0.57	64.32^{c}±2.03	88.88^{c}±0.57	0.0001	0.0001	0.0001	3.57

^{ab}Means in the same row with different superscripts in a row differ significantly; p<0

Mineral retention: The daily intakes of birds fed control diets had significantly higher Ca, P, Mg and K compared to the other three treatments containing *mopane* worm meal. High daily Fe (0.1842 and 0.3503g) and Zn (0.7132g and 0.1387g) intakes at 7 and 13 weeks of age respectively were observed in guinea fowl fed diets containing 9% *mopane* worm meal (Table 7 and 8). Nobo *et al.* (2012) reported no significant effect of treatment diets on feed intake and no differences in average daily gains (0.0138 kg), feed conversion ratio (3.83) and dressing percentage of 75.82 between guinea fowl fed fishmeal (control diet) as a protein source and 4.5% *mopane* worm meal.

Generally, the faecal mineral excretions for all elements under study were highest in birds fed control diet at both 7 and 13 weeks of age (Tables 7 and 8). Faecal mineral excretions were positively related to daily mineral intakes. High daily mineral intakes also resulted in high mineral levels being excreted in the faecal matter of the guinea fowl. In this regard, Moreki *et al.* (2011b) reported that increasing Ca levels in the diet from 1.5% and 3.5% resulted in increased faecal Ca excretion in broiler breeder hens reared from 27 to 42 weeks. Furthermore, Bao *et al.* (2007) observed that Cu, Mn and Zn excretion increased significantly with increasing intakes of these trace minerals. This clearly suggests that high levels of Cu, Mn and Zn in the diets do not contribute to bird growth due to high excretion of these trace elements.

Manganese, Cu and Fe retention increased with age. Manganese is essential for growth and fertility of animals (Underwood and Suttle, 1999). Furthermore, Mn plays an important role in bone development, both in the embryo and after birth or hatch, thus explaining the increased Mn retention from 59.80% at 7 weeks to 63.14% at 13 weeks of age. As the bird ages, a greater percentage of minerals is required to support both growth and reproduction, thus explaining the increased mineral retentions at 13 weeks of age. Dietary treatment also had a significant effect on mineral retention as a percentage of mineral intakes for all elements at 7 and 13 weeks. A significant treatment x age interaction occurred for all parameters under investigation except for Mg faecal excretion and percentage retention. To eliminate differences in dietary mineral intake as a factor, retention was expressed as a percentage of intakes. Guinea fowl fed 4.5% *mopane* worm meal diet had higher retention of Ca (98.65 and 83.98%), Cu (77.22 and 92.13%), P (98.20 and 97.75%), Mg (37.61 and 48.21%) and K (79.51 and 64.91%) than other treatment diets at 7 and 13 weeks of age, respectively, suggesting that the level of mineral intake is adequate to support growth.

Conclusions: From the results it is concluded that diets containing 3% fishmeal, 4.5% *mopane* worm meal or 9% *mopane* worm meal generally promoted higher mineral intakes, bone physical development, bone and meat mineral compositions and retentions compared to diets containing 13.5% *mopane* worm meal. Blood mineral composition and mineral retention increases with age as more minerals are required to support growth. The current results suggest that *mopane* worm meal can replace fishmeal by up to 9% without negatively affecting mineral intake, retention and utilization.

ACKNOWELDGEMENTS

We would like to thank Botswana College of Agriculture for financial support. Mr. S. Mogwase, Ms. G. Nobo and Ms. S. Dierenge are sincerely thanked for their assistance with data collection. Our special gratitude is extended to the National Veterinary Laboratory (Department of Veterinary Services) and Department of Agricultural Research for providing laboratory facilities; and to Messrs T. Khumoetsile and M. Mataio for technical support. Mr. J. Makore and Dr. B. Sebolai are also thanked for help with statistical analysis.

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