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REGULAR ARTICLES

Dietary replacement of maggot meal for soybean meal: implication on performance indices, nutrient digestibility, nitrogen utilisation and carcass characteristics of grower rabbits

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Abstract

A study was conducted to investigate the effect of replacing soybean meal (SBM) with maggot meal (MM) in growing rabbits' diets on their performance, nutrient digestibility, and carcass characteristics. In the 56 days feeding trials, sixty unsexed mixed breeds (New Zealand White x California) rabbits were allotted on a weight equalization basis into five dietary treatments where a standard corn-soybean meal based diet (0% of maggot meal) (MM0 diet) served as the while other diets had soybean meal replaced with MM at graded levels of 25, 50, 75 and 100% to give MM25, MM50, MM75, and MM100 diets respectively. Each treatment comprises of four replicates having three rabbits each (12 rabbits per treatment). Growth performance parameters were monitored and recorded weekly, carcass and organ weights evaluation was conducted on day 56. Nutrient digestibility commenced on the 56th day and lasted for 6 days. Feed and water were offered to the rabbits ad-libitum throughout the experimental period. All the performance parameters were significantly ($P<0.05$) affected by MM inclusion in the diet of rabbits. Rabbits fed MM100 diet had the highest ($P<0.05$) final weight (FW), total weight gain (TWG), and the best feed conversion ratio (FCR). The feed cost reduced ($P<0.05$) with inclusion of MM in rabbit's diet. Feed cost per kg live weight (FC/LW) (1110.79 ₦/kg) and feed cost per kg weight gain (FC/WG) (1110.62 ₦/kg) was lowest ($P<0.05$) for rabbits fed MM100 diet. Crude protein digestibility (CPD) (74.05%) was highest ($P<0.05$) for rabbits fed the MM100 diet. The feeding of MM75 and MM100 diets to rabbits resulted in increased ($P<0.05$) dry matter digestibility (DMD) (68.22 and 69.34%), nitrogen free extract digestibility (NFED) (65.52 and 65.22%) and neutral detergent fibre digestibility (NDFD) (70.05 and 69.58%). The highest ($P<0.05$) nitrogen retained (NR) (2.10 g/d) occurred in rabbits fed the MM100 diet. The dressing percentage (DP) (71.01%) increased ($P<0.05$) for rabbits fed the MM100 diet. The weight of forelimbs (10.48 and 10.45%) and hind limbs (17.42 and 18.07%) were highest ($P<0.05$) for rabbits fed MM50 and MM100 diets respectively. Total gastrointestinal tract (GIT) and liver weight were highest ($P < 0.05$) for rabbits fed MM0 and MM100 diets respectively. It was concluded that MM can conveniently replace SBM in the diets of rabbits up to 100% for improved growth performance and increased nutrient digestibility. In addition, it can enhance DP and increase the carcass yield of rabbits.

Keywords Carcass characteristics · Maggot meal · Nutrient digestibility · Performance · Rabbit

Introduction

Protein constitutes an integral part of the body's requirement apart from energy for healthy living (Sakurai et al., 2023). There is a mass record of low protein intake by humans which leads to nutritional deficiencies resulting in sarcopenia (Loss of muscle mass and strength) (Amaduruonye et al., 2018). The average cost of most animal protein sources is high in comparison to the average per capita income of Nigerians (Fabiyi, 2015), and the alternative sources which

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are plant sources are incorporated majorly in livestock feeds (Bamba et al., 2017) and this constitutes the major contributory factors to the human low protein intake which should be tackled with urgent attention. In recent times, the production of rabbit meat has been encouraged due to its nutritive quality and the easy management of the animal. Its production can be increased to meet the animal protein demand of the growing population (Mailafia et al., 2010). Rabbit meat is low in cholesterol, high in calcium and phosphorus and it is referred to as healthy meat (Bielanski et al., 2000). Rabbit has a short gestation period and is highly prolific giving birth to between 12 and 14 bunnies (Ozor and Madueke, 2001). However, commercial production of rabbits will require the need for available non-conventional feed resources especially protein feed ingredients as alternatives to the conventional feed ingredients to produce meat at a reduced cost to meet the purchasing power of the growing populace.

The high cost of feed ingredients used in feed formulation for livestock has played a major role in the reduction of protein intake by man. The use of fish meal in feed formulation is no longer encouraging due to its high cost and short shelf life (Burel and Médale, 2014). The production of soyabean meal which has been the major plant protein ingredient used in livestock feeding has been challenged by rural-urban migration as a result of insecurity and insurgency in Nigeria which displaced farmers from their place of production. The infrastructural development in urban areas has also greatly reduced the available land space for crop production in Nigeria. This has made soyabean to now become very expensive and scarce (Samuel and Idris, 2021). Another plant protein source used in animal feeding is groundnut cake (GNC) however its usage is limited due to the problem associated with aflatoxicosis which poses a great health hazard to all categories of livestock. Cotton seed cake, which is another alternative protein feedstuff available to livestock is limited in its utilization due to its high fiber content as well as its constituent gossypol (Mafimidiwo et al., 1998, Davila et al., 2007). Therefore, conscious effort is needed to search for non-crop yet cheaper alternative livestock protein feedstuff that can ameliorate the current challenges faced in feed production for livestock feeding to produce meat at a frugal rate (Ashayerizadeh et al., 2018).

The quest for cheaper and available alternative feed resources for soybean have prompted animal nutritionist to search for suitable alternatives like maggot meal. The crude protein content of Maggot meal ranges from 40 to 64% with higher values of amino acids especially cysteine, histidine, phenylalanine, tryptophan, and tyrosine than that of fish meal (Adesulu and Mustapha, 2000; Makinde, 2015). Maggot meal contains 3.37% crude fibre and 3955 Kcal/kg as reported by Ahmad et al. (2022). Maggot meal is reported to have a high biological value comparable to that of fish meal (Ogunji et al., 2008). Its incorporation in the diet of cockerels resulted in reduced feed intake with improved weight gain (Bamgbose, 1999). The inclusion of maggot meal up to 50% as a replacement for soyabean in the diet of *Oreochromis niloticus* stimulated increased growth (Ezewundo et al., 2015). Makinde (2015) reported that maggot meal as an unconventional protein source does not possess noticeable anti-nutritional factors unlike soybean meal that had trypsin inhibitor if not properly processed. Based on this background, it was hypothesized that the use of maggot meal will reduce the competition for the highly priced soyabean meal and as well increase protein intake through increased rabbit production. Furthermore, Maggot meal had been used in the diet of fish (Ezewundo et al., 2015) and poultry (Hwangbo et al., 2009) however, there is a paucity of information on its incorporation in rabbit diets. Therefore, this study was conducted to determine the growth performance, nutrient digestibility and carcass characteristics of grower rabbits fed diets containing graded levels of maggot meal as a replacement for soybean meal.

Materials and methods

Experimental site

The experiment was carried out at the Teaching and Research Farm of the Department of Agricultural Technology, Yaba College of Technology, Epe Lagos. The rabbit house had average temperature and humidity of 30.10^{o}C and 75.60% respectively.

Animals, experimental diets and management

Sixty (unsexed) mixed breed (New Zealand x California) rabbits weighing about 758 $\pm$ 2.50 g (5 weeks old) were procured from a reputable farm in Ibadan and were acclimatized for seven days at the Teaching and Research Farm of the Department of Agricultural Technology, Yaba College of Technology, Epe Lagos on Latitude 3. 58^{o}E and Longitude 6. 47^{o}N (Google Earth, 2022). They were offered feed and water *ad-libitum* and all pre-experimental medications were strictly adhered to. The protocol for the experiment was reviewed and approved (AUCC/22/MAF/MM/010) by the Animal Use and Care Committee at Yaba College of Technology Lagos. Maggot meal produced from black fly (*hermetia illucens*) was procured from Magmeal Industries, Ora estate, Epe Lagos, and other feed ingredients were purchased from a reputable feed mill. The proximate composition of soya bean meal and maggot meal was determined using AOAC (2005), calcium and phosphorus content were

Table 1 Nutrient composition of soyabean meal (SBM) and maggot meal (MM)

Item (% dry matter)	Soyabean meal	Maggot meal
Dry matter	89.00	95.00
Crude protein	44.43	55.56
Crude fibre	5.60	8.23
Ether extract	6.20	18.62
Calcium	0.31	0.45
Phosphorus	0.65	1.46
Acid detergent fibre	8.60	12.45
Neutral detergent fibre	13.50	28.56
Ash	6.50	9.21
NFE	33.30	19.62

Table 2 Ingredients and nutritional composition of experimental diets

Items	MM0	MM25	MM50	MM75	MM100
Ingredients (%)					
Maize	30.00	30.00	30.00	30.00	30.00
Maggot meal	0.00	3.75	7.50	11.25	15.00
Soybean meal	15.00	11.25	7.50	3.75	0.00
Wheat offal	38.00	38.00	38.00	38.00	38.00
Palm Kernel Cake	10.00	10.00	10.00	10.00	10.00
Molasses	2.50	2.50	2.50	2.50	2.50
Bone meal	2.00	2.00	2.00	2.00	2.00
Limestone	2.00	2.00	2.00	2.00	2.00
Salt (NaCl)	0.35	0. 35	0.35	0. 35	0.35
Premix*	0.05	0.05	0.05	0.05	0.05
Lysine	0.05	0.05	0.05	0.05	0.05
Methionine	0.05	0.05	0.05	0.05	0.05
Total	**100**	**100**	**100**	**100**	**100**
Feed cost/kg (₦)**	**460.37**	**458.50**	**456.62**	**454.76**	**452.87**
Analysed Nutrients[a]					
Dry matter (%)	90.12	89.22	87.95	88.45	87.84
Crude protein (%)	16.21	16.03	16.20	16.34	16.41
Crude fibre (%)	16.14	16.04	15.95	15.55	15.34
Ether extract	2.83	2.85	2.97	3.21	3.32
Ash	5.21	5.10	4.90	4.89	4.78
Gross energy (Kcal/kg)	3554.34	3563.45	3585.84	3601.88	3643.52
Metabolisable Energy (kg/kcal)[b]	2538	2553	2570	2584	2596

*Each 1 kg vitamin and mineral premix provides the following per kg diet: Vit. A 12,000,000 IU, Vit. D3 750,000 IU, Vit. E 10,000 mg, Vit. K 2000 mg, Vit B1 1000 mg, vit B2 4000 mg, Vit. B6 1500 mg, Vit B1210 mg, Pantothenic acid 10,000 mg, Niacin 20,000 mg, Biotine 50 mg, Folic acid 1000 mg, Choline chloride 500 mg, selenium 100 mg, Manganese 55 gm, Zinc 50 gm, Fe 60 gm, CU 2.5 gm, CO 6 mg and Iodine 1gm

MM0 = without maggot meal (Control), MM25 = 25% maggot meal, MM50 = 50% maggot meal, MM75 = 75% maggot meal, MM100 = 100% maggot meal

a = dry matter basis, b = calculated using the pauzenga equation: ME= (37 × CP % + 81.8 × CF % + 35.5 × NFE %) (Pauzenga, (1985)

**₦= Nigerian Naira where 1 US dollar = ₦750

analysed using an atomic absorption spectrophotometer (Perkin Elmer Optima 4300DV ICP spectrophotometer, UK), and fibre fractions were conducted using the standard method by McCleary (2007) (Table 1).

The rabbits were randomly allotted on a weight equalization basis in a completely randomised design into five dietary treatments with four replicates of three rabbits and the rabbits were housed in aluminium wire cages (60 × 45 × 50 cm). The diets comprise a corn-soybean meal-based diet (Diet 1) (MM0 = diet with 0% MM), while diets 2, 3, 4, and 5 had the soybean meal in the feed replaced with maggot meal at 25% (MM25), 50% (MM50), 75% (MM75) and 100% (MM100) levels respectively (Table 2). The feeding trial lasted for 56 days while feed was offered liberally to the rabbits and they had unlimited access to clean drinking water. The humidity in the experimental pen was 65 ± 10% and the temperature was 27 ± 2.5°C. A cycle of 12 h of light and 12 h of dark was maintained throughout the feeding trial.

Data collection

Performance parameters

Growth performance parameters were monitored and record was taken weekly. Before the commencement of feeding trial, initial weight of rabbits was taken to determine subsequent weight gain. The total weight gain (TWG) was determined by calculating the difference between the initial weight (IW) and final weight (FW). The average weight gain (AWG) was calculated by dividing the weight gain by the number of rabbits in each replicate. The average daily weight gain (ADWG) obtained by dividing the AWG by the number of days. Total feed intake (TFI) was recorded daily by calculating the difference between the feed offered and refused feed. The average feed intake (AFI) was calculated by dividing the feed intake by the number of rabbits in each replicate while the average daily feed intake (ADFI) was obtained by dividing the AFI by the number of days. The feed conversion ratio (FCR) was calculated by dividing the TFI by TWG. Mortality did not occur throughout the experiment and hence no mortality data was recorded.

The cost analysis was also carried out to determine the feed cost per kilogram (FC, ₦/kg), cost of feed consumed (CFC, ₦/bird), feed cost per weight gain (FC/WG, ₦/g). The feed cost was determined from the cost of each feed ingredient used. The prices of the feed ingredient based on prevailing market price within the period of September 2022 was used to calculate the cost of each experimental diet. The MM at the period of study was purchased at ₦300/kg (0.40 US dollar) and SBM was purchased at ₦400/kg (0.53 US dollar). The feeding cost was calculated considering the feed intake per bird and multiplied by the cost of diet. The cost indices considered were calculated using the formula below:

$$\text{Feed cost per kg} = \frac{\text{Cost of ingredients for100kg}}{100}$$

$$\text{Cost of feed consumed per bird} = \text{Total feed intake} \times \text{feed cost per kg}$$

$$\text{Feed cost per kg live weight} = \frac{\text{Feed Cost per kg} \times \text{FCR}}{100}$$

$$\text{Feed cost per kg weight gain} = \frac{\text{Feed Cost per kg} \times \text{Total feed intake}}{\text{Total weight gain}}$$

Carcass measurements

The carcass measurement was done on day 56; four rabbits representing a rabbit per replicate were selected, slaughtered, and skinned. Meanwhile, the rabbits were deprived of feed for six hours before slaughter. The carcass weight was measured and recorded after the removal of the viscera and the gastrointestinal tract (GIT). The carcass was cut into parts which comprise the head, tail, shoulder, rack/ribs, loin, and hind legs and were weighed. The weights of the heart, liver, lungs, and kidneys were also measured using sensitive digital scale. The measured value of carcass cut parts and organ weights was recalculated and expressed as a percentage of the live weight.

Nutrient digestibility and Nitrogen utilisation

At day 56, the remaining rabbits (8 rabbits per group; 2 rabbits in 4 replicates) were used to investigate nutrient digestibility. They were housed in metabolic cages with attachments for the separate collection of faeces and urine. They were allowed to acclimatize to the cage for two days while faecal and urine samples were collected for four days. The collected faeces were used to determine the total tract apparent digestibility (TTAD) for dry matter (DM), crude protein (CP), ether extract (EE), nitrogen free extract (NFE), acid detergent fibre (ADF), and neutral detergent fibre (NDF) according to Pérez et al. (1995). The urine was used for the determination of nitrogen balance (NB) and nitrogen retention (NR). The excreta was collected daily at 7:00 and 20:00 h for each replicate; weighed and oven-dried (60°C) for 48 h, and then ground to 0.5 mm size. The collected faeces were pooled together for each treatment and a sample of 150 g of faeces was used for proximate analysis (AOAC, 2005), fibre fraction (McCleary, 2007). Urine excreted over 24 h period was collected daily at 8:00 h in plastic bottles and acidified with 15mL/L (v/v) 95% H_2SO_4 according to Gidenne et al. (2013). 10% (10 mL/100 mL) of urine was collected as samples, pooled, and frozen at -20°C before chemical analysis for nitrogen content. The TTAD was estimated using the formula according to Adeola (2001) below:

$$\text{Apparent nutrient digestibility} = \frac{[(\mathrm{F_i} \times \mathrm{N_f}) - (\mathrm{E\,x} \times)]}{\mathrm{F_i} \times \mathrm{N_f}} \times 100$$

Where F_i and E are the quantity of feed intake and excreta output (g DM) during the metabolic trial. The N is the nutrient, N_f is the nutrient composition in the feed while Ne is the nutrient composition in excreta voided (g DM).

The nitrogen intake (NI), excreted nitrogen in faeces, and excreted nitrogen in urine were calculated by multiplying the nitrogen composition of diets, faeces, and urine, by the quantity of feed intake, the quantity of excreted faeces and urine, respectively. Nitrogen retained (NR) was calculated as the difference between the NI and total nitrogen output (Nitrogen in faeces + Nitrogen in urine) and the net protein utilisation (NPU) was calculated as the ratio of NR to NI (NPU = NR/NI).

Statistical analysis

All data collected were subjected to one-way analysis of variance using SAS (2009) and the means were separated using Duncan multiple range test (Duncan, 1955) obtained in the same software. Differences among treatments were considered significant at 5% ($P < 0.05$).

Result

Growth performance

The growth performance and feed cost analysis of rabbits fed diets containing MM is shown in Table 3. The result shows a significant ($P < 0.05$) effect of MM inclusion on FW, TWG, DWG, TFI, DFI and FCR. Rabbits fed diets containing MM at 100% had the highest ($P < 0.05$) FW while those fed the MM25 diet had the lowest ($P < 0.05$) FW but those fed MM0, MM50, and MM75 diets had intermediate FW. The highest ($P < 0.05$) TWG was observed for rabbits fed the MM100 diet while those fed MM25 had the lowest TWG and the same trend was observed for DWG. Rabbits fed the diet containing MM0 had the highest ($P < 0.05$) TFI while those fed MM25, MM75, and MM100 diets had the lowest TFI but those fed diet containing MM50 had intermediate TFI. The same trend was also observed for DFI. Rabbits fed MM100 diets had the best ($P < 0.05$) FCR but those fed MM0 and MM25 had the worst FCR while those fed MM50 and MM75 diets had intermediate FCR.

Table 3 Growth performance of growing rabbits fed diets containing maggot meal as a replacement for soybean meal

Parameters	MM0	MM25	MM50	MM75	MM100	Pooled SEM	*P*-value
Initial weight (g/rabbit)	753.33	751.70	750.00	758.33	756.70	7.89	0.854
Final weight (g/rabbit)	1850.00^{bc}	1675.00^{c}	1825.00^{b}	1825.00^{b}	1925.32^{a}	18.42	0.032
TWG (g/rabbit)	1096.67^{b}	923.30^{c}	1075.00^{bc}	1066.67^{bc}	1168.30^{a}	15.01	0.020
DWG (g/rabbit	19.58^{b}	16.49^{c}	19.20^{bc}	19.05^{bc}	20.86^{a}	0.58	0.010
TFI (g/rabbit)	3185.95^{a}	2874.21^{c}	2928.02^{b}	2887.86^{c}	2866.34^{c}	15.43	0.002
DFI (g/rabbit)	56.90^{a}	51.33^{c}	52.29^{b}	51.57^{c}	51.19^{c}	1.33	0.043
FCR	2.91^{a}	3.11^{a}	2.72^{ab}	2.71^{ab}	2.45^{b}	0.04	0.037
Cost Analysis							
Feed cost per kg (₦/kg)	460.32^{a}	458.50^{ab}	457.56^{b}	454.73^{c}	452.77^{c}	0.75	< 0.001
Cost of feed consumed (₦/rabbit)	1466.17^{a}	1317.70^{c}	1334.21^{b}	1312.95^{c}	1289.33^{d}	16.80	< 0.001
Feed cost per kg live weight (₦/kg)	1341.12^{b}	1427.60^{a}	1242.62^{c}	1232.80^{d}	1110.79^{e}	28.63	< 0.001
Feed cost per kg weight gain (₦/kg)	1337.15^{b}	1427.35^{a}	1243.98^{c}	1231.75^{d}	1110.62^{e}	28.49	< 0.001

[abcde]Means within a row with different superscripts differ ($P < 0.05$)

MM0 = without maggot meal (Control), MM25 = 25% maggot meal, MM50 = 50% maggot meal, MM75 = 75% maggot meal, MM100 = 100% maggot meal

SEM = Standard error of mean

TWG - Total weight gain; DWG – Daily weight gain; TFI – Total feed intake; DFI – Daily feed intake; FCR – Feed conversion ratio

Table 4 Nutrient digestibility and nitrogen utilisation of grower rabbits fed diets containing maggot meal as a replacement for soybean meal

Items	MM0	MM25	MM50	MM75	MM100	Pooled SEM	*P*-value
TTAD (%)							
Dry Matter	50.52^{c}	56.46^{b}	59.82^{bc}	68.22^{a}	69.34^{a}	2.02	< 0.001
Crude Protein	63.49^{b}	58.10^{b}	35.10^{c}	58.36^{b}	74.05^{a}	3.46	< 0.001
Ether extract	55.61^{a}	48.82^{b}	54.26^{a}	56.20^{a}	61.11^{a}	2.15	< 0.001
Crude fibre	55.46^{a}	44.96^{b}	54.80^{a}	54.42^{a}	56.98^{a}	2.23	< 0.001
Ash	54.46^{b}	53.04^{b}	69.37^{a}	66.83^{a}	65.10^{a}	1.87	< 0.001
Nitrogen free extract	49.59^{c}	63.49^{a}	56.85^{b}	65.52^{a}	65.22^{a}	3.85	0.021
Neutral detergent fibre	67.77^{ab}	66.56^{ab}	56.54^{b}	70.05^{a}	69.58^{a}	2.90	0.042
Acid detergent fibre	46.43	45.72	44.18	45.62	46.17	2.02	0.652
Nitrogen utilisation (g/d)							
Nitrogen intake	3.12^{b}	3.01^{b}	3.14^{b}	2.89^{b}	4.51^{a}	1.02	0.013
Nitrogen excretion in urine	1.19^{b}	1.18^{b}	1.09^{b}	1.21^{b}	1.98^{a}	0.05	0.032
Nitrogen excretion in faeces	0.98	0.87	0.92	0.95	0.85	0.03	0.486
Nitrogen retained	1.18^{b}	1.16^{b}	1.22^{b}	1.14^{b}	2.10^{a}	0.07	0.002
Net protein utilisation	0.38^{b}	0.39^{b}	0.39^{b}	0.39^{b}	0.47^{a}	0.11	0.010

[abc]Means within a row with different superscripts differ ($P < 0.05$)

TTAD = Total tract apparent nutrient digestibility

MM0 = without maggot meal (Control), MM25 = 25% maggot meal, MM50 = 50% maggot meal, MM75 = 75% maggot meal, MM100 = 100% maggot meal

SEM = Standard error of mean

The feed cost per kg (FC) was significantly ($P < 0.05$) different across treatment, the MM0 diet (460.32 ₦/kg) had the highest ($P < 0.05$) cost and the MM75 (454.73 ₦/kg) and MM100 (452.77 ₦/kg) diet had lowest cost while the MM25 and MM50 had intermediate cost. The cost of feed consumed (CFC) was highest ($P < 0.05$) for rabbits fed MM0 diet (1466.17 ₦/rabbit) and lowest for those fed MM100 diet (1289.33 ₦/rabbit). The CFC for group of rabbits fed MM50 diet was higher ($P < 0.05$) than those fed MM25 and MM75 diet. Feed cost per kg live weight (FC/LW) and Feed cost per kg weight gain (FC/WG) followed the same trend and it was highest ($P < 0.05$) for rabbits fed MM25 diet followed by those fed MM0 diet while it reduces with increasing inclusion level of MM from 50 to 100%.

Nutrient digestibility and nitrogen utilisation

Table 4 shows the nutrient digestibility and nitrogen utilisation of rabbits fed diets containing MM. Dry matter digestibility (DMD) was highest ($P < 0.05$) for rabbits fed MM75 and MM100 diets while those fed MM0, MM25, and MM50 diets had reduced DMD. Crude protein digestibility (CPD) was highest ($P < 0.05$) for rabbits fed the MM100 diet while those fed the MM50 diet had the lowest CPD but those fed MM0, MM25, and MM75 had intermediate CPD. Rabbits fed diets containing MM25 had lower ($P < 0.05$) ether extract digestibility (EED) and crude fibre digestibility (CFD) compared to other treatments. Rabbits fed MM50, MM75, and MM100 diets had increased ($P < 0.05$) ash digestibility (AD) while those fed MM0 and MM25 diets had reduced AD. Nitrogen free extract digestibility (NFED) was highest ($P < 0.05$) for rabbits fed MM25, MM75 and MM100 diets and were lowest for rabbits fed the MM0 diet while those fed MM50 diet had intermediate NFED. Rabbits fed MM75 and MM100 diets had the highest ($P < 0.05$) neutral detergent fibre digestibility (NDFD) and those fed the MM50 diet had the lowest NDFD. Acid detergent fibre digestibility (ADFD) was not significantly ($P > 0.05$) affected by dietary inclusion of MM for rabbits.

Nitrogen intake (NI), nitrogen excretion in urine (NEU), nitrogen retained (NR) and net protein utilisation (NPU) was significantly ($P < 0.05$) influenced by MM inclusion in the diets of rabbits but nitrogen excretion in faeces (NEF) was not significantly ($P > 0.05$) affected. Rabbits fed the diet containing MM100 had higher ($P < 0.05$) NI than other treatments and a similar trend occurred for NEU, NR, and NPU.

Carcass characteristics and organ weight

The carcass characteristics and organ weights of rabbits fed diets containing MM are presented in Table 5. The live weight (LW) was highest ($P < 0.05$) for rabbits fed diets containing MM100 and those fed MM25 diets had the lowest ($P < 0.05$) LW while those fed MM0, MM50, and MM75 diets had intermediate LW. The dressed weight (DW) followed a similar trend as the LW. Increased ($P < 0.05$) dressing percentage (DP) was observed for rabbits fed the MM100 diet and those fed MM25 and MM50 diets had reduced DP while the groups fed MM0 and MM75 diets had intermediate DP. The inclusion of MM50 and MM100 in the diets of rabbits resulted in the highest ($P < 0.05$) fore limbs and those fed the MM0 diet had the lowest fore limbs while those fed MM25 and MM75 diets had intermediate forelimbs. The hind limbs were highest for rabbits fed MM50 (17.42%) and MM100 (18.07%) diets but lowest for rabbits fed MM0 (16.35%) and MM75 (16.00%) diet and the group fed MM25 diet had intermediate hind limb weight. The rack/ribs weight increased ($P < 0.05$) for rabbits fed MM25 and MM50 diets but reduced for rabbits fed the MM75 diet while the groups fed MM0 and MM100 diets had intermediate rack/ribs weight. The weight of loin was highest ($P < 0.05$) for rabbits fed MM0 and MM100 diets but lowest for those fed the MM75 diet while those fed MM25 and MM50 diets had intermediate loin weight. The head weight was higher ($P < 0.05$) for rabbits fed MM100 diets than for other dietary treatments. Dietary inclusion of MM75 and MM100 for rabbits resulted in higher ($P < 0.05$) trotters' weight than other treatments.

The result of organs shows that rabbits fed the MM0 diet had increased ($P < 0.05$) total gastrointestinal tract (GIT) weight (26.38%) and those fed the MM100 diet had reduced total GIT weight (19.22%) while the groups fed MM25, MM50 and MM75 diets had intermediate total GIT.

Table 5 Carcass characteristics and organ weights of growing rabbits fed diets containing maggot meal as a replacement for Soybean meal

Parameters	MM0	MM25	MM50	MM75	MM100	SEM	*P*-value
Average Live weight (g)	1845.01^{ab}	1670.25^{b}	1820.23^{ab}	1815.12^{ab}	1925.02^{a}	9.57	0.003
Dressed weight (g)	1296.12^{ab}	1150.42^{b}	1255.23^{ab}	1269.41^{ab}	1352.74^{a}	13.02	0.034
Dressing (%)	68.96^{ab}	60.70^{b}	62.72^{b}	69.92^{ab}	71.01^{a}	5.06	0.016
Cut parts (%)							
Fore Limbs	9.38^{c}	9.68^{b}	10.48^{a}	9.78^{ab}	10.45^{a}	2.23	0.017
Hind Limb	16.35^{c}	16.89^{b}	17.42^{a}	16.00^{c}	18.07^{a}	0.44	0.040
Rack/ribs	10.15^{b}	12.27^{a}	12.21^{a}	9.19^{c}	10.89^{ab}	1.02	0.002
Loin	4.58^{a}	3.84^{ab}	3.51^{ab}	2.92^{b}	4.43^{a}	0.03	0.043
Head	9.73^{b}	9.89^{b}	10.14^{b}	10.22^{b}	11.15^{a}	0.04	0.011
Trotters	2.34^{b}	2.17^{b}	2.23^{b}	3.12^{a}	3.28^{a}	0.03	0.005
Organs (%)							
Total GIT	26.38^{a}	20.97^{b}	22.23^{ab}	19.89^{bc}	19.22^{c}	1.10	0.010
Heart	0.23	0.28	0.21	0.30	0.34	0.02	0.586
Lungs	0.74^{a}	0.55^{b}	0.69^{ab}	0.85^{a}	0.78^{a}	0.02	0.034
Liver	2.34^{b}	2.93^{ab}	2.98^{ab}	3.04^{ab}	3.36^{a}	0.03	0.022
Spleen	0.07	0.06	0.06	0.05	0.07	0.01	0.725

^{abc}Means within a row with different superscripts differ ($P < 0.05$)

MM0 = without maggot meal (Control), MM25 = 25% maggot meal, MM50 = 50% maggot meal, MM75 = 75% maggot meal, MM100 = 100% maggot meal

SEM = Standard error of mean

Rabbits fed MM0, MM75, and MM100 diets had increased ($P < 0.05$) lung weight while those fed the MM25 diet had reduced lung weight. Increased ($P < 0.05$) liver weight was observed for rabbits fed the MM100 diet and those fed the MM0 diet had reduced liver weight while the groups of rabbits fed MM25, MM50, and MM75 diets had intermediate liver weight.

Discussion

Growth performance

This study reveals that the inclusion of MM at 100% in the diet of rabbits resulted in the highest FW, TWG, and DWG of rabbits while those fed the MM25 diet had reduced FW, TWG, and DWG. Those fed diets with MM at 50 and 75% replacement for SBM were intermediate for these performance parameters and also similar to those fed MM0 diet. This suggests that MM inclusion at 100% for rabbits was able to elicit improved performance over those fed the control diet. The improved weight gain could be associated with higher crude protein content of MM at 100% replacement for SBM which enhanced protein synthesis for improved tissue accretion. Research report on the use of MM in the diet of rabbits is rare however, the use of MM in the diet of poultry birds has been shown to improve the live weight of broilers at the starter, grower, and finisher phases (Téguia et al., 2002). Hwangbo et al. (2009) also observed significantly higher body weight gain (BWG) of broilers fed diet supplemented 10 and 15% MM than those fed the diet without maggot meal supplementation. An increase in egg weight and chick weight was reported for layers fed diet supplemented with 30 and 50 g of live *Musa domestica* (MD) (Dankwa et al., 2002). A contrary report by Adeniji (2007) indicated no significant effect on performance when MM was used to replace groundnut cake in the diet of broilers. A decline in egg production was noticed for layers with 100% inclusion of MM as a substitute for fishmeal (Agunbiade et al., 2007). However, in this present study, the substitution of 100% of MM for SBM in the diet of rabbit resulted in increased FW and WG. These discrepancies observed could be due to differences in the substitution levels and they can also be associated with species differences due to differences in the digestive tract capacities. The report on the use of other insect meals shows that the total replacement of SBM with Ground yellow mealworms (*Tenebrio molitor L.* (TM)) in the diet of broilers increased BWG (Khan et al., 2018). The report by Ballitoc and Sun (2013) shows there was improved live weight for broilers fed a diet containing 10 g/kg TM. However, the inclusion of *Hermetia illucens* (HI) meal in the diet of rabbits yielded no effect on performance (Gasco et al., 2019). The differing reports are associated with the distinctive varying properties of the insects used. The TFI and DFI of rabbits in this study significantly reduced with the replacement of SBM with MM irrespective of inclusion level but the lowest was observed for rabbits fed MM25, MM75, and MM100 diets but did not adversely affect the FCR. This is in agreement with the observation of Dankwa et al. (2002) who reported no adverse effect of MM as replacement of fishmeal at 50% in the diet of layers on FI with better FCR. A similar report was given by Sumbule et al. (2021a, b), the authors observed reduction in FI of layers with increasing inclusion of black soldier fly larvae meal (BSFLM), and the authors attributed the reduction to the effect of the increase in fibre due to chitin. However, the reduction in FI observed in this study did not decline weight gain with better FCR and this suggests that the reduction in feed intake may be due to the relatively higher metabolisable energy of the diets with MM. It is also known that rabbits are better utilizer of fibre which is the function of the enlarged caecum with the activity of the resident microbes yielding vitamins for the nourishment of the rabbits (Mafimidiwo et al., 2022). The rabbits fed MM50, MM75, and MM100 diets had better FCR compared to other treatments but precisely those fed MM100 diets had the best FCR. This observation implies that there was better utilisation of the diet resulting in increased weight gain despite reduced feed intake. The report of Okah and Onwujiariri (2012) is similar to our findings, the authors reported better FCR for broilers fed a diet containing MM as a replacement for fish meal for finisher broilers. Marono et al. (2017) also reported an improved FCR when laying birds (24–45 weeks) were fed diets with HI as a total replacement for SBM over those fed the control diet. Contrary to our findings, previous studies revealed that the replacement of fish meal with maggot meal in the diet of broilers did not influence FCR (Téguia et al., 2002; Awoniyi, et al., 2003; Dordevic et al., 2008). The improved FCR observed in our study can be attributed to the better utilisable capability of rabbits over poultry birds.

The cost analysis shows that the FC reduced significantly with the inclusion of MM in the diet of rabbits at 75 and 100% replacement levels while it increased with the use of SBM at 100%. This has proven that the price of feed can be reduced with the use of MM as replacement for maize in feeding rabbits. This is in agreement with the findings of Sumbule et al. (2021a, b), the authors observed reduced feed cost of chicks and grower pullets when BSFLM was used as replacement for FM at 100%. Onsongo et al. (2018) also observed reduced feed cost when BSFLM was used to replace FM and SBM in the diet of broilers. The CFC reveals that feeding MM100 diet to rabbits resulted in the lowest CFC and feeding MM50 diet to rabbits resulted to higher CFC compared to other treatments apart from the control. This observation indicates that it is more economical to feed rabbits with the MM100 diet. The reduction in the CFC is associated to the reduced feed consumed in addition to the lower cost of feed as the level of MM increased in the diet. The report of Hatab et al. (2020) is similar to the outcome of this study, the authors reported reduced CFC by 9 and 39% when insect meal replaced meat and bone meal in the diet of Japanese quail at 50 and 100% respectively. The FC/LW and FC/WG shows that increasing inclusion of MM at 50 to 100% resulted in increasing reduction of FC/LW and FC/WG. It was observed in the result that the feeding of MM100 diet to rabbits resulted in the lowest FC/LW and FC/WG which indicates that each 1 kg weight gain can be achieved at a lower cost when rabbits are fed MM100 diet. This is in agreement with the findings of Ijaiya and Eko (2009) who reported lowest FC/WG for broilers fed diet containing silkworm (*Anaphe infracta*) caterpillar meal as replacement for FM at 100%. Okah and Onwujiariri (2012) also observed reduced FC/WG with the use of MM up to 50% in the diet of broilers as replacement for FM which further affirms that the cost of feeding can be reduced with the incorporation of MM in diet of rabbits as replacement for the conventional protein sources.

Nutrient digestibility and nitrogen utilisation

The substitution of SBM with MM at 75 and 100% in the diet of rabbits increased DMD and neutral detergent fibre digestibility (NDFD). This is different from the findings of Bovera et al. (2016) who reported that high inclusion of TM larva meal in the diet of broilers reduced the apparent ileal digestibility coefficient of dry matter (DM) and organic matter (OM). The use of HI larva meal at high inclusion in the diet of laying hens resulted in reduced DM and OM digestibility (Bovera et al. 2018). The discrepancies observed for DM digestibility could be associated with the peculiarities in animal species and insect meals in terms of nutrient utilisation capacity and digestibility of insects respectively. The reports by previous authors have also indicated that chitin as a constituent of the insect meal can influence the digestibility of nutrients negatively and collectively hamper the digestion of DM despite being a good source of energy and amino acid (De Marco et al., 2015; Schiavone et al., 2017). The inclusion of fibre at a lower level may be beneficial but levels as high as 30 g/kg have been reported to negatively affect nutrient utilisation (Tejeda and Kim, 2021). The total replacement of MM for SBM in the diet of rabbits resulted in the highest CPD which is in agreement with the report of Hwangbo et al. (2009) who reported higher CPD (98%) in broilers fed a diet containing 300 g/kg of dried house fly larva meal as a replacement for SBM. The increased CPD observed is indicative of adequacy of the nutrient in MM100 diets and this suggests it can easily replace SBM in the diets of rabbits because the feeding of MM100 diet to rabbits also resulted in the highest FW and TWG. However, Bovera et al. (2018) and Cutrignelli et al. (2018) reported decreasing CPD with increasing inclusion levels of HI larva meal up to 14.60 and 17% respectively as substitute to SBM in the diet of laying hens. Increased levels of TM larva meal in the diet of broiler chickens resulted in reduced apparent ileal digestibility coefficient of crude protein and dry matter (Bovera et al., 2016). The variation in reports observed could be associated with differences in the nutritive constituent of insects, diet composition, and animal species.

The EED of rabbits fed MM50, MM75and MM100 diets were similar to those fed the MM0 diet (control). This observation indicates that the replacement of MM for SBM in diets of rabbits at these levels was able to elicit the same EED digestibility as that of the control diet. The relatively higher EED observed for the group of rabbits fed the MM100 diet could be attributed to the higher fat content of MM with the inclusion level. This is similar to the findings of Kiero´nczyk et al. (2018) who reported increased EED for broilers fed diets containing TM oil as a replacement for soybean oil. Cullere et al. (2016) also reported higher EED (89.60%) for broiler quails fed a diet containing 15% defatted HI larva meal compared to other treatments. Increased complete total tract apparent digestibility (CTTAD) of EE was reported by Gariglio et al. (2019) when the inclusion of HI larva meal increased in the diet of Muscovy ducks during grower and finisher periods. Furthermore, the nutrient digestibilities for EE, and CF of rabbits fed MM50, MM75 and MM100 diets and those fed the MM0 diet were comparable. It is an indication that the diets contain similar levels of these nutrients as the soyabean meal required by rabbits for optimum growth response. The AD observed increased for the rabbits fed MM50, MM75, and MM100 diets and this suggests increased mineral availability and utilisation by the rabbits. It was also observed that NFED increased for rabbits fed MM25, MM50, MM75, and MM100 diets. This diverges from the report of Ajiboye et al. (2022) who reported no significant difference in the AD of broilers fed a diet containing differently processed MM as a total replacement for fishmeal. Nampijjaa et al. (2023) however observed reduced AD for broilers fed diets containing BSFLM as a substitute for FM at 75 and 100% within 1–28 days. These authors attributed the reduction in digestibility of broilers with increasing dietary BSFLM to chitin which is a component of the cell wall of the exoskeleton of black Soldier fly larvae. It is not known to be indigestible and inhibits nutrient digestibility and utilization (Sánchez-Muros et al., 2014). The increased digestibility observed in the current study implies that the rabbit was able to utilise MM efficiently. The ADFD showed no significant difference among dietary treatments. However, Strychalski et al. (2021) reported increased digestibility coefficients of acid detergent fiber and acid detergent lignin for rabbits fed diets containing 4% each of silkworm pupae meal and mealworm larvae meal as a replacement for SBM. The differing reports could be due to differences in insect meals and diet composition.

The nitrogen utilisation followed the same trend for all parameters determined. The rabbits fed MM100 diets had significantly higher values than other treatments. The increased NI and NR observed for rabbits fed the MM100 diet is associated with the high crude protein content of maggot meal which is evident with increased NPU obtained with the same group of rabbits. The nitrogen excreted in urine (NEU) is higher for rabbits fed MM100 diets but nitrogen excreted in faeces (NEF) is similar across treatment and this implies that despite the increased NI by the group of rabbits fed MM100 diets, it did not lead to the resultant increase in NEF which indicates good nitrogen utilisation. It has been known that ingested crude protein by rabbits is been utilise for protein synthesis and tissue accretion and the unutilised is excreted in urine and faeces (Calvet et al., 2008). The reports, however, by Gugołek et al. (2021) revealed that an increased inclusion rate of silkworm pupae meal in the diets of rabbits resulted in deceased NI. This contrary report could be associated with differences in diet composition.

Carcass characteristics and organ weights

The observations from carcass characteristics of rabbits fed diets with MM as a replacement for SBM show that rabbits fed the MM100 diet had increased LW and those fed MM25 diet had reduced LW. However, those fed MM50 and MM75 diets had comparable LW with those fed MM0 diet. A similar pattern was observed for DW. The result obtained indicates that the replacement of SBM with MM at 100% was able to yield increased live weight due to nutrient availability particularly protein for increased tissue formation. The DP also shows that rabbits fed the MM100 diet had increased DP but those fed MM25 and MM50 diets had reduced DP while those fed MM0 and MM75 diets had similar DP. This observation suggests that MM could replace SBM at 100% in the diet of rabbits conveniently without compromising carcass yield and the similar DP obtained for rabbits fed MM0 and MM75 diets implies that the MM75 diet can support as much growth as the conventional MM0 diet. This agrees with the report of Schiavone et al. (2017) who reported increased live weight and carcass weight of broilers fed a diet with 10% HI larva meal as a substitute for SBM. Improved carcass weight was also reported by Loponte et al. (2017) for Barbary partridges (*Alectoris barbara)* fed diets with HI and TM partially replacing SBM at 25 and 50% respectively. However, Biasato et al. (2018) and Onsongo et al. (2018) observed no significant effect of yellow mealworm larvae and BSFLM inclusion respectively in the diet of broilers on carcass traits. The contradictory reports may be due to differences in diet formulations.

The fore limb and hind limb weight were highest for rabbits fed MM50 and MM100 diets and this may partially be attributed to their LW. This is in agreement with the report of Pieterse et al. (2014) who reported higher carcass weight as well as breast and thigh weight for broilers fed a diet containing 10% MD larva meal as the protein source than those fed the control diet. Rabbits fed MM0 and MM100 diets had increased loin weight and this suggests the suitability of MM inclusion in the diet of rabbits. Higher head weight was observed for the group of rabbits fed the MM100 diet than other treatment groups. Trotters' weight increased for rabbits fed MM75 and MM100 diets. The increased weight of the cut part is a result of the increased LW. Latorre et al. (2008) also reported that the weight of cut parts increased with an increase in weight at slaughter. This is also in agreement with the report of Njidda and Isidahomen (2010) who reported better slaughter and trotters' weight for rabbit fed diet containing grasshopper meal at 50% replacement for FM than the control group.

The GIT weight of rabbits fed the MM0 diet increased which suggests the effect of pressure on the GIT in digesting the feed components which may be linked to the percentage fibre composition of the diet. The weight of lungs increased for rabbits fed MM75 and MM100 diets however, it was similar to those fed MM0 diets. This is an indication that there was no deleterious effect of MM inclusion on the lungs of the rabbit. The liver weight increased for rabbits fed the MM100 diet which is similar to the report of Téguia et al. (2002) who reported an increase in liver weight of broilers fed a diet containing maggot meal as a replacement for FM at starter and finisher phase. Hatab et al. (2020) also reported increasing liver weight of Japanese quail with increasing dietary inclusion of *Spodopter littoralis* larvae. The increased liver weight of rabbits fed a diet containing MM irrespective of inclusion level compared to those fed MM0 diets can be attributed to diet composition precisely MM which contains high ether extract. In addition, the increased liver weight can also be due to the fact that the liver functions in the emulsification of fat. However, the study of Sumbule et al. (2021a, b) showed no significant effect of BSFLM inclusion in the diet of layer chicks and growers on all internal organs. Njidda and Isidahomen (2010) also reported no significant effect of grasshopper meal inclusion as a replacement for FM in the diet of rabbits on the weight of the heart, liver, lungs, and kidneys. The contrasting reports could be due to differences in specie of animal used and insect meal. It was also observed that the heart and spleen weight were not significantly different across treatment which suggests that the inclusion of MM in the diet of rabbits did not negatively influence these vital organs of the rabbits. This study has revealed the benefits that could be achieved with the use of MM in the diet of rabbits however, further studies should be considered to investigate the meat quality and lipid profile of rabbits as affected by the dietary inclusion of MM.

Conclusion

From the result of this experiment, it could be inferred that maggot meal can successfully be used to replace soybean meal in the diet of rabbits up to 100% level for improved WG, FCR, reduced FC and reduced FC/WG. The feeding of MM75 and MM100 diets to rabbits increased rabbits' ATTD of DM, CP, EE, CF, Ash, NFE and NDF. The NI, NR and NPU increased with the feeding of MM100 diet to rabbits. Increased LW, DW, DP and cut parts can be achieved with inclusion of MM as replacement for SBM up to 100%. The total GIT decreased while the liver increased in weight with the feeding of MM100 diet to rabbits without adverse effect on other internal organs. It is therefore recommended that maggot meal could be substituted for soybean meal in growing rabbits' diet up to 100%.

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Data availability The datasets used and/or analysed during the current study are available from the corresponding author.

Code availability Not applicable

Declarations

Compliance with ethical standards All experimental procedures were executed in accordance with the approved guidelines for Animal Research by the Animal Use and Care Unit at Yaba College of Technology Lagos.

Consent to participate (Not applicable)

Consent for publication (Not applicable)

Conflict of interest The authors declare that they have no conflict of interest.

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