sustainability

MDPI

Article

A Nutritional Evaluation of Insect Meal as a Sustainable Protein Source for Jumbo Quails: Physiological and Meat Quality Responses

Fezile G. T. Mbhele [1,2], Caven Mguvane Mnisi [1,2,*] and Victor Mlambo [3]

1. Department of Animal Science, Faculty of Natural and Agricultural Science, North-West University, Mafikeng 2735, South Africa; mbhelefezile@gmail.com
2. Food Security and Safety Niche area, Faculty of Natural and Agricultural Science, North-West University, Mafikeng 2735, South Africa
3. School of Agricultural Sciences, Faculty of Agriculture and Natural Sciences, University of Mpumalanga, Nelspruit 1200, South Africa; victor.mlambo@ump.ac.za

* Correspondence: mnisiecm@gmail.com or 23257539@nwu.ac.za; Tel.: +27-18-389-2738

Received: 4 November 2019; Accepted: 15 November 2019; Published: 22 November 2019

check for updates

Abstract: The use of insect meals in place of soybean meal in diets is critical for sustainable intensification of poultry production, but the utility of this alternative dietary protein source is unknown for the Jumbo quail. Therefore, this study investigated the effect of partial substitution of soybean with black soldier fly larvae (BSFL) meal on feed intake, physiological, and meat quality parameters of Jumbo quails. Three hundred and fifteen mixed-gender quails (53.8 ± 5.19 g live-weight) were reared on five isonitrogenous and isoenergetic experimental diets formulated by replacing soybean products with BSFL meal at 0 (BSFL0), 25 (BSFL25), 50 (BSFL50), 75 (BSFL75), and 100 (BSFL100) g/kg. Feed intake, body weight gain, gain-to-feed ratio (G:F), blood parameters, and carcass and meat quality traits were determined. Quadratic trends were observed for overall feed intake ($y = 605\ (\pm 17.56) + 2.1\ (\pm 0.82)x - 0.02\ (\pm 0.008)x^2$; $R^2 = 0.20$; $p = 0.023$) and overall body weight gain ($y = 155\ (\pm 4.70) + 0.57\ (\pm 0.22)x - 0.005\ (\pm 0.002)x^2$; $R^2 = 0.22$; $p = 0.026$) in response to BSFL levels. However, there were neither linear nor quadratic trends for meat quality and blood parameters, except for albumin-to-globulin ratio. Only gizzard size linearly increased ($y = 0.05\ (\pm 0.004)x + 2.3\ (\pm 0.09)$; $R^2 = 0.18$; $p = 0.04$) with BSFL levels. We concluded that BSFL meal could replace soybean products in Jumbo quail diets at 54 g/kg without compromising weight gain and meat quality.

Keywords: feed production; growth performance; insect meal; jumbo quails; meat quality; soybean; sustainable intensification

1. Introduction

The production and use of feed in the livestock sector account for approximately 14.5% of total greenhouse gas emissions [1]. An anticipated increase in the demand for poultry products means more arable land will be required for feed grain production. This will inevitably lead to higher levels of atmospheric carbon [2] due to deforestation and land preparation activities. The demand for soybean, the main protein source in poultry diets, has also steadily increased due to competition between animal and human needs [3]. This has led to higher market prices for this vegetable protein thus compromising its contribution to food and nutrition security. Sustainable intensification of poultry production requires the use of feed ingredients whose production requires less water, land, and results in lower greenhouse gas emissions [4]. This approach will ensure environmental, financial, and social sustainability of the poultry industry. The sustainability of the poultry industry also requires diversification of bird species used to supply animal protein. This has seen the introduction of novel bird species such as the quail.

The Jumbo quail (*Coturnix coturnix*), in particular, is a recently developed meat-type breed that grows fast and reaches sexual maturity as early as six weeks of age. It is a larger and meatier version of the Japanese quail (*Coturnix coturnix japonica*). However, in order to sustainably intensify the production of the Jumbo quail, alternative dietary protein sources with lower environmental costs compared to soybeans are required [5]. Examples of such alternative and sustainable protein sources include insect meals such as black soldier fly (*Hermetia illucens*) larvae meal [6].

Black soldier fly larvae meal contains about 50% protein of higher biological value compared to that of soybean protein [6,7]. Insect meals have been nutritionally evaluated in chickens to some degree [8] but not in Jumbo quails. In particular, the tolerance level for this novel protein source in Jumbo quails is unknown. This is despite the fact that wild birds and scavenging chickens commonly consume adult insects, larvae, and pupae [9]. In addition, current research on the use of insect meals as an ingredient in animal diets has focused on the housefly (*Musca domestica*) in both fish and poultry diets and on black soldier fly larvae (BSFL) in fish diets [9,10]. Inclusion of insect larvae meal in broiler diets decreased the incidence of metabolic skeletal disorders while improving bird health [11]. Positive effects of *Tenebrio molitor* and *Hermetia illucens* meals on broiler production and health have also been reported by Oyegoke et al. [12] and Biasato et al. [13]. In contrast, there is no information on the effect of feeding insect meals to Jumbo quails, presumably because these birds are relatively new entrants into the commercial poultry production sector. Indeed, no studies have attempted to determine the optimal inclusion level of BSFL meal in Jumbo quail diets. Therefore, we determined the optimum inclusion level of black soldier fly larvae meal when used as a partial replacement for soybean products using growth performance, hematology, serum biochemistry, and carcass and meat quality traits of Jumbo quails as response indicators. We hypothesized that the inclusion of graded levels of insect meal protein in place of soybean products would elicit a quadratic response in terms of feed intake, physiological, and meat quality parameters of Jumbo quails.

2. Materials and Methods

2.1. Study Site and Dietary Ingredient Sources

The feeding trial was conducted at the North-West University Molelwane farm (25°40.459′ S, 26°10.563′ E), in the North West province of South Africa. The study was carried out during winter season when ambient temperatures ranged between −3 and 25 °C. Infrared lamps were used to provide warmth to the quails. Dried and defatted black soldier fly larvae (BSFL) meal was bought from AgriProtein (PTY) LTD (Cape Town, South Africa), a feed manufacturing company located in Cape Town (Western Cape, South Africa). The BSFL meal was produced on organic waste before undergoing quality control checks. The chemical composition of BSFL meal was quoted by the supplier as 900 g/kg dry matter, 500 g/kg crude protein, 130 g/kg crude fibre and 100 g/kg crude fat. Soybean products (soya oilcake and full-fat soya) and all other ingredients were purchased from Optifeeds (PTY) LTD (Lichtenburg, South Africa).

2.2. Diet Formulation

The BSFL meal was milled (2 mm; Polymix PX-MFC 90 D) prior to blending with other dietary ingredients. The experimental diets (Table 1) were formulated to be isonitrogenous and isoenergetic by replacing soybean products with BSFL meal as follows: (1) BSFL0 = commercial grower diet with no BSFL meal inclusion, (2) BSFL25 = commercial grower diet in which 25 g/kg of soybean products was replaced with BSFL meal, (3) BSFL50 = commercial grower diet in which 50 g/kg of soybean products was replaced with BSFL meal, (4) BSFL75 = commercial grower diet in which 75 g/kg of soybean products was replaced with BSFL meal, and (5) BSFL100 = commercial grower diet in which 100 g/kg of soybean products was replaced with BSFL meal.

Table 1. Ingredients and chemical composition (g/kg as-fed basis, unless stated otherwise) of experimental diets.

	[1] Diets				
	BSFL0	**BSFL25**	**BSFL50**	**BSFL75**	**BSFL100**
Ingredients					
Black soldier fly larvae meal	0.0	25.0	50.0	75.0	100.0
Yellow maize	661.0	681.0	669.0	660.0	631.0
Soya oilcake	193.0	201.0	149.0	142.0	92.0
Full fat soya	74.0	15.0	15.0	15.0	15.0
Sunflower oilcake	25.0	31.0	71.0	64.0	100.0
[2] MDCP	12.7	12.2	11.4	10.4	10.0
Feed lime	10.4	10.4	10.5	10.8	10.6
Wheaten bran	10.0	10.0	10.0	10.0	30.0
Salinomycin (12%)	5.0	5.0	5.0	5.0	5.0
Zinc bacitracin (15%)	5.0	5.0	5.0	5.0	5.0
Salt-Fine	3.40	3.27	3.06	3.70	3.01
Hemicell® (β-mannanase)	3.0	3.0	3.0	3.0	3.0
Lysine	2.65	2.44	2.42	1.73	1.41
Vitamin premix	2.5	2.5	2.5	2.5	2.5
Methionine	2.44	2.34	2.11	1.92	1.68
Sodium bicarbonate	1.51	1.57	1.74	0.40	1.56
Threonine	0.52	0.55	0.53	0.39	0.30
Axtra® Phy (Phytase)	1.0	1.0	1.0	1.0	1.0
Chemical composition					
Dry matter	900.0	899.8	901.0	895.4	904.0
Crude protein	184.9	185.2	188.1	193.2	192.3
Ash	51.1	50.1	49.2	49.5	48.9
Crude fat	44.2	40.1	45.4	50.6	56.5
Crude fibre	40.9	42.1	49.2	48.1	56.5
[3] ME (MJ/Kg)	12.04	12.04	12.04	12.04	12.04
Calcium	7.9	7.9	7.9	7.9	7.9
Potassium	7.2	7.1	7.1	6.7	7.5
Phosphorus	5.5	5.6	5.8	5.9	6.0
Chlorine	3.0	3.0	3.0	3.0	3.0
Sodium	1.8	1.8	1.8	1.8	1.8

[1] Diets: BSFL0 = a commercial grower diet with no black soldier fly larvae meal inclusion, BSFL25 = a commercial grower diet in which 25 g/kg of soybean products was replaced with black soldier fly larvae meal, BSFL50 = a commercial grower diet in which 50 g/kg of soybean products was replaced with black soldier fly larvae meal, BSFL75 = a commercial grower diet in which 75 g/kg of soybean products was replaced with black soldier fly larvae meal, and BSFL100 = a commercial grower diet in which 100 g/kg of soybean products was replaced with black soldier fly larvae meal.; [2] MDCP = mono-dicalcium phosphate; [3] ME = predicted metabolizable energy.

2.3. Chemical Analyses

Subsamples of formulated diets (BSFL0, BSFL25, BSFL50, BSFL7,5 and BSFL100) were analyzed using the AOAC international methods [14] for laboratory dry matter (method no. 930.15), ash (method no. 924.05), crude fibre (method no. 978.10), crude fat (method no. 920.39), and crude protein (method no. 984.13). Metabolizable energy (ME) contents were predicted using the near-infrared reflectance spectroscopy (NIRs) SpectaStar XL (Unity Scientific, Emu Heights, Australia). Minerals were determined following Agri Laboratory Association of Southern Africa guidelines [15].

2.4. Experimental Design and Quail Management

The rearing and slaughter procedures of the quails were approved by the Animal Research Ethics Committee of the North-West University (approval no. NWU-00483-18-A5) according to established guidelines for use and care of research animals. A total of 315, day-old mixed-gender, Jumbo quails were purchased from a Quail Breeder (Gauteng, South Africa). The quails were reared using a commercial starter mash from Nutrifeeds (PTY) LTD (Lichtenburg, South Africa), until one week of age. The five dietary treatments were randomly allocated to 35 pens (experimental units), which were replicated seven times per dietary treatment with each replicate pen (100 cm long × 60 cm wide × 30 cm high) carrying nine quails. The pens had wire mesh floor but without bedding. On average, the temperature and humidity inside the poultry house during the experimental period were 30 °C and 40%, respectively. Rearing was done under natural lighting (12 h of daylight). The birds were then adapted to the dietary treatments for one week before the commencement of measurements at two weeks of age. Fresh, clean water and the diets were offered ad libitum during the 42-day feeding trial.

2.5. Feed Intake and Growth Performance

At two weeks of age, initial live-weights of the birds were taken and subsequently weighed weekly per pen until they were six weeks of age (final weight). Feed intake per bird was measured by dividing total intake per pen by the total number of quails in the pen. The live weights obtained weekly were used to calculate the average weekly body weight gain (ABWG). The ABWG and AWFI were then used to calculate gain-to-feed ratio (G:F).

2.6. Slaughter and Hemato-Biochemical Analyses

Six-week-old quails were transported to Rooigrond poultry abattoir (North West, South Africa) where they were humanely slaughtered. While bleeding the birds, blood was collected into two sets of tubes from two randomly selected birds per pen. For hematological analysis, tubes containing ethylenediaminetetraacetic acid were used during blood collection. Hematological parameters: hemoglobin, white blood cells (WBC), heterophils, eosinophils, monocytes, and lymphocytes were determined using an automated IDEXX LaserCyte Hematology Analyzer (IDEXX Laboratories, Inc., Johannesburg, South Africa). Serum was generated for biochemical analysis according to Washington and van Hoosier [16]. Albumin-to-globulin ratio (ALB/GLOB), total bilirubin, albumin, lipase, alkaline phosphate (ALKP), phosphorus, alanine transaminase (ALT), amylase, creatinine, calcium, globulin, glucose, total protein, and urea were analyzed using an automated IDEXX Vet Test Chemistry Analyzer (IDEXX Laboratories, Inc., Johannesburg, South Africa).

2.7. Carcass Traits and Internal Organs

Immediately after slaughter and for each replicate treatment group, the carcasses were labelled and placed in tagged transparent plastic bags. The carcasses were immediately weighed to determine hot carcass weight (HCW). After chilling for 24 h, the carcasses were reweighed to determine cold carcass weight (CCW). Dressing (%) was calculated as the proportion of HCW on slaughter weight. Wings, thighs, drumsticks, and breast, as well as weights of liver, gizzard, heart, proventriculus, and small and large intestine, were weighed and expressed as a proportion of HCW.

2.8. Meat Quality

Meat pH and temperature were measured on the pectoralis major muscle using a Corning Model 4 pH–temperature meter (Corning Glass Works, Medfield, MA, USA). A thigh muscle sample was used to determine meat color (L^* = lightness, a^* = redness, and b^* = yellowness) following the guidelines of the Commission Internationale de l'Eclairage [17]. Hue angle and chroma values were calculated as described by Priolo et al. [18].

To determine cooking loss, breast muscle samples were weighed (w1) and cooked in an oven at 130 °C for 20 min. After cooking, meat samples were cooled and re-weighed (w2). The loss in weight was expressed as a proportion of the initial sample weight. Cooked breast samples (~22 g) were then sheared using a Texture Analyzer (TA XT plus, Stable Micro Systems, Surrey, UK) to measure shear force in Newtons.

Water holding capacity (WHC) was determined according to Grau and Hamm [19] using the pectoral major muscle (~10 g), which was placed between plexiglass plates and held under pressure (60 kg of pressure) using dumbbell weights. For drip loss measurements, triplicate breast meat samples from each replicate treatment group were sliced with a knife into strips (~3 g; $w1$) and thereafter sewed on a flat cardboard using wool and hung on top of the cold room (4 °C) sealing so that the samples did not touch the cardboard. After 72 h, the samples were gently removed and reweighed ($w2$). The percentage drip loss was calculated by expressing the loss in weight ($w1 - w2$) of breast meat sample as a proportion of the initial weight of the meat sample ($w1$).

2.9. Statistical Analysis

Data for all measured parameters were analyzed for linear and quadratic effects with the aid of polynomial contrasts. The response of these parameters to incremental levels of BSFL was determined through response surface regression analysis (Proc RSREG; [20]). Weekly measured parameters (feed intake, weight gain, and gain-to-feed ratio) were analyzed using the repeated measures analysis [20] to determine any significant week × diet interaction effects. Data for parameters measured only once such as blood parameters, size of internal organs, carcass characteristics, meat quality, overall feed intake, weight gain, and gain-to-feed ratio were analyzed using the general linear model procedure of statistical analysis system [20] with diet as the only main factor. For all statistical tests, significance was declared at $p \leq 0.05$. Treatment means were separated using the probability of the difference option in the LSMEANS statement of SAS [20].

3. Results

Repeated measures analysis showed a significant diet × week interaction for G:F but not for average weekly feed intake (AWFI) and ABWG. Table 2 shows that there were significant linear trends for G:F in week 3 ($y = 0.40\ (\pm0.016) - 0.0009\ (\pm0.00077)x$; $R^2 = 0.159$; $p = 0.047$) and week 5 ($y = 0.189\ (\pm0.0217) + 0.0023\ (\pm0.00101)x$); $R^2 = 0.290$; $p = 0.011$) in response to BSFL levels. However, there were neither linear nor quadratic effects ($p > 0.05$) for G:F in Weeks 4 and 6.

Table 2. The average weekly gain-to-feed ratio in Jumbo quails fed diets containing black soldier fly larvae meal as a partial replacement of soybean products.

Week	[1] Diets						Significance	
	BSFL0	BSFL25	BSFL50	BSFL75	BSFL100	[2] SEM	Linear	Quadratic
3	0.396	0.386	0.357	0.347	0.352	0.015	0.047	0.572
4	0.345	0.359	0.340	0.340	0.356	0.012	0.533	0.888
5	0.235	0.261	0.274	0.277	0.281	0.029	0.011	0.117
6	0.186	0.125	0.129	0.150	0.131	0.025	0.312	0.322

[1] Diets: BSFL0 = a commercial grower diet with no black soldier fly larvae meal inclusion, BSFL25 = a commercial grower diet in which 25 g/kg of soybean products was replaced with black soldier fly larvae meal, BSFL50 = a commercial grower diet in which 50 g/kg of soybean products was replaced with black soldier fly larvae meal, BSFL75 = a commercial grower diet in which 75 g/kg of soybean products was replaced with black soldier fly larvae meal, and BSFL100 = a commercial grower diet in which 100 g/kg of soybean products was replaced with black soldier fly larvae meal; [2] SEM: standard error of the mean.

No linear trends ($p > 0.05$) were observed for overall feed intake, overall BWG, and final weight (Table 3). However, there were significant quadratic trends for overall feed intake ($y = 605\ (\pm17.56) + 2.1\ (\pm0.82)x - 0.02\ (\pm0.0077)x^2$; $R^2 = 0.20$; $p = 0.023$) and overall BWG ($y = 155\ (\pm4.70) + 0.57\ (\pm0.22)x - 0.0049\ (\pm0.002)x^2$; $R^2 = 0.22$; $p = 0.03$), from which an optimum BSFL inclusion level was calculated to be 5.4%.

Table 3. Overall feed intake (g/bird), overall body weight gain (g/bird) and slaughter weight (g/bird) of Jumbo quails fed diets containing black soldier fly larvae meal in place of soybean products.

	[1] Diets						Significance	
	BSFL0	**BSFL25**	**BSFL50**	**BSFL75**	**BSFL100**	**[2] SEM**	**Linear**	**Quadratic**
Overall FI	598.9	651.3	650.7	656.0	627.7	15.54	0.543	0.023
Overall BWG	151.2	170.0	166.7	168.1	164.3	5.094	0.263	0.026
Final body weight	207.3	223.6	213.4	218.2	217.2	6.210	0.428	0.557

[1] Diets: BSFL0 = a commercial grower diet with no black soldier fly larvae meal inclusion, BSFL25 = a commercial grower diet in which 25 g/kg of soybean products was replaced with black soldier fly larvae meal, BSFL50 = a commercial grower diet in which 50 g/kg of soybean products was replaced with black soldier fly larvae meal, BSFL75 = a commercial grower diet in which 75 g/kg of soybean products was replaced with black soldier fly larvae meal, and BSFL100 = a commercial grower diet in which 100 g/kg of soybean products was replaced with black soldier fly larvae meal; [2] SEM: standard error of the mean.

Table 4 shows that there were no linear nor quadratic effects for all the blood parameters, except for the ABL/GLOB ratio, which showed a quadratic trend ($y = 0.39\ (\pm 0.065) + 0.008\ (\pm 0.0031)x - 0.00007\ (\pm 0.000027)x^2$; $R^2 = 0.337$; $p = 0.030$) in response to BSFL meal inclusion levels. A significant quadratic trend was observed for breast weights ($y = 21.9\ (\pm 0.637) + 0.054\ (\pm 0.0299)x - 0.00058\ (\pm 0.000278)x^2$; $R^2 = 0.168$; $p = 0.046$) in response to BSFL levels. However, no significant trends were observed for dressing percentage and any of the other carcass traits (Table 5).

Table 4. The effect of black soldier fly larvae meal-containing diets on blood parameters of six-week-old Jumbo quails.

[2] Parameters	[1] Diets					[3] SEM	Significance	
	BSFL0	**BSFL25**	**BSFL50**	**BSFL75**	**BSFL100**		**Linear**	**Quadratic**
Hemoglobin (g/dL)	10.8	12.3	11.3	12.1	12.2	0.942	0.442	0.918
WBC ($\times 10^9$/L)	31.3	31.0	30.2	41.8	22.2	10.14	0.475	0.074
Heterophils ($\times 10^9$/L)	4.22	5.93	4.38	9.90	3.60	1.975	0.474	0.165
Lymphocytes ($\times 10^9$/L)	18.0	19.9	22.6	21.7	16.4	5.294	0.562	0.077
Monocytes ($\times 10^9$/L)	8.67	4.58	2.84	9.54	2.12	4.370	0.562	0.290
Eosinophils ($\times 10^9$/L)	0.41	0.46	0.28	0.61	0.41	0.181	0.633	0.955
ALB/GLOB	0.37	0.60	0.55	0.45	0.45	0.050	0.878	0.030
Albumin (g/L)	29.0	23.3	26.0	20.8	19.6	5.750	0.398	0.337
ALKP (U/L)	855.8	414.2	474.0	480.0	511.7	177.2	0.428	0.121
ALT (U/L)	15.3	13.0	14.8	10.0	19.6	8.130	0.903	0.709
Amylase (U/L)	410.5	316.9	357.7	131.8	294.3	81.53	0.515	0.781
Calcium (mmol/L)	3.83	3.04	3.22	3.38	3.45	0.400	0.821	0.114
Creatinine (µmol/L)	33.3	19.9	40.9	30.2	12.4	15.66	0.644	0.881
Globulin (g/L)	59.0	37.0	50.1	41.5	47.0	14.62	0.219	0.129
Glucose (mmol/L)	23.8	12.3	17.2	26.2	20.0	4.810	0.703	0.535
Lipase (U/L)	181.1	263.4	172.4	190.0	199.8	59.65	0.757	0.965
Phosphorus (mmol/L)	4.50	4.82	4.59	4.20	4.34	0.580	0.595	0.560
Bilirubin (µmol/L)	22.8	11.7	14.5	12.4	10.1	6.790	0.153	0.392
Total protein (g/L)	95.0	68.4	76.0	100.0	66.8	14.74	0.221	0.235
Urea (mmol/L)	1.24	0.98	1.21	0.83	0.63	0.400	0.976	0.884

[1] Diets: BSFL0 = a commercial grower diet with no black soldier fly larvae meal inclusion, BSFL25 = a commercial grower diet in which 25 g/kg of soybean products was replaced with black soldier fly larvae meal, BSFL50 = a commercial grower diet in which 50 g/kg of soybean products was replaced with black soldier fly larvae meal, BSFL75 = a commercial grower diet in which 75 g/kg of soybean products was replaced with black soldier fly larvae meal, and BSFL100 = a commercial grower diet in which 100 g/kg of soybean products was replaced with black soldier fly larvae meal; [2] Parameters: WBC = white blood cells; ALB/GLOB = albumin/globin ratio; ALKP = alkaline phosphate; ALT = alanine aminotransferase; [3] SEM: standard error of the mean.

Table 5. Internal organs and carcass characteristics (g/100 g HCW, unless stated otherwise) of six-week-old Jumbo quails fed with black soldier fly meal-containing diets.

[2] Parameters	[1] Diets					[3] SEM	Significance	
	BSFL0	BSFL25	BSFL50	BSFL75	BSFL100		Linear	Quadratic
Dressing (%)	67.7	68.8	69.2	68.2	68.5	0.462	0.652	0.273
HCW (g)	140.4	154.0	147.5	148.7	148.7	4.260	0.460	0.511
CCW (g)	139.5	152.7	145.6	147.3	147.8	4.230	0.355	0.493
Wing	4.29	4.29	4.29	4.49	4.26	0.120	0.815	0.322
Thigh	6.04	6.27	6.14	6.25	6.27	0.210	0.649	0.448
Drumstick	4.25	4.22	4.26	4.26	4.25	0.130	0.973	0.510
Breast	22.4	21.9	22.3	22.3	21.3	0.750	0.425	0.044
Liver	2.90	3.03	2.98	3.20	3.12	0.162	0.252	0.645
Large intestine	1.37	1.52	1.57	1.43	1.42	0.072	0.881	0.040
Small intestine	3.69	3.84	4.00	4.11	3.87	0.159	0.242	0.155
Proventriculus	0.58	0.52	0.64	5.59	0.55	2.470	0.550	0.463
Heart	1.15	1.17	1.22	1.06	1.14	0.055	0.507	0.703
Gizzard	2.32	2.38	2.45	2.52	2.52	0.082	0.037	0.445

[1] Diets: BSFL0 = a commercial grower diet with no black soldier fly larvae meal inclusion, BSFL25 = a commercial grower diet in which 25 g/kg of soybean products was replaced with black soldier fly larvae meal, BSFL50 = a commercial grower diet in which 50 g/kg of soybean products was replaced with black soldier fly larvae meal, BSFL75 = a commercial grower diet in which 75 g/kg of soybean products was replaced with black soldier fly larvae meal, and BSFL100 = a commercial grower diet in which 100 g/kg of soybean products was replaced with black soldier fly larvae meal; [2] Parameters: HCW = hot carcass weight; CCW = cold carcass weight; [3] SEM: standard error of the mean.

Table 5 shows that there were linear effects ($p < 0.05$) for gizzard weight, which linearly increased ($y = 0.05\ (\pm 0.004)x + 2.3\ (\pm 0.085)$; $R^2 = 0.18$; $p = 0.04$) with BSFL levels. There were significant quadratic effects for size of large intestine ($y = 1.4\ (\pm 0.077) + 0.0074\ (\pm 0.0036)x - 0.000073\ (\pm 0.0000337)x^2$; $R^2 = 0.16$; $p = 0.04$). There were no dietary effects ($p > 0.05$) on carcass characteristics, dressing percentage, size of internal organs, and meat quality parameters of Jumbo quails. Similarly, there were neither linear nor quadratic trends ($p > 0.05$) for meat quality parameters (Table 6).

Table 6. The effect of black soldier fly larvae meal-containing diets on meat quality parameters of six-week-old Jumbo quails.

	[1] Diets					[3] SEM	Significance	
	BSFL0	BSFL25	BSFL50	BSFL75	BSFL100		Linear	Quadratic
pH	6.13	6.14	6.13	6.14	6.15	0.030	0.777	0.875
Temperature (°C)	11.8	12.0	11.9	11.6	11.5	0.274	0.287	0.272
*L** (lightness)	43.8	44.5	44.3	44.2	44.6	0.437	0.157	0.641
*a** (redness)	5.77	6.22	6.65	5.88	5.73	0.375	0.310	0.188
*b** (yellowness)	9.90	10.45	10.24	9.95	10.32	0.370	0.807	0.940
Hue angle	1.04	1.03	0.99	1.04	1.07	0.022	0.134	0.129
Chroma	11.5	12.2	12.2	11.6	11.8	0.460	0.791	0.608
[2] WHC (%)	6.35	7.01	6.25	6.09	7.40	0.850	0.981	0.353
Drip loss (%)	40.2	43.4	40.8	40.4	42.1	0.462	0.670	0.992
Cooking loss (%)	17.1	19.3	21.4	22.6	22.1	1.830	0.125	0.941
Shear force (N)	6.20	6.85	7.55	6.40	6.57	0.760	0.523	0.291

[1] Diets: BSFL0 = a commercial grower diet with no black soldier fly larvae meal inclusion, BSFL25 = a commercial grower diet in which 25 g/kg of soybean products was replaced with black soldier fly larvae meal, BSFL50 = a commercial grower diet in which 50 g/kg of soybean products was replaced with black soldier fly larvae meal, BSFL75 = a commercial grower diet in which 75 g/kg of soybean products was replaced with black soldier fly larvae meal, and BSFL100 = a commercial grower diet in which 100 g/kg of soybean products was replaced with black soldier fly larvae meal; [2] WHC: water holding capacity; [3] SEM: standard error of the mean.

4. Discussion

Repeated measures analyses showed a significant diet and week interaction effect on G:F, indicating that the efficiency of the birds in converting the dietary treatments into body mass depended on their age. The optimum inclusion level for the BSFL meal was found to be 54 g/kg, suggesting that substituting soybean products with BSFL meal at higher rates depress overall feed intake and body weight gain. Indeed, at three weeks of age, G:F linearly decreased with BSFL meal levels, confirming that higher inclusion levels reduced the feed conversion efficiency. This could be due to the presence of chitin in the larvae, a fibrous substance, which reduces nutrient utilization and digestibility [21]. Indeed, Marono et al. [22] reported a decrease in feed intake in laying hens fed *H. illucens* larvae meal. However, Cullere et al. [23] reported that overall performance of Japanese quails reared on BSFL meal was comparable to the ones fed de-fatted soybean meal and soybean oil. Similarly, a feeding trial conducted by Maurer et al. [24] with Leghorn laying hens, where SBM was partly substituted with de-fatted BSFL meal at inclusion levels of 50% and 100%, showed no significant dietary effects.

There is a dearth of information on blood indices of Jumbo quails fed BSFL meal. In this study, a quadratic response was observed for the ALB/GLOB ratio, indicating that at higher inclusion levels, the BSFL may compromise autoimmunity of the quails and cause plasma cell disorders. Indeed, Griminger and Scanes [25] reported that a low ALB/GLOB ratio is an indicator of low immune response for the birds. The fact that the ALB/GLOB initially increased and then declined at even higher inclusion levels of BSFL meal confirms that its inclusion must be capped at 54 g/kg to avoid the overproduction of globulins, which may cause autoimmune diseases. Nonetheless, no dietary influences were observed for all the other blood parameters including the liver enzymes (ALKP and ALP), suggesting that partial replacement of soybean products with BSFL meal did not compromise the health status of the birds. Furthermore, the hemato-biochemical values reported in this study fell within the normal ranges reported for quails [3,26,27]. In addition, several studies also revealed no significant dietary effects on blood parameters of broilers [21], laying hens [22], and Barbary partridges [28] when fed with a variety of insect meals.

Breast weights showed a quadratic response to dietary levels of BSFL meal. This trend was not surprising because a quadratic trend was also observed for overall feed intake and overall weight gain, verifying that including BSFL meal beyond 54 g/kg depressed voluntary feed intake and subsequently reduced the development of the pectoralis major muscle. Gizzard weights linearly increased with the inclusion of BSFL meal, indicating that the fibrous nature of chitin present in the larvae meal challenged the birds. As a result, they responded by developing enlarged gizzards as an anatomical adaptation mechanism to physically degrade this structural polysaccharide. A quadratic response was observed for large intestines, which was not expected. For all the other internal organs, there were no significant dietary effects, which is in agreement with several studies that have reported a lack of dietary effects on the size of internal organs of broiler quails fed BSFL meal [23] and broiler chickens fed mealworm [13].

There were no linear and quadratic trends for all the meat quality parameters in response to incremental levels of BSFL meal, suggesting that substituting soybean products with the larvae meal neither negatively nor positively affected the quality of the meat. Similarly, the experimental diets had no effect on meat pH. These findings are in line with those of Secci et al. [29], who observed a lack of dietary effects on meat pH of Barbary partridges. Nonetheless, the pH values observed from these studies were normal for poultry meat. The lack of dietary effects on color is consistent with the findings of Secci et al. [29] and Cullere et al. [30]; however, it was expected that the presence of carotenoids (~2.15 mg/kg) in BSFL meal would improve the yellowness of the meat [29]. In this study, no dietary effects were observed on drip loss, WHC, and shear force. Schiavone et al. [31] also observed similar results on cooking loss, shear force, and drip loss in Barbary partridges and broiler chickens fed BSFL meals.

5. Conclusions, Limitations and Future Research

It was concluded that BSFL meal could replace soybean products in Jumbo quail diets at an optimal inclusion level of 54 g/kg without compromising their productive performance, health status, and quality of the meat. What may limit the contribution of BSFL to sustainable intensification of the Jumbo quail is the possible reduction in bird performance at inclusion rates beyond 54 g/kg. The antinutritional effects of chitin most likely impose this upper limit in the tolerance level of BSFL.

The use of the enzyme chitinase may allow for the inclusion of higher levels of BSFL meal in Jumbo quail diets thus increasing the utility of this insect meal as a sustainable solution to the current environmental and social challenges that arise from soybean production for animal feed.

Author Contributions: F.G.T.M., C.M.M. and V.M. were equally involved in the conceptualization and execution of this investigation, data analysis, manuscript writing and editing.

Funding: This research received no external funding.

Acknowledgments: Sincere gratitude to Molatelo Madibana (Department of Agriculture, Forestry and Fisheries) for assisting with the procurement of the insect meal used in this study. The financial assistance received by the first author from AgriSeta is also acknowledged.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Vries, M.; Boer, I.J.M. Comparing environmental impacts for livestock products: A review of life cycle assessments. *Livest. Sci.* **2010**, *128*, 1–11. [CrossRef]
2. Foley, J.A.; Fries, R.; Asner, G.P.; Barford, C.; Bonan, G.; Carpenter, S.R.; Chapin, F.S.; Coe, M.T.; Daily, G.C.; Gibbs, H.K. Global consequences of land use. *Science* **2005**, *309*, 570–574. [CrossRef] [PubMed]
3. Mnisi, C.M.; Mlambo, V. Protease treatment of canola meal-containing Japanese quail diets: Effect on physiological parameters and meat quality traits. *J. Appl. Anim. Res.* **2018**, *46*, 1389–1394. [CrossRef]
4. Cassidy, E.S.; West, P.C.; Gerber, J.S.; Foley, J.A. Redefining agricultural yields: From tonnes to people nourished per hectare. *Environ. Res. Lett.* **2013**, *8*, 034015. [CrossRef]
5. Mungkung, R.; Aubin, J. Life cycle assessment for environmentally sustainable aquaculture management: A case study of combined aquaculture systems for carp and tilapia. *Int. J. Life Cycle Assess.* **2013**, *11*, 55–59. [CrossRef]
6. Shumo, M.; Osuga, I.M.; Khamis, F.M.; Tanga, C.M.; Fiaboe, K.K.M.; Subramanian, S.; Ekesi, S.; van Huis, A.; Borgemeister, C. The nutritive value of black soldier fly larvae reared on common organic waste streams in Kenya. *Sci. Rep.* **2019**, *9*, 10110. [CrossRef]
7. Newton, L.; Sheppard, C.; Watson, D.; Burtle, G.; Dove, R. *Using the Black Soldier Fly, Hermetia Illucens, as a Value-Added Tool for the Management of Swine Manure*; College of Agriculture and Environmental Science, University of Georgia: Athens, GA, USA, 2005.
8. Diener, S.; Zurbrugg, C.; Tockner, K. Conversion of organic material by black soldier fly larvae: Establishing optimal feeding rates. *Waste Manag. Res.* **2009**, *27*, 603–610. [CrossRef]
9. Zuidhof, M.; Molnar, C.; Morley, F.; Wray, T.; Robinson, F.; Khan, B.; Al-Ani, L.; Goonewardene, L. Nutritive value of house fly (*Musca domestica*) larvae as a feed supplement for turkey poults. *Anim. Feed Sci. Technol.* **2003**, *105*, 225–230. [CrossRef]
10. Bondari, K.; Sheppard, D.C. Soldier fly larvae as feed in commercial fish production. *Aquaculture* **1981**, *24*, 103–109. [CrossRef]
11. Pieterse, E.; Pretorius, Q.; Hoffman, L.; Drew, D. The carcass quality, meat quality and sensory characteristics of broilers raised on diets containing either Musca domestica larvae meal, fish meal or soya bean meal as the main protein source. *Anim. Prod. Sci.* **2014**, *54*, 622–628. [CrossRef]
12. Oyegoke, O.O.; Akintola, A.J.; Fasoranti, J.O. Dietary potentials of the edible larvae of Cirinaforda (westwood) as a poultry feed. *Afr. J. Biotechnol.* **2006**, *5*, 1799–1802.
13. Biasato, I.; Gasco, L.; Marco, D.M.; Rennab, M.; Rotolob, L.; Dabboub, S.; Capucchioa, M.T.; Biasibettia, I.E.; Tarantolaa, M.; Bianchia, C.; et al. Effects of yellow mealworm larvae (*Tenebrio molitor*) inclusion in diets for female broiler chickens: Implications for animal health and gut histology. *Anim. Feed Sci. Technol.* **2017**, *234*, 253–263. [CrossRef]
14. AOAC. *Official Methods of Analysis of AOAC International*, 16th ed.; Association of Official Analytical Chemists: Arlington, VA, USA, 2005.
15. AgriLASA. *Feed and Plant Analysis Methods*; Agri Laboratory Association of Southern Africa: Pretoria, South Africa, 1998.
16. Washington, I.M.; van Hoosier, G. *Clinical Biochemistry and Hematology*; University of Washington: Seattle, WA, USA, 2012; Volume 8, pp. 59–91. [CrossRef]

17. CIE. *Recommendations on Uniform Color Spaces-color Difference Equations, Psychometric Color Terms*; Supplement No. 2 to CIE Publication No. 15 (E-1.3.1.) 1978, 1971/(TC-1-3); Commission Internationale de l'Eclairage: Paris, France, 1976.
18. Priolo, A.; Moorhead, D.; Agabriel, J. Effects of grass feeding systems of ruminant meat color and flavour: A review. *Anim. Res.* **2002**, *50*, 185–200. [CrossRef]
19. Grau, R.; Hamm, R. About the water-binding capacity of the mammalian muscle. II. *Commun. Z. Lebensm. Unters. Brisk.* **1957**, *105*, 446. [CrossRef]
20. SAS. *Users Guide*; Statistical Analysis System Institute Inc.: Carry, NC, USA, 2010.
21. Bovera, F.; Piccolo, G.; Gasco, L.; Marono, S.; Loponte, R.; Vassalotti, G.; Mastellone, V.; Lombardi, P.; Attia, Y.A.; Nizza, A. Yellow mealworm larvae (Tenebrio molitor) as a possible alternative to soybean meal in broiler diets. *Br. Poult. Sci.* **2015**, *56*, 569–575. [CrossRef]
22. Marono, S.; Loponte, R.; Lombardi, P.; Vassalotti, G.; Pero, M.E.; Russo, F.; Gasco, L.; Parisi, G.; Piccolo, G.; Nizza, S.; et al. Productive performance and blood profiles of laying hens fed *Hermetia illucens* larvae meal as total replacement of soybean meal from 24 to 45 week of age. *Poult. Sci.* **2017**, *96*, 1783–1790. [CrossRef]
23. Cullere, M.; Tasoniero, G.; Giaccone, V.; Miotti-Scapin, R.; Claeys, E.; De Smet, S.; Dalle Zotte, A. Black soldier fly as dietary protein source for broiler quails: Apparent digestibility, excreta microbial load, feed choice, performance, carcass and meat traits. *Animal* **2016**, *10*, 1923–1930. [CrossRef]
24. Maurer, V.; Holinger, M.; Amsler, Z.; Früh, B.; Wohlfahrt, J.; Stamer, A.; Leiber, F. Replacement of soybean cake by Hermetia illucens meal in diets for layers. *J. Insects Food Feed* **2016**, *2*, 83–90. [CrossRef]
25. Griminger, P.; Scanes, C.J. Protein Metabolism. In *Avian Physiology*; Sturkie, P.D., Ed.; Springer: New York, NY, USA, 1986.
26. Mnisi, C.M.; Mlambo, V.; Phatudi, K.G.G.; Matshogo, T.B. Exogenous carbohydrases do not improve nutritional status, growth performance, and meat quality traits of female Japanese quails fed canola-based diets. *S. Afr. J. Anim. Sci.* **2017**, *47*, 923–932. [CrossRef]
27. Mulaudzi, A.; Mnisi, C.M.; Mlambo, V. Dietary Moringa oleifera leaf meal improves growth performance but not haemo-biochemical and meat quality parameters in female Japanese quails. *Pak. J. Nutr.* **2019**, *18*, 953–960. [CrossRef]
28. Loponte, R.; Nizza, S.; Bovera, F.; Riu De, N.; Fliegerova, K.; Lombardi, P.; Moniello, G. Growth performance, blood profiles and carcass traits of Barbary partridge (Alectoris barbara) fed two different insect larvae meals (Tenebrio molitor and Hermetia illucens). *Res. Vet. Sci.* **2017**, *115*, 183–188. [CrossRef] [PubMed]
29. Secci, G.; Moniello, G.; Gasco, L.; Bovera, F.; Parisi, G. Barbary partridge meat quality as affected by Hermetia illucens and Tenebrio molitor larva meals in feeds. *Food Res. Int.* **2018**, *112*, 291–298. [CrossRef] [PubMed]
30. Cullere, M.; Woods, M.J.; van Emmenes, L.; Pieterse, E.; Hoffman, L.C.; Zotte, A.D. Hermetia illucens larvae reared on the different substrates in broiler quail diets: Effect on physiochemical and sensory quality of quail meat. *Animals* **2019**, *9*, 595. [CrossRef] [PubMed]
31. Schiavone, A.; Dabbou, S.; Petracci, M.; Zampiga, M.; Sirri, F.; Biasato, I.; Gai, F.; Gasco, L. Black soldier fly defatted meal as a dietary protein source for broiler chickens: Effects on carcass traits, breast meat quality and safety. *Animal* **2019**, *13*, 2397–2405. [CrossRef]