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Research Article

Superworm Meal Supplementation in Broilers: Impacts on Growth, Immunity, and Profitability

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ABSTRACT

This study investigated the efficacy of superworm-based diets on broilers' performance, immunity, and economics from 1 to 42 days. A total of 120 day old chicks, were divided into four groups having three replicates with 10 birds in each, and were kept in cages. The first group was kept as a control group and fed a basal diet. Group SW1 was supplemented with 1 g/kg of defatted superworm meal (D-SWM) in the feed. Group SW2 was added 2 g/kg of defatted superworm meal to the diet, while Group SW3 was supplemented with 3 g/kg of defatted superworm meal. The Body weight (BW) at day 42 was significantly ($p<0.05$) increased in the SW1 group, while the lowest was recorded in the control group. The overall BW in the finisher phase was significantly highest in the SW1 group, as compared to the control group. On day 35, feed intake (FI) was significantly higher in the control group compared to the supplemented groups. On day 42, the D-SWM supplementation significantly affected broiler chickens' feed consumption ($p<0.05$). The highest FI at day 42 was reported in the control group compared to the D-SWM supplemented groups. The overall feed intake was the highest ($p<0.05$) in the control group, followed by the SW2 and SW3 groups, while the lowest was reported in the SW1 defatted mealworm supplemented group. The feed conversion ratio (FCR) on day 35 significantly increased in the control group compared to the superworms supplemented group. At day 42, the D-SWM supplementation significantly affected broiler chickens' feed conversion ($p<0.005$). The overall FCR in the finisher phase was significantly ($p<0.05$) highest in the control group, while the lowest was reported in the SW1 group. The carcass weight (CW) was significantly affected by DSWM supplementation. The highest carcass weight was reported in the SW1 group, while the lowest was noted for the SW2 group. The eviscerated weight (EW) was the highest in the M1 group as compared to the control group. The dry matter % of broiler chickens supplemented with D-SWM was significantly increased in the control and SW1 groups, followed by SW2 and SW3 groups. The crude protein (CP) digestibility was significantly higher in the control, while it was lowered in the SW3 group. The superworm meal supplementation had a significant effect on the ether extract (EE) digestibility. The EE digestibility was the highest in the control as compared to SW3 group. The Newcastle disease virus (NDV) titer significantly increased in the SW1, SW2, and SW3 while it decreased in the control group. The gross return (GR) and profit margin (PM) were significantly highest in the SW1 group, while the lowest was reported in the control group. In the duodenum, the villus height (VH), crypt depth (CD), and villus surface area VSA were significantly ($p< 0.005$) affected by the DSWM supplementation. The VH, CD, and VSA also significantly increased in the SW supplemented group compared to the control group, which was lower than the supplemented group. In the Jejunum, the VSA was significantly higher in the defatted SW supplemented group than in the control. It was concluded that the DSWM at the rate of 1% improved the body weight, feed conversion ratio, carcass weight, eviscerated weight, histomorphology, gross return, and profit margin.

Keywords: Superworm Meal, Broilers, Performance, Feed Conversion Ratio, Carcass Quality.

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INTRODUCTION

The rapid increase in world population (Onsongo et al., 2018) is driving higher demand for poultry meat and eggs (Bahadori et al., 2017). Feedstuffs currently make up 60%–70% of the total cost of production for broilers, with protein accounting for over 15% of the total (Khan, Khan, Alam, & Sultan, 2018). The protein is a major component responsible for the optimal growth of broiler chickens. Soybeans and fishmeal are the top sources of protein used in broiler diets. However, their higher cost led poultry nutritionists to seek alternatives to these ingredients (Onsongo et al., 2018). Recently, the utilization of insect meal in the broiler diet as a protein source is gaining popularity (Bovera et al., 2016).

Raising insects as an alternative protein source in poultry diets has gained popularity due to their ability to consume organic waste, which reduces environmental contamination and converts low-quality plant waste into high-quality protein (Khan, Khan, Sultan, Khan, Hayat, & Shahid, 2016). Among various insect meals, the superworm larvae meal (SW-LM) is derived from (*Zophobas morio*; ZM). Another widely known insect species is the yellow mealworm, produced from the larvae of *Tenebrio molitor* (Ramos-Elorduy, Gonzalez, Hernandez, & Pino, 2002). Although often confused as the same, superworms and mealworms come from different species, with superworms being notably larger. The superworm larvae (SW-L) contain 32% crude fat, 39.52% protein, 65.21 mg/100 g Ca, 651.15 mg/100 g P, and 44.01% essential amino acids, with a satisfactory ratio of 1.5 of n6/n3 fatty acids (Dragojlović et al., 2022). The dry matter and ash contents in SW-L are 38.06% and 0.84%. The α-tocopherols content in the superworms is (0.83 µg/g) (Mattioli et al., 2024). The essential amino acids in SW include methionine, methionine + cystine, and arginine (Veldkamp et al., 2012). Superworm can feed on wheat bran and low-quality fruits and vegetables and quickly convert these low-quality plant waste into high-quality protein, fat, and energy for broilers (Makkar, Tran, Heuzé, & Ankers, 2014).

In various existing literature, insect larvae have been proven as substitutive protein sources in meat and egg-type chicken diet with different levels of addition, i.e., from 1% up to a complete substitution of the soybean and fish meal (Bovera et al., 2016; Ramos-Elorduy et al., 2002; Ballitoc & Sun, 2013; Bovera et al., 2015; Biasato et al., 2017). Their vigorous nutrient content ensures that they can efficiently maintain the dietary requirements of poultry, paying attention to overall health and growth (Aguilar-Miranda, López, Escamilla-Santana, & Barba de la Rosa, 2002).

A recent study showed that trivial amounts of insect meals, i.e., from 0.05 to 0.2% in the broiler chicken diet, can enrich the healthy microbiota composition of the intestine (Józefiak & Engberg, 2018). Magsalay et al. (2024) replaced soybean with superworm larvae, augmenting growth performance and refining meat quality in growing chicks. Previous studies focused on the partial or complete replacement of superworm meal with soybean and fishmeal. However, this study focused on supplementing lower levels of superworms to improve broilers' growth performance, immunity, and economics in the starter phase.

MATERIALS AND METHODS

Ethical consideration

The Ethics Committee of the Faculty of Animal Husbandry and Veterinary Sciences, University of Agriculture, Peshawar, Pakistan, approved the animal care and rearing used in this study.

Study location

This trial was conducted at the Poultry Farm Complex, University of Agriculture, Peshawar, Pakistan.

Preparation of superworm premix

Superworms were produced in the Mealworm lab, developed under a PSF-funded project, PSF/NSLP/KP-UAP (709) at the University of Agriculture. The larvae were collected and oven-dried for 2-4 hours at 60-80°C. The dried worms were then defatted using a cold press oil extractor and crushed to form a powder. Based on the proximate analysis, the superworm was added to make the premix (Table 1).

Birds husbandry

A total of 120 day-old broilers were divided into four groups, each with three replicates of 10 birds, and kept in cages in an open-sided poultry house. A superworm-based premix was prepared by adding 150 g/kg of fish waste powder to superworm powder. The control group received a basal diet, while groups SW1, SW2, and SW3 were supplemented with 1 g/kg, 2 g/kg, and 3 g/kg of superworm, respectively. Experimental diets were pelleted (Parr Instruments Co., USA) and fed until 42 days of age under optimal temperature, humidity, ventilation, and lighting, with data recorded daily and weekly. At 42 days, three birds per replicate were slaughtered for carcass quality analysis. The compositions of the basal diet and superworm meal are shown in Table 1.

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Table 1. Basal diet and superworm meal composition & nutritional value.

Components	(g/kg)	Components	(g/kg)
Soybean meal	359.66	Corn	546.22
Limestone	5.59	Di-calcium phosphate	24.35
Premix vitamin	2.84	TiO	2 3.0
Salt NaCl	2.27	DL-Methionine	2.75
Sodium Sulphate (Na2SO4)	1.24	L-Lysine	1.80
Tryptophan	0.28		
Calculated nutritive value (g/kg)		Calculated nutritive value (g/kg)	
ME (MJ/kg)	11.6	Crude protein	228.0
Crude fat	27.0	Crude fiber	27.5
Na	1.5	Ca	9.8
P total	8.5	P available	4.9
Lysine	13.7	Methionine	5.9
Methionine + Cysteine	9.6	Threonine	8.6
Super-worms meal composition (%)			
Dry matter	92.43 (%)		
Crude protein	47.40 (%)		
Crude fat	40.02 (%)		
Ash	3.56 (%)		

Parameters to be evaluated

Performances

The feed intake, body weight, and mortality were recorded weekly to calculate the feed conversion ratio.

Dressing percentage

Two birds were carefully chosen from each replicate. The first live body weight was calculated using a digital balance. After the slaughtering of selected birds, the skin was removed. Various edible parts were weighed, such as the legs, wings, thighs, and breasts.

Determination of apparent metabolizable energy (AME)

Five birds from each group were housed in metabolic cages and fed an experimental diet. The bird's digesta were collected in labelled polythene bags and kept cold. The gross energy (AME) of feed and digesta was calculated after standardization using a bomb calorimeter with benzoic acid (IKA Werke, C7000, Germany). The AME was calculated using the given formula.

$$\text{AME} = \left[\frac{(Energy\ content\ of\ ration \times feed\ consumed)\times(Energy\ content\ of\ excreta \times excreta\ lost\ )}{(Energy\ content\ of\ ration \times feed\ consumed)}\right]$$

Nutrient digestibility

For nutrient digestibility, 5 birds per group were euthanized with a phenobarbitone injection. Digesta were collected, freeze-dried, and apparent digestibility was determined using TiO_2–3.0 g/kg as a marker. Dry matter, ash, crude protein, crude fiber, and ether extract were analyzed following AOAC (2000) (17) standard procedures.

Gut morphology

At the end of the trial, 3 birds per replicate were randomly selected and slaughtered. Segments (1 cm) from the midpoint of the duodenum, jejunum, and ileum were collected, fixed in 10% buffered formalin, and processed for gut morphology. Villus height and crypt depth and their ratio (VH/CD) were calculated as described by (18-19).

Immunity

At the end of the experiment, blood samples were taken from three birds per replicate to determine the antibody titer against Newcastle disease (ND). A haemagglutination inhibition (HI) test was used to determine the antibody titer (20).

Economics of superworm meal supplementation

The economic feasibility of the present study was computed based on the total cost and net return. The operational price per bird and net return were determined using the existing market rate. The feed cost was computed by multiplying the feed intake by the price/kg of feed. The total feed cost was the sum of feed cost, superworm cost, and Miscellaneous cost. The Gross return was computed as flive BW (21 or 42 days) multiplied with the price/kg live weight. The Profit margin was calculated as gross return (GR) subtracted total feed cost (TFC). The gross profit (per kg basis) per bird was calculated using the market price of birds.

Statistical analysis

The data were collected using a completely randomized design and analyzed using analysis of variance (ANOVA). The statistical differences among the different group means were matched by the Duncan multiple range test, at a probability level of 5%.

RESULTS

Performances

Body weight

Table 2 shows that defatted superworm meal (D-SWM) significantly affected broiler body weight (BW) at 14, 21, 28, and 42 days ($p<0.05$), but not at 7 or 35 days. The highest BW was recorded in SW1 at 14, 21, 42, and overall, while SW2 had the highest BW at 28 days. The control group consistently had the lowest BW.

Table 2. Effect of defatted superworm meal on the body weight (kg) of broiler from 1-42 days (mean ± standard error).

Groups	Control	SW1	SW2	SW3	p-value	SEM
7days	0.17±0.003	0.18±0.000	0.18±0.003	0.17±0.007	0.256	0.002
14days	0.54^{b}±0.007	0.59^{a}±0.006	0.55^{b}±0.010	0.52^{b}±0.014	0.006	0.008
21days	1.22^{b}±0.003	1.25^{a}±0.003	1.23^{b}±0.006	1.23^{b}±0.003	0.011	0.003
28days	1.52^{c}±0.005	1.53^{b}±0.003	1.54^{a}±0.007	1.53^{b}±0.003	0.019	0.003
35days	1.59±0.005	1.61±0.003	1.60±0.003	1.60±0.003	0.103	0.002
42days	1.86^{b}±0.003	1.91^{a}±0.006	1.88^{b}±0.006	1.88^{b}±0.003	0.001	0.005
Overall	1.15^{c}±0.014	1.21^{a}±0.004	1.17^{b}±0.012	1.17^{b}±0.008	0.010	0.009

SEM=Standard error of mean; SW1= superworm meal @1g/kg, SW2= superworm meal @2g/kg, SW3=superworm meal @3g/kg significance $P<0.05$

Feed Intake

Table 3 shows the effects of defatted superworm meal (D-SWM) on broiler feed intake. No significant differences were observed at 7, 14, or 28 days ($p > 0.05$). At 21 days, the control group was significantly higher than SW2 ($p < 0.05$), while SW1 and SW3 did not differ significantly from each other. At 35 and 42 days, the control group remained significantly higher than SW1 and SW2 ($p < 0.05$), but was similar to SW3. Overall, the control group had the highest feed intake, followed by SW3, SW1, and SW2 ($p < 0.05$).

Table 3. Effect of defatted superworm meal on broiler feed intake (kg) from 1-42 days (mean ± standard error).

Groups	Control	SW1	SW2	SW3	p-value	SEM
7days	0.19±0.003	0.19±0.009	0.19±0.003	0.19±0.003	1.000	0.002
14days	0.59±0.010	0.59±0.005	0.59±0.014	0.58±0.006	0.740	0.004
21days	1.32^{a}±0.006	1.30^{ab}±0.003	1.29^{b}±0.006	1.31^{ab}±0.003	0.008	0.004
28days	2.25±0.003	2.23±0.004	2.23±0.006	2.23±0.006	0.067	0.003
35days	2.88^{a}±0.007	2.85^{b}±0.006	2.85^{b}±0.007	2.86^{ab}±0.005	0.028	0.004
42days	3.33^{a}±0.006	3.30^{b}±0.003	3.30^{b}±0.003	3.31^{b}±0.003	0.006	0.004
Overall	1.76^{a}±0.007	1.74^{c}±0.011	1.74^{c}±0.008	1.75^{b}±0.004	0.013	0.008

SEM=Standard error of mean; SW1= superworm meal @1g/kg, SW2= superworm meal @2g/kg, SW3= superworm meal @3g/kg, significance $P<0.05$.

Feed conversion ratio

The feed conversion ratio of broilers fed defatted superworm meal is presented in Table 4. The FCR of broiler chickens offered D-SWM was not significantly affected at 7 and 14 days ($p >0.05$). However, from 21 days onwards, significant differences ($p < 0.05$) were present among groups. At 21, 28, 35, and 42 days, the control group had notably the highest and least efficient FCR than SW1 ($p < 0.05$), SW2 and SW3, where the FCR was the lowest. Overall, FCR in the control group was the highest, followed by SW2, and SW3, while the SW1 had the lowest FCR ($p < 0.05$).

Carcass characteristics

Table 5 shows carcass characteristics of broilers fed defatted superworm meal (D-SWM). D-SWM significantly affected live body weight (LBW) at day 42 ($p<0.05$), with SW1 highest, followed by SW2 and SW3, and control lowest. Carcass weight (CW) was also notably influenced ($p < 0.05$), with SW1 being the highest, followed by the control, and SW3 while the lowest was noted in the SW2. Eviscerated weight (EW) was significantly influenced as well, with SW1 highest, followed by SW2 and SW3, and control lowest. D-SWM had no significant effects on dressing %, breast, thigh, wing, or leg weights.

Table 4. Effect of defatted superworm meal on the feed conversion ratio of broiler from 1-42 days (mean ± standard error).

Groups	Control	SW1	SW2	SW3	p-value	SEM
7days	1.10±0.032	1.07±0.037	1.08±0.040	1.10±0.040	0.473	0.017
14days	1.08 ±0.018	1.00 ±0.009	1.07 ±0.040	1.11 ±0.042	0.079	0.018
21days	1.08^{a} ±0.010	1.05^{b} ±0.007	1.05^{b} ±0.009	1.07^{ab}±0.003	0.008	0.005
28days	1.48^{a} ±0.007	1.45^{b} ±0.003	1.45^{b} ±0.003	1.45^{b} ±0.006	0.005	0.004
35days	1.81^{a} ±0.010	1.77^{b} ±0.009	1.78^{b} ±0.003	1.78^{b} ±0.003	0.032	0.005
42days	1.79^{a} ±0.007	1.73^{c} ±0.004	1.76^{b} ±0.002	1.76^{b} ±0.003	0.008	0.007
Overall	1.41^{a}±0.005	1.35^{c}±0.006	1.37^{b}±0.003	1.37^{b}±0.004	0.014	0.004

SEM=Standard error of mean; SW1= superworm meal @1g/kg, SW2= superworm meal @2g/kg, SW3=superworm meal @3g/kg, significance P<0.05

Table 5. Effect of D-SWM on carcass characteristics of broiler from 21-42 days (mean ± standard error).

Carcass traits	controls	SW1	SW2	SW3	value	SEM
LBW (g)	1.86^{c}±0.003	1.91^{a}±0.006	1.88^{b} ±0.005	1.88^{b} ±0.003	0.002	0.005
CW (g)	1.64^{b} ±0.006	1.67^{a}±0.009	1.60^{c} ±0.006	1.62^{bc} ±0.009	0.008	0.008
EW (g)	1.31^{c} ±0.003	1.38^{a}±0.013	1.34^{b} ±0.003	1.35^{b} ±0.003	0.002	0.008
D%	70.48±0.053	72.43±0.380	71.45±0.740	71.51±0.158	0.302	0.276
Breast (g)	21.73 ±0.349	23.78±0.122	23.70 ±1.14	22.66±0.668	0.406	0.388
Thigh(g)	20.16 ±0.022	20.29 ±0.038	20.21 ±0.069	20.72±0.461	0.167	0.120
wing(g)	10.16 ±0.228	10.32 ±0.055	10.20 ±0.027	10.26±0.082	0.777	0.056
Leg (g)	21.37 ±1.16	23.47 ±0.560	22.13±0.411	22.21±1.273	0.781	0.556

LBW=live body weight, CW= carcass weight, EW= Eviscerated weight, D %= dressing percentage SEM=Standard error of mean; SW1= superworm meal @1g/kg, SW2= superworm meal @2g/kg, SW3=superworm meal @3g/kg significance P<0.05, VH=villus height, CD= crypt depth, VSA= villus surface area, SEM = standard error of mean.

Digestibility and antibody titer

Table 6 shows ileal digestibility, metabolizable energy (ME), and NDV titer in broilers fed defatted superworm meal (D-SWM). Dry matter (DM digestibility was significantly affected ($p<0.05$), with control and SW1 highest, and SW2 and SW3 lower. Crude protein (CP) digestibility was the highest and statistically similar in the control and SW1, while the SW2 was significantly lower than SW1 ($p = 0.001$) but higher than SW3. Ether extract (EE) digestibility was highest in control, SW1, and SW2 and lower in SW3, while crude fiber, ash, and ME were not significantly affected. The NDV titer was significantly influenced by D-SWM, with SW1, SW2, and SW3 exhibiting higher titers than the control.

Table 6. Effect of DSWM on the ileal digestibility of nutrients and the Immune response of broilers from 21-42 days (mean ± standard error).

Nutrients	controls	SW1	SW2	SW3	P-value	SEM
DM (%)	88.17^{a}±0.158	87.89^{a}±0.284	85.86^{b} ±0.222	85.20^{b} ±0.498	0.001	0.407
CP (%)	88.64^{a} ±0.055	88.30^{a}±0.251	87.57^{a} ±0.635	86.10^{b} ±0.339	0.001	0.336
CF (%)	88.43 ±0.148	88.27 ±0.466	87.70 ±0.430	87.38 ±0.578	0.093	0.226
EE (%)	89.60^{a}±0.089	89.06^{a} ±0.206	89.12^{a}±0.269	87.91^{b}±0.317	0.001	0.212
Ash (%)	68.75 ±2.015	71.33 ±2.881	69.66 ±2.299	68.29 ±3.017	0.800	1.156
ME	11.60±0.057	11.57 ±0.120	11.73 ±0.120	11.73±0.088	0.241	0.048
ND titer	4.18^{b} ±0.044	4.83^{a} ±0.118	4.92^{a} ±0.070	4.77^{a} ±0.203	0.011	0.103

DM=dry matter, CP= crude protein, CF= crude fiber, EE %= ether extract, ME= metabolizable energy, ND= Newcastle disease, SEM=Standard error of mean; SW1= superworm meal @1g/kg, SW2= superworm meal @2g/kg, SW3=superworm meal @3g/kg significance P<0.05.

Economics

Table 7 presents the economic benefits of D-SWM supplementation in broilers. The feed cost per kilogram was higher in the D-SWM groups, with SW1 being the highest at day 42. The total feed cost was highest in SW3, followed by SW2, SW1, and the control. The gross return (GR) was highest in SW1 at both day 21 and 42, while the profit margin (PM) was highest in SW1, followed by SW2, SW3, and lowest in the control.

Histomorphology

Table 8 shows the effects of D-SWM on small intestine histomorphology. In the ileum, villus height (VH), crypt depth (CD), and villus surface area (VSA) were not significantly affected by D-SWM (Figure 1). In the duodenum, D-SWM significantly increased VH, CD, and VSA ($p<0.005$) compared to control (Figure 2). In the jejunum, VH, CD, and VSA were significantly affected, these were significantly higher in the D-SWM group as compared to the control (Figure 3).

Table 7. Effect of D-SWM on the economics of broilers from 21 and 42 days (mean BW ± standard error).

Items	controls	SW1	SW2	SW3	P-value	SEM
21 days						
Feed Intake (Kg)	1.32^{a}±0.006	1.30^{ab}±0.003	1.29^{b}±0.006	1.31^{ab}±0.003	0.008	0.004
Feed cost/Kg	179.52^{a}±0.785	177.25^{ab}±0.453	175.63^{b}±0.148	177.85^{b}±0.527	0.009	0.503
DSWM cost/g	0.00	2.00	4.00	6.00		
Misc Cost	50.00	50.00	50.00	50.00		
Total Feed Cost	229.52 ^{b}±0.785	229.25^{b} ±0.453	229.63^{b}±0.779	233.85^{a}±0.526	0.002	0.638
Gross return	489.44 ^{b}±1.918	498.67^{a}±1.333	492.40 ^{b}±1.973	490.67 ^{b}±1.333	0.011	1.285
Profit margin	259.92 ^{b}±2.431	269.41^{a}±1.787	262.78^{ab}±2.445	256.82^{b}±1.637	0.006	1.666
42 days						
Feed Intake (Kg)	3.33 ^{a} ±0.006	3.30 ^{b} ±0.003	3.30 ^{b} ±0.003	3.31 ^{b} ±0.003	0.006	0.004
Feed cost/Kg	253.41^{c}±0.453	259.76^{a}±0.785	255.68^{b}±0.785	256.13^{b}±0.453	0.002	0.738
Total feed cost	303.41^{c}±0.453	311.76^{ab} ±0.785	309.68^{b}±0.785	312.13^{a}±0.453	0.002	1.088
Gross return	745.33 ^{c}±1.333	764.00 ^{a} ±2.309	752.00^{b}±2.309	753.33 ^{b}±1.333	0.002	2.172
Profit margin	441.92 ^{b}±0.880	452.24 ^{a}±1.524	442.32 ^{b}±1.524	441.29 ^{b}±0.880	0.002	1.466

SEM=Standard error of mean; SW1= superworm meal @1g/kg, SW2= superworm meal @2g/kg, SW3=superworm meal @3g/kg significance $P<0.05$, VH=villus height, CD= crypt depth, VSA= villus surface area, SEM= standard error of mean.

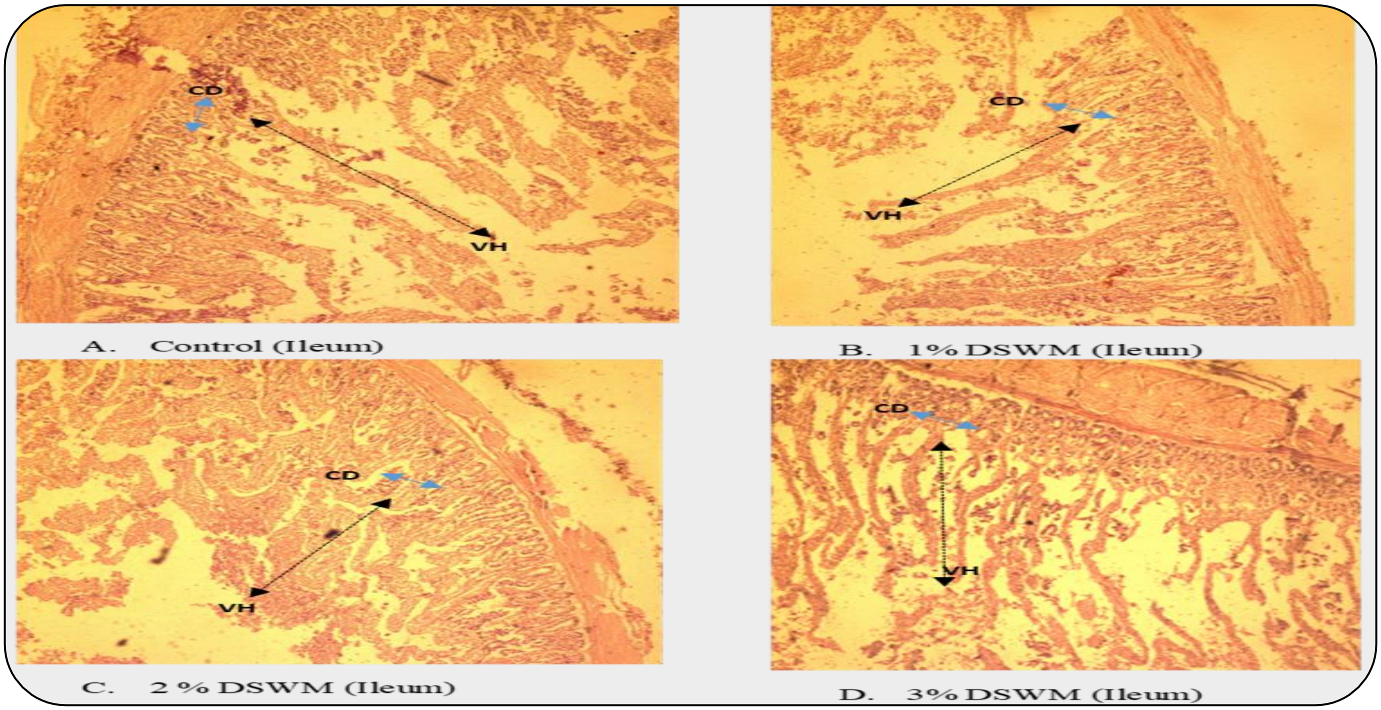
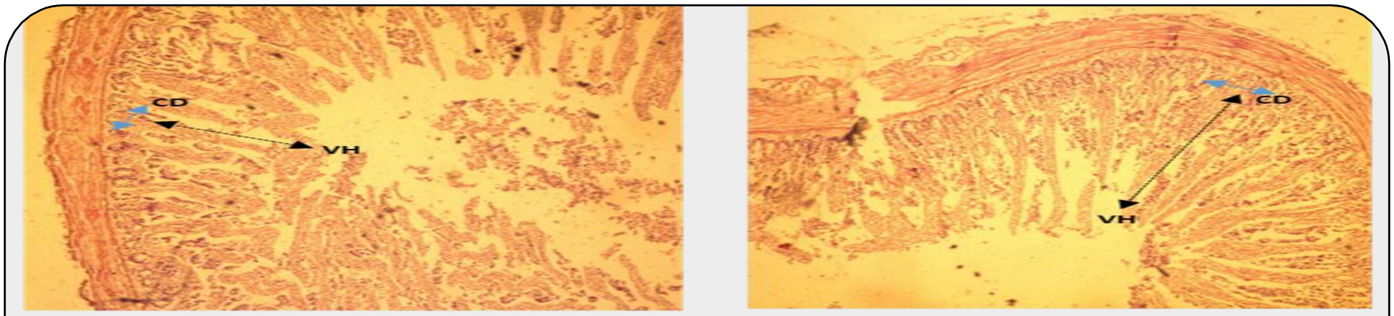
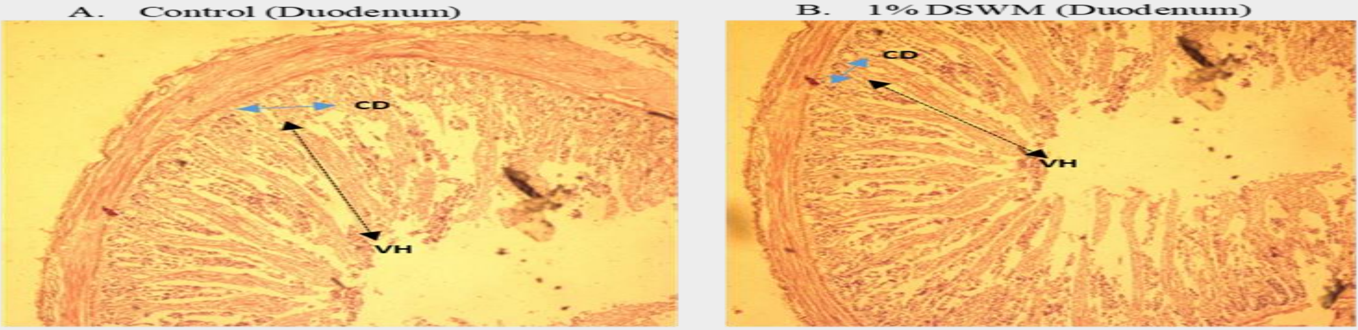


Figure 1. Effect of D-SWM on the ileum histomorphology of broilers on the 42nd day. CD = crypt depth and VH = villus height. The slides were stained with hematoxylin and eosin and examined under a light microscope at a magnification of 100X.



A. Control (Duodenum)

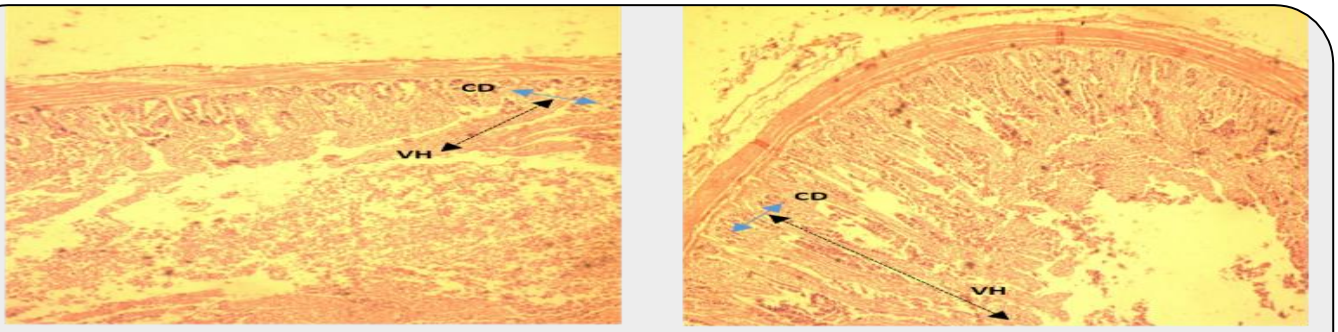
B. 1% DSWM (Duodenum)



C. 2 % DSWM (duodenum)

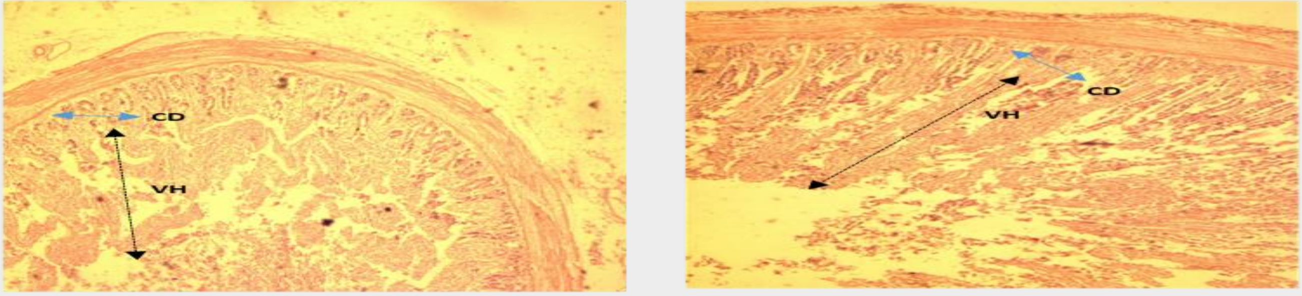
D. 3% DSWM (Duodenum)

Figure 2. Effect of D-SWM on the duodenum histomorphology of broilers on 42nd day. CD = crypt depth and VH = villus height.The slides were stained with hematoxylin and eosin and examined under a light microscope at a magnification of 100X.



A. Control (jejunum)

B. 1% DSWM (Jejunum)



C. 2 % DSWM (jejunum)

D. 3% DSWM (Jejunum)

Figure 3. Effect of D-SWM on the jejunum histomorphology of broilers on the 42nd day. CD = crypt depth and VH = villus height. The slides were stained with hematoxylin and eosin and examined under a light microscope at a magnification of 100X.

DISCUSSION

Previous research studies used different insect larvae in chicken rations at diverse levels, ranging from 1% to a complete substitution of soybean and fish meal.Feed intake in this study was decreased in SW supplemented groups after 14 days of feeding as compared to the control group, in which the feed intake was the highest. Superworms (*Zophobas morio*) provide a good protein profile (40%) and essential amino acids, which can trigger appetite-regulating mechanisms, leading to reduced feed intake as birds satisfy their protein requirements more quickly.

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Certain amino acids, like glutamic and aspartic acid, contribute to umami taste, enhancing feed appeal. Magsalay et al. (2024) reported higher feed intake with increasing SWs, but in this study feed intake was highest in the control group, possibly due to lacking SW supplementation. Supplementing SWs at 0.3% resulted in greater weight gain, and Islam and Yang (2017) also observed improved weight gain with 0.4% SWs. Similar to these studies, our study improved body weight at lower levels 1 g/kg (at 14, 21, 35, 42 days and overall BW), and 2 g/kg (at 28th day), possibly due to better nutrient profile, better digestibility, and enhanced immune response. Drying methods may affect insect biochemical profiles (Benzertiha et al., 2020; Veldkamp et al., 2012), and adding fresh SWs as a protein replacement had no influence on body weight gain or FCR in grower chickens (Makkar et al., 2014).

Biasato et al. (2016) reported improved FCR with 1% mealworm, while Ramos-Elorduy et al. (1997) and Biasato et al. (2018) found no effects with 5–10% or 7.5% mealworm meal. Our findings indicate that dietary inclusion of 1 g/kg or 2 g/kg of D-SWM in broiler feed resulted in a progressive improvement in feed conversion ratio (FCR), with noticeable effects emerging after 14 days of supplementation and persisting consistently until day 42. This demonstrated a lower level of superworm meal in achieving better FCR. In contrast, Bovera et al. (2015) and Biasato et al. (2016) observed improved performance with higher mealworm inclusions (10–15% or 29.6%), which differ from our findings. Insect species, life stage, rearing substrate, and processing methods can influence their nutritional profiles.

Insect meal can affect meat quality and immune response in broilers. In this study, SW had a significant effect on carcass weight, eviscerated weight, or dressing percentage, in line with *Magsalay et al*. (2024), who reported increases with fresh superworm meal. Superworms are a rich protein source (42–54%) with essential amino acids, vitamins, and fatty acids, which may contribute to improved carcass traits. In this study, the mealworm supplementation did not affect the meat cut weights. In contrast, the chickens were fed a diet of 15% SW and 0% soybean, producing greater meat cut weights. Moreover, Biasato et al. (2018) found that carcass weight was higher in broiler chickens fed MWM than in conventional soybean meal.

Insect larvae are a rich source of nutrients and antimicrobial peptides (AMPs) that help strengthen innate immunity. In this study, SW supplementation enhanced the immune response, likely due to chitin in their exoskeleton as proved by several studies. Furthermore, Islam and Yang (2017) reported higher immunoglobulin (IgG and IgA) levels with mealworm and superworm supplementation, reflecting improved humoral immunity. The combination of high-quality amino acids, immunostimulatory compounds like chitin, and gut health-promoting effects likely explains the observed enhancement of the immune response in broilers receiving superworm meal supplementation as an insect source of protein.

The insect exoskeleton contains chitin, an indigestible fiber composed of N-acetyl-D-glucosamine, which can reduce nutrient digestibility in poultry. In this study, ileal digestibility of dry matter, protein, and fat was lower in broilers fed higher D-SWM (3 g/kg), likely due to chitin. However, the nutrient digestibility at 1 g/kg and 2 g/kg was statistically similar to the control, indicating that small amounts of chitin can be digested by birds. Other contributing factors, such as fat-binding properties of chitin or processing methods of insect meal (e.g., drying, defatting, or heat treatment), may also influence nutrient digestibility.

Intestinal morphology, especially villi and crypts, plays a key role in nutrient digestion and absorption. Longer villi and shallower crypts typically indicate a healthy gut, while shortened villi and deep crypts may impair performance. Higher insect meal levels (15% TM) have been associated with unfavorable morphology. In contrast, lower D-SWM supplementation in this study significantly affected gut morphology, in agreement with Biasato et al. (2016), and may contribute to the improved growth performance observed in the present study.

D-SWM supplementation resulted in higher feed costs but also greater gross return (GR) and profit margin (PM), with SW1 outperforming SW2, SW3, and the control group. This improvement may be due to enhanced body weight as indicated by gross return and profit margin as compared to the control group. Similar to our previous study, better gross return and profit margin were reported, although the insect production was a bit costly. Previous studies show insect supplementation can reduce feed costs. The global mealworm market is projected to grow at a CAGR of approximately 26.5% by 2030, indicating strong potential for profitable and cost-effective production through advanced processing technologies and cross-sector collaboration (Coherent Market Insights, 2025; Meticulous Research®, 2024)

CONCLUSION

It can be concluded that the inclusion of defatted superworm meal (D-SWM) at a higher level (3 g/kg) in broiler diets resulted in increased feed costs and reduced nutrient digestibility, indicating limited economic and nutritional benefits at excessive inclusion rates. In contrast, supplementation with D-SWM at lower levels, particularly at 1 g/kg, positively influenced broiler performance by enhancing body weight gain and strengthening the immune response against Newcastle Disease Virus (NDV). Furthermore, the 1 g/kg inclusion level also contributed to improved gross return and profit margin, highlighting its potential as a cost-effective feed additive for broiler production.

AUTHOR CONTRIBUTIONS

Mian Shahab Shah contributed to the conception and design of the study, conducted the experimental work, collected and analyzed the data, and drafted the initial manuscript. He was responsible for interpreting the findings and preparing the visual representations used in the paper. **Sarzamin Khan** supervised the entire research process, provided critical guidance in study design and data interpretation, ensured the availability of necessary resources, and reviewed and edited the manuscript for intellectual content and clarity.

COMPETING OF INTEREST

The authors declare no competing interests.

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