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MEALWORM (*Tenebrio molitor*) AS A PROTEIN SOURCE: EFFECTS ON GROWTH PERFORMANCE, CARCASS TRAITS AND NITROGEN EXCRETION IN QUAILS

Ela Evin TASTAN, Muzaffer DENLI

University of Dicle, Faculty of Agriculture, Department of Animal Science, 2120, Sur, Diyarbakır, Türkiye

Corresponding author email: muzaffer.denli@gmail.com

Abstract

This study aimed to assess the impact of substituting soybean meal with mealworm (Tenebrio molitor L.) as the primary protein source in compound feeds on growth performance, carcass traits, nutrient digestibility and nitrogen excretion in Japanese quails. A total of 120 one-day-old quails were assigned to four groups, each with 10 replications, and the experiment lasted 35 days. The control group was fed a 34% soybean meal-based diet, while the experimental groups had 1.4% soybean meal replaced with 2.8% or 5.6% mealworm meal. Lowest body weight gain and feed consumption occurred in the 1.4% mealworm group (P<0.05), with mealworm content displaying a cubic effect. The 5.6% mealworm group exhibited significantly improved feed efficiency (P<0.05). Furthermore, mealworm supplementation significantly increased the digestibility of dry matter, crude ash, and metabolizable energy (P<0.001). Moreover, fecal nitrogen excretion and nitrogen retention rates increased linearly with mealworm supplementation (P<0.001). In conclusion, Mealworm can replace 5.6% soybean meal in quail diets, improving growth and protein use as a sustainable alternative.

Key words: *broiler quails, digestibility, growth performance, mealworm (Tenebrio molitor L.), nitrogen excretion.*

INTRODUCTION

The search for sustainable and alternative protein sources in animal feed has become a critical focus in modern livestock and poultry production due to increasing concerns about feed costs, environmental sustainability, and the limitations of conventional protein sources such as soybean meal and fishmeal (van Huis et al., 2013; Oonincx et al., 2015; Gasco et al., 2019). In this context, insect-based proteins have emerged as a promising alternative due to their high nutritional value, rapid growth, and ability to be produced with minimal environmental impact (Mekonnen & Hoekstra, 2012; Smetana et al., 2015). Among the various insect species evaluated for feed applications, mealworms (*Tenebrio molitor*) have gained particular attention due to their relatively high protein and fat content, as well as their efficient conversion of organic waste into valuable nutrients (Dobermann et al., 2017; Halloran et al., 2016; Ramos-Elorduy et al., 2017).

The incorporation of mealworm meal into poultry diets has been explored for its potential to enhance growth performance, improve feed efficiency, and contribute to environmental sustainability by reducing nitrogen excretion (Almeida et al., 2019; Khan et al., 2021). Quail (*Coturnix coturnix japonica*) is an economically significant species in the poultry industry, known for its rapid growth, early sexual maturity, and high reproductive efficiency, making it an ideal model for research on alternative feed ingredients (Hassan et al., 2021; Cullere & Dabbou, 2021). However, studies on the effects of mealworm inclusion in quail diets remain limited, particularly concerning growth performance, feed efficiency, carcass traits, and nitrogen metabolism - critical factors for assessing the sustainability and environmental impact of animal production systems (Iji et al., 2017).

The nutritional composition of mealworms includes high-quality protein, essential amino acids, and unsaturated fatty acids, which suggest potential benefits for poultry growth and development (Liu et al., 2013; Van der Borght et al., 2022). Additionally, the inclusion of insect meal in poultry diets may influence carcass traits by affecting body composition, muscle growth, and fat deposition (van der Fels-Klerx et al., 2018; Bovera et al., 2016). Nutrient digestibility and nitrogen excretion are also essential considerations when evaluating the ecological footprint of poultry production, as excessive nitrogen output contributes to environmental pollution through ammonia emissions and nitrate leaching (Mottet et al., 2017; Wang et al., 2020). The digestibility of nutrients, particularly proteins, and the impact on nitrogen excretion are also vital considerations in assessing the ecological footprint of poultry production. Reduced nitrogen excretion is an important factor in minimizing the environmental impact of livestock farming, as nitrogen compounds, such as ammonia and nitrate, can contribute to water and air pollution (Mottet et al., 2017).

This study aims to investigate the effects of mealworm inclusion in quail diets on growth performance, carcass characteristics, nutrient digestibility, and nitrogen excretion. By integrating mealworms as a protein source in quail feed, this research seeks to provide insights into their viability as a sustainable alternative protein source, supporting both economic and environmental benefits in poultry production.

MATERIALS AND METHODS

This study was conducted following ethical guidelines and was approved by the Dicle University Experimental Animal Ethics Committee (DÜHADEK) under protocol number 2022/201. A total of 120 one-day-old Japanese broiler quails (*Coturnix coturnix japonica*) were randomly assigned to four dietary treatment groups, each consisting of 30 birds. Each treatment group was further divided into 10 replicates, with three birds per replicate. The experiment lasted for 35 days

The control group received a basal diet containing 34% soybean meal as the primary protein source. In the experimental groups, soybean meal was partially replaced with mealworm (*Tenebrio molitor* L.) meal at inclusion levels of 1.4%, 2.8%, and 5.6%. All diets were formulated to meet the nutrient requirements of Japanese quails as per the National Research Council (NRC, 1994). The mealworms were obtained from a commercial supplier and processed by drying at 60°C for 24 hours before being ground into a fine powder for feed formulation.

The quails were housed in a controlled environment within a cage-based broiler quail test coop at the Department of Animal Science, Faculty of Agriculture, Dicle University. The room temperature was maintained at 25°C with 60% relative humidity. A 23-hour light and 1-hour dark cycle was applied throughout the experiment. Quails were provided with *ad libitum* access to feed and water.

The dietary treatments were formulated to ensure similar protein levels among the groups, with mealworm meal being used to replace part of the soybean meal. The ingredients and composition of the experiment dies is shown in Table 1.

Table. 1 Ingredients, composition and nutrient content levels of quail's diets

Ingredients	%			
	MW0	MW1.4	MW2.8	MW5.6
Wheat	5.00	5.00	5.00	5.00
Maize	57.00	57.00	57.00	57.00
Soybean Meal (48% CP)	34.00	32.60	31.20	28.40
Mealworm Meal	0.00	1.40	2.80	5.60
Dicalcium Phosphate[a]	1.00	1.00	1.00	1.00
Bone Meal (30% Ca, 13% CP)	2.00	2.00	2.00	2.00
DL-Methionine	0.15	0.15	0.15	0.15
L-Lysine	0.20	0.20	0.20	0.20
NaCl	0.40	0.40	0.40	0.40
Vitamin and Mineral Premix[b]	0.25	0.25	0.25	0.25
Parameters	**Analysis values, %**			
Dry Matter	89.7	89.7	89.7	89.7
Crude Protein	22.1	22.1	22.1	22.1
Ether extract	2.12	2.12	2.12	2.12
Crude Ash	5.90	5.90	5.90	5.90
Crude Fiber	2.73	2.73	2.73	2.73
Parameters	**Calculated values, %**			
Metabolizable energy (ME poultry), kcal/kg	2910	2910	2910	2910
Ca	0.96	0.96	0.96	0.96
Available Phosphorus	0.60	0.60	0.60	0.60
Na	0.19	0.19	0.19	0.19
Cl	0.28	0.28	0.28	0.28
Methionine + Cysteine	0.88	0.88	0.88	0.88
Lysine	1.33	1.33	1.33	1.33
Threonine	0.82	0.82	0.82	0.82
Tryptophan	0.29	0.29	0.29	0.29
Linoleic acid	1.20	1.20	1.20	1.20
Electrolyte Balance (mEq/kg DM)	251	251	251	251

[a]Composition: 240 g Ca and 17.5 g P/kg;

[b]Composition (per kg feed): Vitamin A, 8,000 IU; Vitamin D3, 1,200 IU; Vitamin E, 10 IU; Vitamin K3, 2 mg; Thiamine, 2 mg; Riboflavin, 5 mg; Pyridoxine, 0.2 mg; Vitamin B12, 0.03 mg; Pantothenic acid, 10 mg; Niacin, 50 mg; Biotin, 0.1 mg; Folic acid, 0.5 mg; Iron, 80 mg; Zinc, 40 mg; Manganese, 60 mg; Iodine, 0.8 mg; Copper, 8 mg; Selenium, 0.2 mg; Cobalt, 0.4 mg.

[c]Composition (per kg feed): Fe, 80 mg; Zn, 40 mg; Mn, 60 mg; I, 0.8 mg; Cu, 8 mg; Se, 0.2 mg; Co, 0.4 mg.

The mealworms used in the experiment were purchased from a commercial supplier, and nutrient analysis was conducted. The nutrient contents are shown in Table 2.

Table 2. Nutrient content of mealworm (%)

Parameters	%
Dry Matter	89.5
Crude Protein	56.1
Crude Fat	25.5
Crude Fiber	5.5
Crude Ash	2.4

The diets were balanced to provide similar protein and energy content. The proximate composition of the experimental diets was determined by standard methods (AOAC, 2005), and the nutrient content of each diet (crude protein, crude fat, ash, fibre, calcium, and phosphorus) was calculated to meet the requirements for broiler quails.

Growth performance was evaluated by measuring body weight gain (BWG), feed intake (FI), and feed conversion ratio (FCR). Body weights were recorded weekly, and feed intake was measured by subtracting the amount of feed remaining from the total amount of feed provided. FCR was calculated as the ratio of feed intake to body weight gain. These parameters were measured for all birds throughout the 35-day experimental period.

Nutrient digestibility was assessed during the final week of the experiment using the total collection method (Schneider & Flatt, 1975). A total of 12 birds from each treatment group (3 birds per replicate) were selected and housed individually in metabolic cages. The quails were acclimatized to the cages for 7 days before the collection period, which lasted 5 days. Faeces were collected daily and stored at -20°C until analysis. The digestibility coefficients for dry matter (DM), crude ash (CA), and metabolizable energy (ME) were calculated based on the difference between the nutrients provided and those excreted in the faeces.

Nitrogen excretion was determined during the same period as the digestibility trial. Nitrogen intake was calculated based on the nitrogen content of the diets, and nitrogen excretion was determined by analyzing the nitrogen content of the faeces. The nitrogen balance was calculated as the difference between nitrogen intake and nitrogen excretion. The results were expressed as fecal nitrogen excretion and nitrogen retention rates per bird per day. Nitrogen excretion and retention rates were analyzed for each treatment group.

At the end of the experiment, six quails per treatment were randomly selected, fasted for 12 hours, and slaughtered by cervical dislocation. Carcass weight, carcass yield, gizzard weight, and intestinal weight were recorded and expressed as a percentage of live body weight.

Data were analyzed using one-way analysis of variance (ANOVA) in SPSS software (version 18.0, IBM Corp., Armonk, NY, USA). Differences between treatment means were evaluated using Tukey's multiple comparison test at a significance level of $P<0.05$. Regression analysis was applied to assess linear, quadratic, and cubic trends in response to mealworm inclusion levels.

RESULTS AND DISCUSSIONS

The effects of replacing soybean meal with mealworms in the diet on body weight gain feed intake and feed conversion ratio of broiler quails are detailed in Table 3. The observation that quails fed with 5.6% mealworm meal achieved the highest body weight gain is in line with studies by Schiavone et al. (2017) and Liu et al. (2018), which found that the inclusion of insect meals, such as mealworms, in poultry diets led to enhanced growth performance. For instance, Schiavone et al. (2017) observed significant improvements in the growth of broilers fed diets supplemented with insect meal, which provided high-quality protein. This is likely due to the balanced amino acid profile and the higher digestibility of insect proteins, which support better muscle development and growth. Similarly, Liu et al. (2018) reported that higher levels of mealworm meal led to increased body weight gain in broilers, supporting the notion that mealworm meal can contribute to improved growth in poultry.

The reduction in feed intake observed as mealworm meal inclusion increased is consistent with findings from Folk et al. (2019), who noted a decrease in feed consumption as insect-based meals were included in broiler diets. This decrease could be attributed to several factors, including the higher nutrient density of mealworm meal, which could lead to satiation at lower feed volumes. Additionally, changes in the palatability of the diet due to the inclusion of insect meal could affect intake levels, as suggested by Belluco et al. (2013). The study by Kidd et al. (2018) also suggests that the inclusion of insect meals could alter the feed's sensory properties, potentially leading to reduced consumption if the feed is not well-accepted by the birds.

The significant improvement in feed conversion rate at the 5.6% mealworm meal level is consistent with results from Oliviero et al. (2017), who found that broilers fed diets containing insect-based protein sources, such as mealworms, had improved feed conversion ratios compared to those fed conventional protein sources. The increased feed conversion rate in the current study suggests that mealworm meal, at higher inclusion rates, allows quails to utilize feed more effectively. This could be due to the high-fat content of mealworm meal, which provides a concentrated energy source, as well as the optimal amino acid profile that supports better protein synthesis and muscle growth. However, it is important to note that the optimal inclusion level of mealworm meal varies across species and production conditions. For example, Ramos-Elorduy et al. (2014) found that the inclusion of mealworm meal at 10% in poultry diets resulted in improved growth performance in chickens, but higher inclusion rates could reduce feed intake, as was observed in our study. This suggests that while mealworm meal is a promising alternative protein source, its inclusion should be carefully balanced to optimize both feed intake and feed conversion rate. Our results support Morsy's (2022) observation that 10% mealworm inclusion enhances growth performance, while contrasting with Secci et al. (2022), who reported detrimental effects beyond 3.3% inclusion. Additionally, it is worth considering that mealworm meal's nutrient profile, including its high levels of lipids and proteins, can contribute to more efficient growth when included in poultry diets. Ravi et al. (2020) highlighted that insect meals, including those from mealworms, provide a balanced nutrient composition that supports better feed conversion and growth, which is evident in our findings where the highest level of mealworm meal (5.6%) improved feed efficiency.

The effects of replacing soybean meal with mealworms in the diet of quails on carcass weight, yield, and slaughter parameters were shown in Table 4. The findings indicated that there was no statistically significant difference in carcass weight between the experimental groups (P>0.05). Similarly, carcass yield values did not show any significant variation among the groups (P>0.05). When examining the findings related to the intestinal weight ratio within slaughter parameters, the differences between the groups were also found to be insignificant (P>0.05). Likewise, the gizzard weight ratio did not show statistically significant differences among the experimental groups (P>0.05). Throughout the experiment, mealworm supplementation at levels of 1.4%, 2.8%, and 5.6% in compound feed did not affect carcass weight, yield, or slaughter parameters. These findings are consistent with the study conducted by Sedgh-Gooya et al. (2021), in which mealworms were added at 2.5% and 5% as a replacement for corn-soybean meal in broiler feed. Additionally, similar findings were reported by Sabırlı & Çufadar (2019), Elahi et al. (2020), and Ait-Kaki et al. (2021), further supporting the conclusions of the present study. Overall, this research aligns with previous literature, demonstrating that mealworm supplementation at the tested levels does not significantly alter carcass and slaughter parameters.

Nutrient digestibility and nitrogen excretion are presented in Table 5 and Table 6. In this study, the presence of mealworms (*Tenebrio molitor* L.) in the diet was found to increase dry matter digestibility linearly (P<0.05) but did not create a cubic or quadratic effect (P>0.05). Compound feeds containing different levels of mealworms had similar effects on dry matter digestibility. However, diets containing 2.8% and 5.6% mealworms significantly improved dry matter digestibility compared to the control group (P<0.05). No statistically significant difference was observed in crude fiber (CF) digestion between the control and experimental groups (P>0.05). In terms of metabolizable energy (AME) utilization, the difference between the control group and the 1.4% mealworm group was insignificant (P>0.05), but the 2.8% and 5.6% mealworm groups exhibited significantly higher values than the other groups (P<0.05).

Crude ash (CA) digestibility was significantly higher in the control group compared to the experimental groups (P<0.05), while no significant difference was found among the other experimental groups. Regarding calcium (Ca) and phosphorus (P) digestibility, no significant differences were detected between the research groups (P>0.05). While crude fiber, Ca, and P digestibility did not show significant variations, dry matter and apparent metabolizable energy (AME) parameters increased proportionally with the level of mealworms in the compound feed. Cullere et al. (2016) conducted a study on broiler quail diets, replacing soybean meal with 0%, 10%, and 15% black soldier fly (*Hermetia illucens*) larvae meal, and reported that increasing the larvae meal proportion positively influenced apparent metabolizable energy values. This finding aligns with the results of our study. However, Kanoğlu (2019) found no significant difference in energy efficiency between a group receiving 0% mealworms and a group in which fish meal was completely replaced by mealworms in broiler quail diets. This result contradicts our study, and the discrepancy is thought to be due to the use of defatted mealworms in Kanoğlu's study. In our study, where mealworms were used as a soybean meal replacement, an increase in the proportion of mealworms in compound feeds enhanced dry matter digestibility. Similarly, Jin et al. (2016) found that the proportional increase of dried mealworms in the diet of weaned piglets improved dry matter digestibility. However, Parlar (2023), in a study on broiler chicken diets replacing fish meal with 25%, 50%, 75%, and 100% mealworms, reported that an increased proportion of mealworms negatively affected dry matter digestibility. This result contrasts with our findings, possibly due to the substitution of fish meal with mealworms in that study. The higher digestibility of fish meal compared to mealworms may explain this discrepancy. No statistically significant difference was found in crude protein intake among the research groups (P>0.05). Fecal crude protein excretion in the experimental groups did not differ among themselves but was significantly lower than in the control group (P<0.05). Similarly, Oonincx et al. (2010) stated that mealworms did not increase ammonia emissions when used in human and animal nutrition. Among the experimental groups, the highest crude protein retention rate was observed in the 5.6% mealworm group, followed by the control group. No statistically significant differences were found among the other groups (P>0.05). Crude protein digestibility was significantly higher in the 2.8% and 5.6% mealworm groups compared to the control and 1.4% mealworm groups (P<0.05), while differences between the control and 1.4% groups were insignificant (P>0.05). Our results indicated that adding 1.4%, 2.8%, and 5.6% mealworms to Japanese quail diets improved digestible crude protein, reduced nitrogen excretion, and enhanced nitrogen retention. Similarly, Jin et al. (2016) found that increasing dried mealworm levels in weaned pig diets resulted in a linear increase in crude protein, dry matter, nitrogen retention, and digestibility, which aligns with our findings. However, Bovera et al. (2015) reported that adding mealworms to broiler diets reduced protein utilization but improved the European efficiency factor, partially aligning with our study. Conversely, Cullere et al. (2016) found that increasing black soldier fly (*Hermetia illucens*) larvae meal levels in quail diets reduced digestible crude protein, contradicting our study's results. Differences in the type of insect used, feed formulation, and experimental conditions could explain this disparity.

Table 3. Effects of replacing soybean meal with mealworms in the diet on the growth performance of broiler quails

Measurements	Mealworm Meal Levels, %				SEM	P	Effects[1]		
	0 (Control)	1.4	2.8	5.6			L	Q	C
Body Weight Gain, g/quail	189.8^{ab}	177.5^{b}	192.1^{ab}	204.1^{a}	2.268	0.040	NS[3]	*	*
Feed Intake, g/quail	750.6^{a}	659.8^{b}	712.5^{ab}	724.9^{ab}	10.627	0.014	NS	*	**
Feed Conversion rate (FI/BWG)	4.01^{a}	3.72^{ab}	3.72^{ab}	3.51^{b}	0.071	0.053	*	NS	NS
Mortality, %	4.01^{a}	3.72^{ab}	3.72^{ab}	3.51^{b}	0.071	0.053	*	NS	NS

Mean values with different superscripts $^{(a,b)}$ within the same row are statistically different at *P < 0.05 and/or **P < 0.01.
[1]Effects: L = Linear, Q = quadratic, C = cubic, [2]SEM = pooled standard error of the mean, [3]NS = not significant.

Table 4. Effects of replacing soybean meal with mealworms in the diet on carcass traits and internal organ weight of broiler quails

Measurements	Mealworm Meal Levels, %				SEM	P	Effects[1]		
	0 (Control)	1.4	2.8	5.6			L	Q	C
Carcass Weight, g	134.0	131.7	131.9	137.1	1.923	0.742	NS	NS	NS
Carcass Yield, %	68.8	68.3	68.3	68.6	0.371	0.946	NS	NS	NS
Intestine Weight Ratio (g/g BW)	3.2	3.0	2.9	3.1	0.058	0.429	NS	NS	NS
Gizzard Weight Ratio (g/g BW)	2.01	2.05	2.12	2.13	0.036	0.866	NS	NS	NS

Mean values with different superscripts (a,b) within the same row are statistically different at *P < 0.05 and/or **P < 0.01.
[1]Effects: L = Linear, Q = quadratic, C = cubic, [2]SEM = pooled standard error of the mean, [3]NS = not significant.

Table 5. Effects of replacing soybean meal with mealworms in the diet on nutrient digestibility of broiler quails

Measurements	Mealworm Meal Levels, %				SEM	P	Effects[1]		
	0 (Control)	1.4	2.8	5.6			L	Q	C
Dry Matter, %	74.0^{b}	74.7^{ab}	76.4^{a}	76.8^{a}	0.34	0.011	**	NS	NS
Crude Fiber, %	43.7	42.5	44.0	43.6	0.41	0.428	NS	NS	NS
AME, kcal/kg	6.19^{b}	6.35^{b}	7.10^{a}	7.32^{a}	0.13	0.001	**	NS	NS
Crude Ash, %	41.4^{a}	42.6^{b}	$42{,}0^{b}$	$42{,}2^{b}$	0.37	0.04	*	*	NS
Ca	51.2	50.8	52.4	52.0.	0,44	0.128	NS	NS	NS
P	45.6	45.0	46.1	46.2	0.38	0.227	NS	NS	NS

Mean values with different superscripts (a,b) within the same row are statistically different at *P < 0.05 and/or **P < 0.01.
[1]Effects: L = Linear, Q = quadratic, C = cubic, [2]SEM = pooled standard error of the mean, [3]NS = not significant.

Table 6. Effects of Replacing Soybean Meal with Mealworms in the Diet on Nitrogen Digestibility of Broiler Quails

Measurements	Mealworm Meal Levels, %				SEM	P	Effects[1]		
	0 (Control)	1.4	2.8	5.6			L	Q	C
Nitrogen intake (g/quail/day)	6.12	6.03	6.14	6.20	0.04	0.607	NS	NS	NS
Fecal nitrogen excretion (g/quail/day)	2.49^{a}	2.30^{b}	2.23^{b}	2.14^{b}	0.03^{b}	0.001	**	NS	NS
Nitrogen retention (g/guail/day)	3.63^{b}	3.73^{ab}	3.92^{ab}	4.07^{a}	0.06	0.003	**	NS	NS
Crude protein digestibility (%)	59.4^{b}	61.8^{ab}	63.7^{a}	65.6^{a}	3.11	0.045	**	NS	NS

Mean values with different superscripts (a,b) within the same row are statistically different at *P < 0.05 and/or **P < 0.01.
[1]Effects: L = Linear, Q = quadratic, C = cubic, [2]SEM = pooled standard error of the mean, [3]NS = not significant.

CONCLUSIONS

The inclusion of 5.6% mealworms resulted in the highest body weight gain and feed efficiency while reducing nitrogen excretion, contributing to more environmentally friendly production. Mealworms increased the digestibility of dry matter, crude ash, and metabolizable energy but had no significant effect on Ca and P digestibility. In conclusion, mealworms can be considered a sustainable and alternative protein source in animal feed.

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