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Effects of a mealworm larvae-based diet on laying performance and egg quality in laying hens

A. Kaddour[1], M. T. Diaw[2], D. Saidj[1], K. Yahi[1], and N. Moula[3,4*]
[1]*Institute of Veterinary Sciences, Saad Dahleb University, Blida 1, Algeria*
[2]*Université Iba Der THIAM, Ecole Nationale Supérieure d'Agriculture, Département Productions Animales, BP A 296 x Thiès, Sénégal*
[3]*Animal Facilities, University of Liège, 4000 Liège, Belgium*
[4] *Research Laboratory Management of Local Animal Resources, Higher National Veterinary School, El Alia, Oued Smar, 1615 Algiers, Algeria*
**Corresponding e-mail: Nassim.Moula@uliege.be*

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ABSTRACT

Soybean meal, the cornerstone of poultry nutrition, is increasingly scrutinized due to its heavy reliance on imported and genetically modified (GMO) crops, raising concerns about sustainability, cost, and compatibility with organic production systems. This challenge has spurred the search for alternative protein sources, with insect meals emerging as a promising solution. Among them, the yellow mealworm (*Tenebrio molitor*) offers a nutrient-dense, environmentally sustainable feed ingredient rich in proteins, lipids, and bioactive compounds. This study investigated the effects of dietary inclusion of *T. molitor* larvae on the performance and egg quality of laying hens. Thirty-six Isa-Brown hens (40 weeks old) were assigned to four dietary treatments: a control diet and diets supplemented with 1%, 2%, or 4% mealworm larvae (TM1, TM2, TM4). Over a four-week period, laying rate, feed conversion ratio (FCR), and egg quality traits (physical parameters, shell integrity, yolk cholesterol, and fatty acid composition) were measured. Results revealed that while laying performance remained unaffected (P = 0.48), hens in the TM4 group achieved significantly improved FCR (P = 0.03). Importantly, no adverse effects were observed on egg weight, shell quality, or nutritional composition. These findings demonstrate that moderate supplementation with *T. molitor* can enhance feed efficiency while maintaining egg quality, positioning insect proteins as a viable pathway toward more sustainable and resilient poultry production.
*Keywords**:** Feed conversion, Insect meal, Poultry feed, Soybean, Tenebrio molitor*

INTRODUCTION

Soybean (*Glycine max*) has long been recognized as a cornerstone of modern animal nutrition, particularly in the formulation of feed for monogastric species such as poultry and swine. Its popularity is primarily attributed to its high protein content, typically ranging between 42% and 48%, as well as a well-balanced amino acid profile, especially rich in lysine, which complements the deficiencies found in most cereal grains (Pope *et al.,* 2023; Janocha *et al.,* 2022; Zhao *et al.,* 2024). Combined with maize or wheat, soybean meal forms a complete protein source, essential for supporting optimal growth and production in livestock (Katu *et al.,* 2025; Rauw *et al.,* 2023).

Despite its nutritional advantages, the extensive reliance on soybean meal presents several limitations. A major concern is its price volatility on global markets, influenced by factors such as climate events, geopolitical tensions, and shifts in trade policy. These fluctuations can significantly impact the cost of animal production. Moreover, most of the soybean meal used in livestock production is derived from genetically modified (GM) crops. This presents a specific challenge in organic farming systems, where the use of GMOs is strictly prohibited. Sourcing non -GMO soybean meal becomes not only a logistical issue but also a financial one, often incurring additional costs exceeding $150 per ton compared to conventional GMO-based alternatives. This economic burden threatens the profitability and long-term viability of organic and small-scale poultry operations.

In response to these constraints, the search for alternative, sustainable protein sources has intensified. Among the various candidates, insects have emerged as a particularly promising solution. They are recognized for their exceptional feed conversion efficiency, high reproductive rates, and minimal environmental footprint. Notably, insects can be reared on a wide range of organic substrates, including agricultural by-products and food waste, thereby contributing to circular economy models and reducing pressure on arable land and freshwater resources (Moula *et al.,* 2018a).

Several insect species have been identified as suitable for industrial-scale feed production, including the black soldier fly (*Hermetia illucens*) (Moula *et al*., 2018a,b), the common housefly (*Musca domestica*) (Hamani *et al.,* 2022a,b), and the yellow mealworm (*Tenebrio molitor*) (Ait-Kaki *et al.,* 2021; 2022). These species are not only rich in protein, often ranging between 40% and 70% on a dry matter basis, but also provide essential fatty acids, vitamins (such as B12), and minerals like calcium and phosphorus. Moreover, the amino acid composition of insect meals often compares favorably with that of fishmeal and soybean meal, making them an excellent alternative for poultry diets. Studies have shown that insect meals can partially or fully replace traditional protein sources in poultry feed without negatively affecting performance parameters such as feed intake, body weight gain, egg production, or feed conversion ratio (Moula and Detilleux*,*2019).

One of the key biological advantages of insects lies in their poikilothermic metabolism, which allows them to grow without expending energy on maintaining a constant body temperature. This contributes to their remarkable efficiency in converting feed into biomass. For instance, to produce one kilogram of beef, approximately 8 kilograms of feed are required, whereas insects can achieve the same output with just 2 kilograms of feed input. Additionally, insects emit significantly fewer greenhouse gases and require much less water and space compared to traditional livestock. These attributes position them as a highly sustainable protein source, particularly in regions facing environmental constraints or limited access to conventional feed ingredients (Moula *et al.,* 2018a; Moula and Detilleux*,* 2019).

In Algeria, as in many other countries with emerging livestock sectors, soybean meal remains the protein source of choice in poultry feed formulations. However, given the rising costs of importation, the environmental impact of soybean cultivation, and the growing demand for local and non-GMO alternatives, the integration of insect-based ingredients into poultry diets is becoming increasingly relevant. Algeria also presents favorable conditions for the development of insect farming, given its abundance of organic waste and agricultural residues that could serve as substrates for insect rearing.

Among the insect species investigated for animal feed, Tenebrio molitor, or yellow mealworm, has shown significant promise, particularly in poultry nutrition. Mealworm larvae are known for their high protein content, lipid profile rich in unsaturated fatty acids, and excellent digestibility. Preliminary trials in various countries have demonstrated that incorporating mealworm meal into the diets of laying hens does not compromise egg quality or laying performance. In some cases, improvements in feed conversion and nutrient absorption have been observed, suggesting a possible enhancement of digestive efficiency.

The current study was conducted to explore the practical application of T. molitor larvae in poultry diets within an Algerian context. Specifically, the study evaluated the effects of different inclusion rates of mealworm meal on the laying performance, feed conversion efficiency, and egg quality of Isa-Brown hens. This research aims to contribute to the growing body of literature on insect-based feed solutions and provide localized insights that could support the development of more sustainable and economically viable poultry production systems in North Africa.

By investigating alternative protein sources that align with both environmental goals and economic realities, this study seeks to support a transition toward more resilient agricultural systems. It also aims to inform policymakers, feed manufacturers, and farmers about the practical viability of insect meal as a partial replacement for conventional soybean meal, especially in regions heavily reliant on imports and vulnerable to supply disruptions.

MATERIALS AND METHODS

Site and Study Overview

This study was carried out at a privately operated poultry facility located in the commune of Chemini, within the Béjaïa province in northern Algeria (Figure 1). This mountainous region, part of the Kabylia area, offers moderate climatic conditions favorable for small-scale poultry production. The trial was conducted under semi-controlled environmental conditions, without the use of artificial temperature or humidity regulation, reflecting typical local farming practices and providing results applicable to real-world Algerian poultry systems. The duration of the experimental period was four weeks, beginning on February 12 and ending on March 12, 2022. A preliminary acclimatization phase of ten days preceded the start of the trial to allow the birds to adapt to their new diets and environment.

Experimental Design and Animal Management

A total of 36 Isa-Brown laying hens, all 40 weeks of age and exhibiting uniform body condition, were selected for the trial. The hens were randomly distributed into twelve identical pens, each measuring 2 square meters. Each pen was equipped with a 65 cm perch and a standard nest box to facilitate egg laying. Pens were arranged prevent cross-contamination between treatments and ensure uniform exposure to natural light and ambient conditions.

The experimental design included four dietary treatments:

· TM0 (Control): Standard commercial diet based on cereals and soybean meal, without insect supplementation (Table 1).

· TM1: Control diet supplemented with 1% *Tenebrio molitor* meal.

· TM2: Control diet supplemented with 2% *T. molitor* meal.

· TM4: Control diet supplemented with 4% *T. molitor* meal.

Each dietary group was replicated three times, with three hens per pen, resulting in a total of 12 pens (3 pens per treatment). A randomized block design was applied to minimize variability and enhance statistical robustness despite the relatively small sample size

Lighting conditions followed a natural photoperiod with approximately 16 hours of light and 8 hours of darkness per day. No artificial lighting was used to manipulate laying cycles. Feed and clean drinking water were provided *ad-libitum* throughout the trial. Feed was delivered

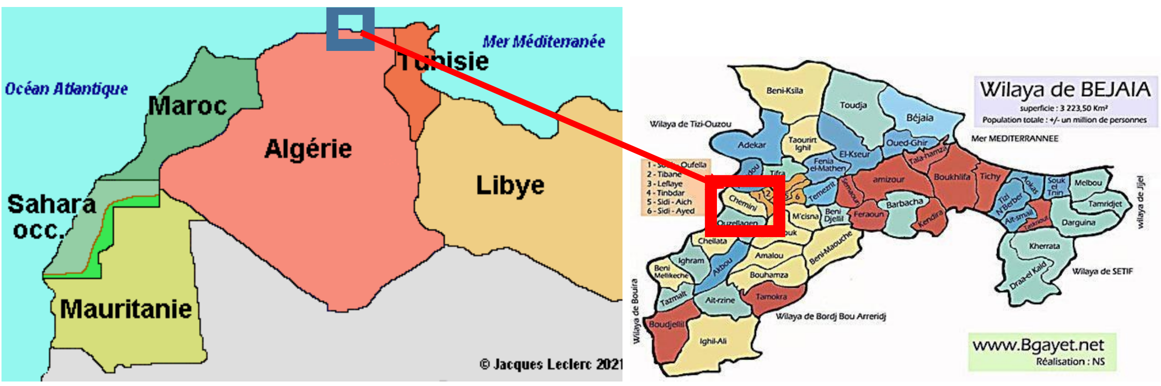

Figure 1. Site of the study

Table 1. Feed composition for laying diet

Ingredients (%)	TM0 (Control)	Analytical composition	
Soybean cake	20.00	Metabolizable energy (kcal/kg)	3060.4
Wheat	11.00	Fat content (g/kg)	54.53
Corn	50.00	Lysine (g/kg)	11.28
Soy oil	3.00	Methionine (g/kg)	4.36
Calcium phosphate	1.00	Calcium (g/kg)	10
Minerals (Vitamins, micronutrients)[1]	1.00	Phosphorus (g/kg)	5.68
Calcium carbonate	7.50	Dry matter (g/kg)	561.26
Methionine	0.10	Crude protein (g/kg)	189
Alfalfa	2.40		
Beets molasse	1.50		
Wheat middlings	2.50		
Tenebrio molitor (mealworm)	0.00		

using individual feeders to monitor consumption precisely.

The insect meal used for supplementation was derived from dried and finely ground *Tenebrio molitor* larvae. The larvae were sourced from a local producer and processed under hygienic conditions. Their proximate composition included approximately 50% crude protein and 30% lipid on a dry matter basis, with favorable levels of polyunsaturated fatty acids.

Data Collection Procedures

To assess the effect of dietary treatments on performance and egg quality, several parameters were monitored throughout the study.

Body Weight and Feed Intake: Hens were weighed individually at the beginning (Day 0) and at the end (Day 28) of the trial using a precision scale (±0.01 g). Daily feed consumption was recorded per pen by weighing the feed offered and subtracting refusals.

Egg Production and Collection: Eggs were collected manually every morning. The number of eggs laid per pen was recorded daily to calculate weekly laying rates. Each egg was weighed individually using a precision digital balance with an accuracy of 0.001 g.

Egg Quality Analysis: Every week, a representative sample of 48 eggs (12 eggs per dietary group, 1 per hen) was selected for physical quality assessments. Parameters measured included egg weight, shell weight, shell thickness, albumen weight, yolk weight, yolk color (based on the Roche color fan scale), and egg dimensions (length and width). These evaluations followed standard methodologies as described in the protocols of Ait-Kaki *et al.* (2022), ensuring consistency with established scientific practices.

Chemical Analysis of Eggs:

Cholesterol Content: On two separate occasions (February 26 and March 12) twelve eggs per group (one egg per hen) were randomly collected within 48 hours prior to analysis to determine yolk cholesterol levels. The analysis was performed using an enzymatic colorimetric method as described by Moula *et al.* (2022), ensuring both reproducibility and high sensitivity.

Essential Fatty Acids: At the end of the study (March 12), one egg from each pen (totaling 12 eggs per group) was analyzed for essential fatty acid content. Specifically, docosahexaenoic acid (DHA) and alpha-linolenic acid (ALA) levels were quantified using gas chromatography techniques performed in collaboration with a certified laboratory. These fatty acids are critical for both poultry and human health, and their presence can reflect the nutritional impact of diet modifications.

Statistical Analysis

All data collected during the study were compiled and subjected to statistical analysis using SAS software (Statistical Analysis System, version 9.1, 2001). The effects of dietary treatment, experimental week, and their interactions were examined using the General Linear Model

(GLM) procedure. When significant differences were detected, post hoc comparisons were made using Tukey's test to identify specific group differences.

Laying rate data, expressed as the percentage of eggs laid per hen per day, were analyzed using Chi-square (χ^2) tests to assess differences among the groups. Statistical significance was established at a threshold of $P < 0.05$.

Descriptive statistics (means and standard deviations) were calculated for all quantitative variables to facilitate interpretation of trends and variability. Additionally, data visualization techniques (box plots and error bars) were employed to graphically represent performance differences between groups, although these are not included in this summary.

RESULTS AND DISCUSSION

Zootechnical Performance

The incorporation of Tenebrio molitor larvae meal into the diets of laying hens provided a concrete means of evaluating the practical effects of this alternative protein source on zootechnical performance. Over the four-week experimental period, no statistically significant differences were observed in the overall laying rate between dietary treatments (p = 0.48; Figure 2). Nonetheless, a closer look at the numbers reveals an interesting trend: while the control, TM1, and TM2 groups achieved laying rates of 80.56%, 83.34%, and 77.22% respectively, the TM4 group dropped to 72.78% (Table 2). Although this decrease was not statistically significant, it could hint at a potential threshold beyond which higher inclusion levels may start to impact laying performance (Bovera *et al.,* 2016; Biasato *et al.,* 2018).

As for body weight, no notable variation was observed between the beginning and end of the trial (P > 0.05), indicating that replacing soybean meal with insect meal did not impair the hens' growth or health. However, hens in the TM4 group showed a slight, non-significant weight loss, which have been linked to reduced palatability or to a subtle nutritional imbalance at higher inclusion rates (Schiavone *et al.,* 2017; Gasco *et al.,* 2018).

In contrast, the feed conversion ratio (FCR), a key indicator of feed efficiency, was significantly affected by the type of diet (P = 0.03). Interestingly, the TM4 group achieved the best FCR, suggesting that despite a slightly reduced laying rate, the hens made more efficient use of their feed. This finding supports the notion that

Table 2. Effect of diet groups (Groups), feeding period (week, WK), and diet-week interaction (Groups×WK) on egg physical quality parameters in Isa Browns

Parameters	Groups				SEM	R2	P-value		
	TM0%	TM1%	TM2%	TM4%			Groups	WK	Groups*WK
Egg-laying rate (%)	80.56	83.34	77.22	72.78	5.02	0.29	0.48	0.32	0.69
FCR (g/g)	3.18[a]	3.08[ab]	3.06[ab]	2.90[b]	0.07	0.51	0.03	0.08	0.11
Egg weight (g)	61.48[a]	60.67[ab]	59.65[b]	61.50[a]	0.54	0.46	0.02	0.14	0.26
Length (mm)	55.81	55.6	56.07	55.94	0.28	0.16	0.72	0.57	0.97
Widh (mm)	43.9	44.08	44.19	43.99	0.16	0.22	0.62	0.72	0.73
Albumen (%)	58.47	59.57	58.97	58.46	0.46	0.35	0.07	0.98	0.43
Yolk (%)	29.49	28.51	29.07	29.79	0.4	0.38	0.04	0.82	0.41
Egg shell (%)	12.05	11.92	11.96	11.79	0.21	0.27	0.22	0.17	0.99
Yolk/albumen ratio	0.5	0.48	0.49	0.51	0.01	0.19	0.67	0.78	0.91
Haugh units (HU)	88.73	87.24	86.95	87.61	0.68	0.21	0.75	0.96	0.61
Shell thickness ($x10^{-2}$ mm)	386	380	373	382	4.54	0.32	0.43	0.57	0.37
Fmax (newton)	38.11	38.04	37.3	38.29	0.45	0.31	0.42	0.58	0.38

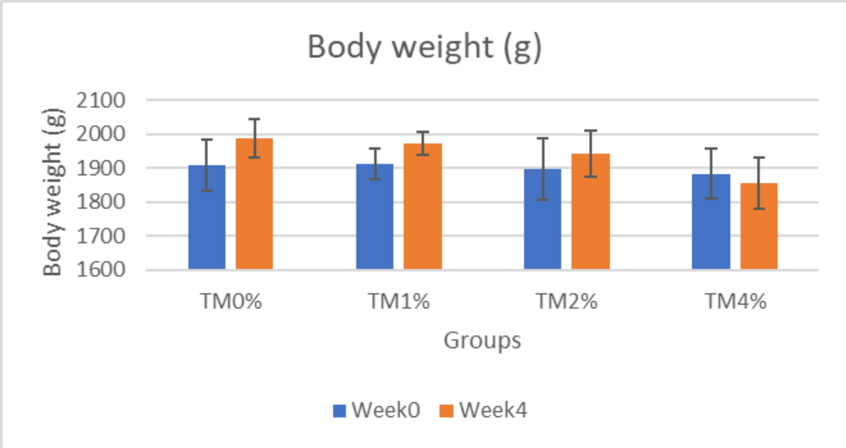

Figure 2. Evolution of hen live weights according to Mealworm Larvae content in diet

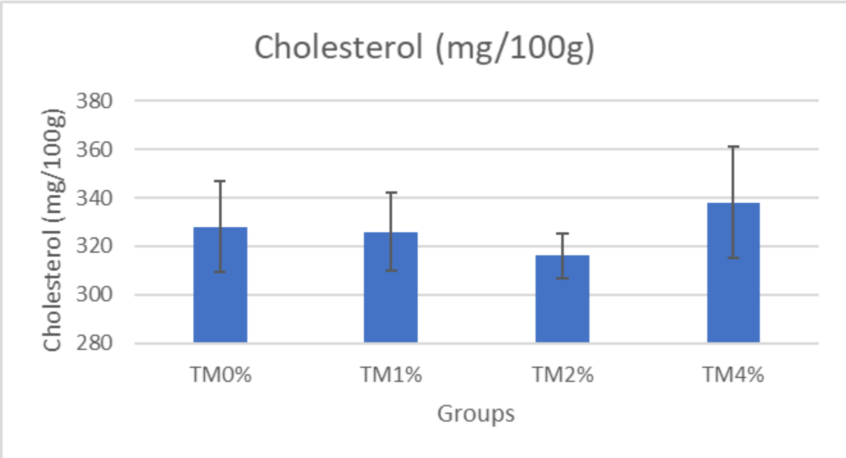

Figure 3. Effect of Mealworm Larvae content in diet on cholesterol levels of the egg yolks

insect protein could contribute positively to optimizing production costs (Kieronczyk *et al.,* 2021; Veldkamp *et al.,* 2012).

Recent studies reinforce this potential, highlighting the digestibility, nitrogen retention, and essential amino acid contributions of insect meal (De Marco *et al.,* 2015; Henry *et al.,* 2015). From an environmental standpoint, the use of insects as a feed ingredient fits squarely within circular economy principles and aligns well with European strategies for sustainable animal nutrition (Van Huis *et al.,* 2013; Rumpold *et al.,* 2013).

Physical Egg Quality

The physical traits of eggs directly affect consumer perception and market value. In this study, no significant differences were observed in egg length, width, or shape index between groups (P > 0.05; Table 2). These traits are typically influenced by factors like hen age, genetics, and housing conditions (Philippe *et al.,* 2020; Samiullah *et al.,* 2017), all of which were carefully controlled here to ensure fair comparisons.

One notable outcome was the significant variation in egg weight depending on the diet (P = 0.02). While eggs from the TM4 group were similar in weight to those from the control group, eggs from TM2 were slightly lighter. This minor fluctuation could reflect individual variability or subtle formulation differences in the TM2 diet (Attia *et al.,* 2017).

Regarding internal egg components, yolk, albumen, and shell, there were no statistically significant differences between groups (P > 0.05). This suggests that the inclusion of insect meal did not negatively impact internal egg quality. Haugh unit values, which assess albumen freshness and quality, were consistent across all treatments, supporting the idea that such diets do not compromise egg integrity (Jones *et al*., 2005).

Shell strength, a critical factor for egg durability during handling and transport, also showed no significant variation. Shell weight, thickness, and breaking force (Fmax) were all within normal ranges ($P > 0.05$), indicating that calcium and phosphorus levels were adequate in all dietary formulations (Nys *et al.,* 2004).

It's worth noting that eggshell quality depends not only on mineral intake, but also on nutrient bioavailability and the hen's metabolic response, factors that can, in turn, be influenced by diet changes (Bar *et al*., 2009).

Cholesterol Content and Fatty Acid Profile

Public perception of dietary cholesterol has evolved significantly in recent years. Current guidelines in both Europe and North America have moved away from strict cholesterol limits, reflecting a more nuanced understanding of the link between dietary intake and blood cholesterol levels (Soliman, 2018; EFSA, 2010). Eggs, once viewed with suspicion, are now appreciated for their high-quality protein, choline content, and fat-soluble vitamins (Blesso *et al.,* 2018).

In our study, cholesterol levels in the egg yolks did not differ significantly among the groups ($P > 0.05$; Figure 3). Values ranged from 0.316 to 0.338 mg/100 g, which aligns with previously reported data and reinforces the stability of this parameter across different diets (Shinn *et al.,* 2018).

The fatty acid composition of egg yolks, particularly omega-3s such as alpha-linolenic acid (ALA) and docosahexaenoic acid (DHA), has garnered growing interest due to their known health benefits. Previous studies showed that

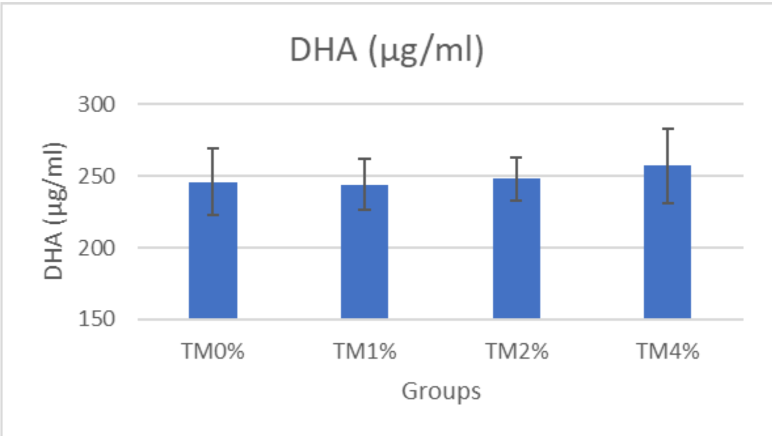

Figure 4. Effect of Mealworm Larvae content in diet on DHA levels of the egg yolks

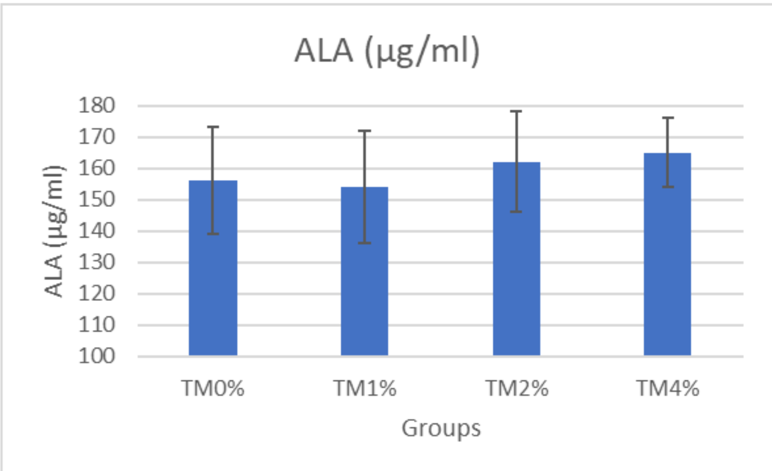

Figure 5. Effect of Mealworm Larvae content in diet on ALA levels of the egg yolks

adding flaxseed or fish oil to poultry diets significantly enhanced these fatty acid levels (González-Esquerra and Lesson, 2001). In this study, however, no significant differences were observed in either ALA or DHA concentrations (P > 0.05; Figure 4 and Figure 5). DHA levels averaged approximately 246 µg/ml, and ALA around 156 µg/ml, suggesting that the T. molitor meal used here lacked sufficient omega-3 content to noticeably affect yolk composition, or that the study duration was too short to observe such changes (Fraeye *et al.,* 2012). However, the lack of direct analysis of the dietary fatty acid composition somewhat limits the interpretation of these results. Future research would benefit from detailed feed composition analyses, including both omega-3 and omega-6 profiles, to better understand nutrient interactions (Surai, 2002). In particular, the omega-6 to omega-3 ratio is now seen as a critical indicator of dietary balance and a potential marker of inflammatory and cardiovascular risk (Calder, 2015).

CONCLUSION

This study demonstrates that *Tenebrio molitor* meal is a viable and sustainable alternative protein source for poultry in Algeria. Inclusion up to 4% did not adversely affect laying performance or egg quality and improved feed conversion efficiency. Key physical traits (egg weight, shell, albumen, yolk) and chemical parameters (cholesterol, fatty acids) remained stable. The slight, non-significant decrease in laying rate at 4% suggests a potential upper inclusion threshold. Further studies on larger flocks and over longer periods are needed to confirm these findings and assess long-term effects on productivity and sustainability.

CONFLICT OF INTEREST

The author declares no conflict of interest.

ETHICAL STATEMENT

All experimental procedures involving animals were conducted in accordance with the guidelines approved by the Animal Welfare and Experimentation Commission of the National Veterinary School of Algiers (CEEA-ENSV Algiers-2022).

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