Entomology and Applied Science Letters
Volume 9, Issue 4, Page No: 48-56
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Available Online at: www.easletters.com

ISSN No: 2349-2864

Evaluation of Nutritional Content of the Larvae of *Tenebrio Molitor*, and Formulation of Broiler Stockfeed

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ABSTRACT

Insects have been utilized as food sources since decades ago as they are readily available, easy to rear, and less harmful to the environment. This study aimed to determine the nutritional value of *Tenebrio molitor* mealworms reared in Zimbabwe for the first time, as well as to carry out a feeding trial on broilers using the *Tenebrio molitor* mealworm powder formulated stockfeed. The methods used in the determination of the nutritional content were based on the standard methods by the Association of Analytical Chemists. The results show that mealworms that are currently being reared in Zimbabwe contain 4.75 % moisture content, 26 % crude fat, 54.8 % crude protein, 4.125 % ash content, 6.1 % crude fiber, and 4.22 % carbohydrates. For the feeding trial, broiler chickens were divided into three groups of 5 chickens each and fed with a feed of different compositions for 6 weeks. The control group (a) was fed with a basal diet of commercially available broiler stockfeed, the second group (b) was fed with commercially available broiler stockfeed, supplemented with 3 % dried *Tenebrio molitor* mealworms and the third group (c) was fed with the formulated *Tenebrio molitor* stockfeed. The chickens in groups a, b, and c were found to have average weights of 2.375 kg, 2.52 kg, and 2.3762 kg respectively. The feed conversion ratio for groups a, b, and c were 1.45, 1.37, and 1.452 respectively. Therefore, T*enebrio molitor* mealworms may be a good source of protein for the production of stockfeed.

Keywords: *Tenebrio molitor*, Yellow mealworms, Nutritional value, Protein source, Chickens, Stockfeed.

HOW TO CITE THIS ARTICLE: Machona O, Matongorere M, Chidzwondo F, Mangoyi R. Evaluation of Nutritional Content of the Larvae of *Tenebrio Molitor*, and Formulation of Broiler Stockfeed. Entomol Appl Sci Lett. 2022;9(4):48-56. https://doi.org/10.51847/1WgQiAHwj4

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Received: 12/08/2022
Accepted: 04/12/2022

INTRODUCTION

Edible insects have been claimed to serve as a source of protein as they have been reported as effective feed converters and have a high nutritional value [1-4]. According to reports, the caloric value of insects is 50 % greater than soybeans, 87 % greater than corn, and 63 % greater than beef [5]. Among the edible insects, the larvae of *Tenebrio molitor* (yellow mealworm) have been reported as one of the most used insects as a protein source for both humans and animals [6]. The larvae are most famous for being used as bait for fish and as food for fish, amphibians, reptiles, turtles, birds, crows, and some small animals kept as pets [7]. In some countries, *Tenebrio molitor* larvae are being produced industrially as feed and feed supplements for pets, zoo animals, and even livestock [8]. They are raised in vast numbers and are referred to as the best source of animal protein. Numerous scientists demonstrated that freshly produced yellow mealworm larvae have a 15 % fat and 20 % protein content. It has also been reported that mealworms do not only consume existing food supplies more effectively than other animals, but they can also quickly transform low-nutrient by-products of popular crops like maize, wheat, millet, and peanuts into high-quality food [9-11].

Some studies have also been conducted on the nutritional makeup of mealworms but it has been reported that values vary by species and developmental [12-15]. The yellow mealworm can be fed to animals in its live form, but more commonly they are dried and may be ground into powder. Currently, the production of soya bean (a major source of protein in Zimbabwe), has been reported to have declined by 46 % due to the harsh economic conditions. Therefore, the decrease in productivity means that the gap has to be met so researchers have decided to look for other sources of protein, particularly the larvae of *Tenebrio molitor*. Mealworm breeding has been reported to be cheap and fast from an economical point of view as its life cycle is very short. Thus, this study aimed to determine the nutritional value of *Tenebrio molitor* mealworms reared in Zimbabwe for the first time and to investigate whether they can serve as a sustainable alternative source of protein for livestock in Zimbabwe. In this particular study, feeding trials were carried out on broiler chickens using the *Tenebrio molitor* stock feed that was formulated in accordance with the standard nutritional quantities of commercial broiler stockfeed.

MATERIALS AND METHODS

The yellow mealworms were reared in plastic containers (35 × 25 × 20 cm) at 28 ±1 °C, on the feed of wheat bran with the addition of carrots as a source of water. The nutritional evaluations of these mealworms were carried out at 10 weeks of age. Approximately 1000 larvae were used for nutrient analysis. The mealworms were fasted for three days before the analysis. After 3 days of fasting, the mealworms were washed 3 times with tap water. The mealworms were blanched in boiling water for 3 minutes. Blanched mealworms were kept in a colander for cooling and removing excess water. After 30 min, the remaining water was removed with a paper towel. The mealworms were then dried using a hot-air dry oven at 60 °C for 12 hours. Dried mealworms were pulverized with a blender (EM-BL-1056-2IN1- Electro Master) until the resulting powder could pass a 30-mesh sieve (535 μm). The mealworm powder was then weighed and stored at room temperature.

Nutritional analysis of the mealworm powder

The methods used in the determination of moisture content, crude fat, crude protein, ash content, mineral analysis, crude fiber, and carbohydrates were based on Standard methods by the Association of Analytical Chemists (AOAC). All of the analyses were done in duplicate for all the nutrients under investigation.

Determination of moisture content

The moisture content was determined by drying the wet sample of *Tenebrio molitor* to a constant weight in an air-circulating oven at 60 °C to ascertain the moisture content of the samples.

Determination crude fat

Extraction of crude fat was carried out using the Soxhlet method. The glassware was rinsed with petroleum spirit and dried in an oven at 102 ºC for 30 minutes. The Soxhlet extraction unit was assembled over an electric heating mantle. A total of 5 g of dried samples of mealworm powder (from moisture determination) were put into thimbles and these thimbles were transferred into the Soxhlet extraction unit. Cotton wool was plugged into the top of each thimble to prevent the sample from spilling. The extraction was done for 6 hours in a fume hood. The extraction unit was removed from the heat source and the extractor and condenser were detached. The flasks were removed from the heat source and the solvent was evaporated off on a rotavapor. The flasks and their contents were placed in an oven at 102 ºC for approximately 1-2 hours until a constant weight was reached.

Determination crude protein

The defatted mealworm powder was used for protein determination. A total of 1.0 g of mealworm powdered sample, 5 g of Kjeldahl catalyst, and 25 ml of concentrated H_2SO_4 were added into the digestion flask. The blank was prepared by adding 5 g of Kjeldahl catalyst and 25 ml of sulphuric acid but no sample was added. The flasks were placed in an inclined position and gently heated in a fume hood until unit frothing ceased. The heating continued until the solution cleared. The flasks were connected and then immediately started to digest the bulb on the condenser, with the tip of the condenser immersed in boric acid. Approximately 5-7 drops of mix indicator (100 ml of 0.1 % methyl red mixed in 95 % ethanol with 200 ml of 0.2 % bromocresol green in 95 % ethanol) were added to a receiver. The receiver was removed as well as the tip of the condenser. Then the solution was titrated with 0.1N hydrochloric acid.

Determination of crude fiber

An amount of 2 g of the mealworm powder was added to 1L flasks. Boiling diluted Sulphuric acid was added to the flask. Each flask was connected to water following the heating of the contents to boiling for 30 minutes. The sample was then filtered through a Whatman No: 54-grade filter paper held in a funnel. The insoluble matter was washed with boiling water until the washings were free from acid. The residue on the filter paper was put back in the original flask using a wash bottle containing boiling sodium hydroxide solution. Immediately each flask was connected to the reflux condenser and boiled for exactly 30 minutes. The flasks were removed and allowed to stand for 1 minute. The sample was then filtered under a suction pump through a Whatman No: 54-grade filter paper. The whole of the insoluble material from the filter paper was transferred using boiling water. It was washed with boiling water and then with hydrochloric acid and finally with boiling water. The insoluble material was washed twice with ethanol and three times with diethyl ether. The insoluble matter was transferred to the porcelain crucible using a wash bottle containing boiling water and evaporated in a water bath. The crucible and the residue were ovens dried at 105 ºC to constant weight for at least an hour. The contents were cooled in a desiccator to room temperature and weighed. The residue was incinerated in the electric muffle furnace at 500 ºC until all the carbonaceous matter was burnt The crucible was allowed to cool to 200 ºC then samples were transferred to a desiccator using tongs for further cooling, followed by weighing.

Determination of ash content

Mealworm powder amounting to 5 g was weighed into the crucibles. The crucibles were heated over a low Bunsen flame with the lid half covered in a fume hood. The crucibles were placed in the furnace at 550 ºC overnight to ensure that impurities on the surface of the crucibles were burnt off. The crucibles were cooled in the desiccator for 2 hours, followed by weighing the crucibles and lids.

Determination of minerals

The metals were measured using atomic absorption spectrophotometry (AAS). The sample was ground into powder using a blender. Concentrated HNO_3 was added to the homogenized samples and left to digest overnight. The samples were heated in a sand bath until a clear solution was obtained. They were cooled to room temperature and filtered. Each sample was transferred to a volumetric flask and diluted to the mark with distilled water. Standard stock solutions with concentrations of 1000 mg/L of Cu $(NO_2)_4$, $Mg(NO_2)_4$, $Na(NO)_2$and KNO_2 were used. Working standards for the metals were prepared by serial dilutions of the standard solutions. Concentrations were determined through linear calibration obtained from absorbance measurements of, at least, five different concentrations of the working standard solutions. Phosphorus was determined using molecular absorption spectrophotometry (UV/VIS).

Determination carbohydrates content

Carbohydrates were determined using the difference method. The percentages of all the other nutrients obtained in the investigation were added and this total was subtracted from 100 %.

Formulation of stockfeed

The *Tenebrio molitor* stock feed was formulated according to the following formula using the feed calculator application in accordance with the standard nutritional quantities of commercial broiler stockfeed. The starter broiler feed contained 59 % carbohydrates (ground maize), 20 % proteins (ground *T. molitor* powder), 5 % Fat (fish meal), 15.6 % minerals (premix), and 0.4 % salt. The grower's broiler feed contained 61 % carbohydrates (ground maize), 18 % proteins (ground *T. molitor* powder), 5 % Fat (fish meal), 15.6 % minerals (premix), and 0.4 % salt. The finisher broiler feed constituted 63 % carbohydrates (ground maize), 16 % proteins (ground *T. molitor* powder), 5 % Fat (fish meal), 15.6 % minerals (premix), and 0.4 % salt.

Broiler feeding trial

Fifteen, one-day-old chicks were purchased at a local poultry store. Upon arrival, the chicks were randomly divided into 3 groups and were used in the feeding trial. Each group consisted of 5 chickens. The control group (A) was fed with a basal diet of commercially available broiler stock feed. Group (B) was fed with the known brand of stock feed, supplemented with 3 % dried *Tenebrio molitor* mealworms, and group (C) was fed with the formulated *Tenebrio molitor* stock feed. Each group was fed on 2 kg of starter feed for the first 2 weeks, 5 kg of growers feed throughout the third and fourth weeks, and 10 kg of broiler finisher for the last 2 weeks. All the rearing conditions, besides feed, were kept constant. The conditions kept constant included ventilation, lighting, feeding times, amount of feed, amount of water, and frequency of cage cleaning. All of the chickens from each group were weighed and mass was recorded after 7 days using a standard scale.

Statistical analysis

Results are the mean of determinations, and the standard deviation (SD) is reported. Results were analyzed by the ANOVA test.

RESULTS AND DISCUSSION

Mealworms were washed and dried, followed by oven drying of the mealworms and crushing of the mealworms to produce the mealworm powder as shown in **(Figure 1)**.

a) b)

c) d)

Figure 1. a) Mealworms after washing and blanching in hot water, b) Oven-dried mealworms, c) mealworm powder during blending, and d) mealworm powder obtained after blending dried mealworms

The proximal contents of *Tenebrio molitor* mealworm powder were determined and results are shown in **(Figure 2)**. The results obtained in this study are in line with those reported by Makkar [16].

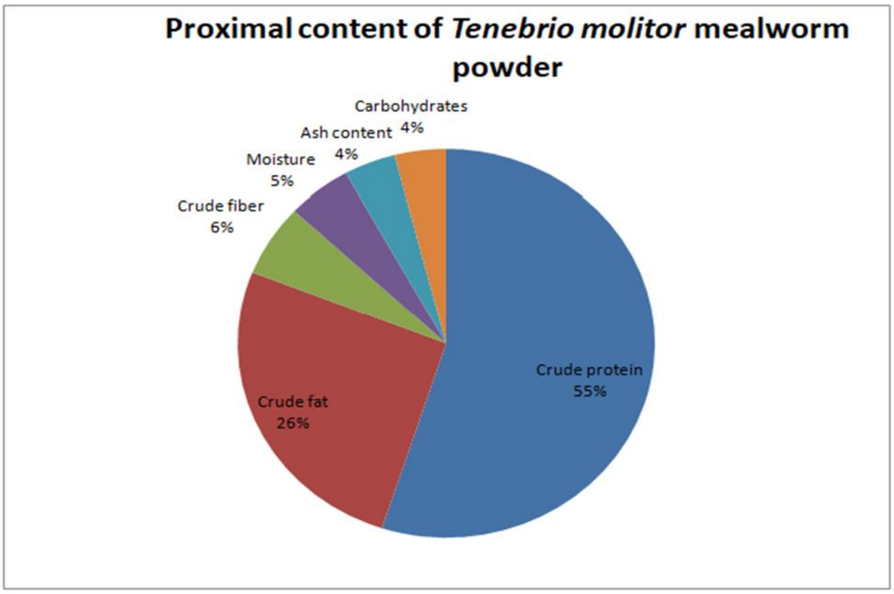

Figure 2. The Proximal content of *Tenebrio molitor* mealworm powder illustrated on a pie chart

The proximate composition of yellow mealworm larvae shown in **(Figure 2)** is similar to the results reported by other authors. The protein content was in the range of values of (41.0 –53.2 %) which has been reported by other authors [12]. The moisture content of 4.75 % obtained in this particular study was slightly lower than what has been reported by other researchers and the moisture is believed to be related to the size of the analyzed mealworms such that a lower moisture content indicates the bigger the mealworms [17]. It is significant to outline that in this particular study a nitrogen-protein conversion factor of 6.25 was used. The fat content that has been obtained in this study also falls in the range of (24.7–50.2 %) previously reported [18]. The ash content was also in the range of values of (2.36–4.74 %) published by quite several researchers [12, 19].

The mineral content of *Tenebrio molitor* larvae powder was also determined and results are shown in **(Table 1)**. These results are in line with those obtained by Aguilar [20] and Kirk [21] who confirmed that *Tenebrio molitor* mealworm contains a considerable amount of vitamins and minerals.

Table 1. The mineral content of *T. molitor* larvae powder (mg of mineral per kg of the sample)

Element	mg /kg
Magnesium (Mg)	2450 ± 184
Copper (Cu)	7 ± 0.5
Sodium (Na)	2100 ± 151
Potassium (K)	7860 ± 524
Calcium (Ca)	450 ± 10
Phosphorus (P)	7500 ± 567

Note: Mineral content determination was done in duplicate

The mineral composition of *Tenebrio molitor* mealworm powder is shown in **Table 1** and the obtained values for each element in this particular study fall in the range of values that have been published by other authors [16]. The levels of Na (2100 mg/kg) and Mg (2450 mg/kg) were slightly higher as well as the sodium content which was (2100 mg/kg). It is important to mention that the amount of Na in 100 g of dried larvae is extremely below the maximum recommended daily uptake, which is advantageous given that high sodium intake increases blood pressure [22].

Carbohydrate content in mealworm powder

Carbohydrates were determined using the

difference method. The percentages of all the other nutrients obtained in the investigation were added and this total was subtracted from 100 %.

$$100\ \% - (4.75 + 26.6 + 6.1 + 54.8 + 4.13) = 4.22 \quad (1)$$

Growth of broilers over six weeks

The chickens were first kept in a container for the first two weeks as it is crucial at this stage to take good care of the chicks for maximum growth and better results. The chicks upon arrival are shown in **(Figure 3)**. The chicks in all three groups had an average weight ranging from 0.033 – 0.034 kg

c) b) a)

Figure 3. a) Chickens fed with a basal diet of commercially available broiler stockfeed, b) chickens fed with commercially available broiler stockfeed, supplemented with 3 % dried *Tenebrio molitor* mealworms and c) chickens fed with the formulated *Tenebrio molitor* stockfeed upon arrival.

After 6 weeks of feeding the chickens, the chickens were found to have an average weight of between 2.3-2.5 kg in all groups. However, group B of chickens fed with commercially available broiler stock feed, supplemented with 3 % dried *Tenebrio molitor* had the highest average weight. The average weights of chickens in groups A and C were almost similar without any discernible difference. The image of the chickens is shown in **(Figure 4).**

Figure 4. (a) Chickens fed with a basal diet of commercially available broiler stockfeed, (b) chickens fed with commercially available broiler stockfeed, supplemented with 3 % dried *Tenebrio molitor* mealworms and (c) chickens fed with the formulated *Tenebrio molitor* stockfeed.

Chickens from group B fed with commercially available broiler stockfeed, supplemented with 3 % dried *Tenebrio molitor* mealworm were the biggest, followed by chickens fed with the formulated *Tenebrio molitor* stockfeed which looked almost similar to the chickens fed with a basal diet of commercially available broiler stockfeed as there was a slight difference in their average weights. This could be because edible insects such as *Tenebrio molitor* mealworm have been reported to have more nutritional value and content compared to other conventional diets. Insects convert food by-products to protein compared to other animals [23]. Protein sources from animals are readily available compared to protein from plant-derived sources. The main reason behind its availability is because of the balanced amino acid composition in animal protein [24].

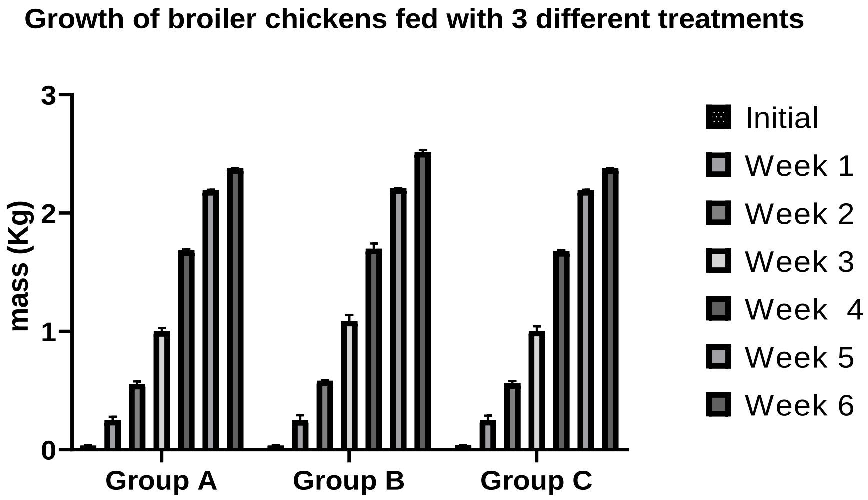

Figure 5. Bar graph showing the average weights of the 3 groups of chickens fed with different treatments over 6 weeks.

Note: All values are mean ± SD for N=7

The weights of the chickens were recorded, and the average weight of each group was calculated over 6 weeks. At week 1, the average weight of the chickens was very similar, as shown in **(Figure 5)**. At week 2, the average weight of the chickens in group B was slightly higher compared to the chickens in the other 2 groups. At week 3, the average weight of chickens in group B was the highest, and the average weights of chickens in groups A and C were almost the same. At weeks 4 and 5, group B was slightly ahead of Groups A and C in terms of average weight, whilst group C was slightly higher than group A. At week 6, the average weight of chickens in group B was markedly higher than the averages of chickens in groups A and C, which were almost equal. Recently research has been conducted on dietary insects as feed ingredients in poultry nutrition, and it has been reviewed that they have a positive impact on growth performance when used as a protein source in poultry nutrition [25, 26]. It has also been reviewed that broilers fed with a diet consisting of 30 % *Tenebrio molitor* larvae meal had more protein content and digestibility compared to the broilers that were fed with normal feed [27]. In another study, catfish showed a good performance of growth when fed on a diet consisting of 80 % mealworm, and they contained higher lipids content in their carcass after being fed on mealworm-based [28].

The feed conversion ratios for the basal diet and the *Tenebrio molitor* feed were higher than that of the basal diet + 3 % *Tenebrio molitor* supplement feed, showing that the broilers were more efficient at converting the supplemented feed into energy, than the other 2 treatments. The feed conversion ratio for each group is shown in **(Table 2)**.

Table 2. The feed Conversion ratio of the broiler chickens fed with different treatments over 6 weeks.

Treatment	Feed conversion ratio
A	1.452
B	1.37

C	1.45

The lower feed conversion ratio for groups A and C obtained in this particular study is convincing that mealworm is a highly nutritive diet and acceptable as an alternative protein source. In a research conducted by Ramos [29], they experimented on 0 %, 5 %, and 10 % dry weight in a 19 percent protein content sorghum–soybean meal basal diet to evaluate feed intake, weight gain, and feed efficiency in broiler chicks. They observed that there were no significant differences between treatments after 15 days.

Tenebrio molitor larvae are a promising alternative to usual protein sources, mostly soybean meal. Dried mealworm of up to 6 % in a weaning pig's diet is beneficial for growth performance as demonstrated by Oonincx [30]. In another study, it was reviewed that adding dried mealworms to livestock feed increases feed intake and nutrient digestibility without any detrimental effect on the immune response. Oils extracted from mealworms are rich in polyunsaturated fatty acids and frequently contain essential linoleic and α-linolenic acids [30, 31]. Linoleic and α-linolenic essential fatty acids have nutritional importance mainly for the healthy development of children [31].

CONCLUSION

Tenebrio molitor mealworm can be regarded as a good food for both animals and humans as it has a good nutritional value which is comparable to sources of protein such as soybean. The chickens showed their maximum growth when fed with commercially available broiler stockfeed, supplemented with 3 % dried *Tenebrio molitor* mealworm, followed by the group of chickens fed with the formulated *Tenebrio molitor* stockfeed, which had a slightly higher average weight than the average weight of the chickens fed with a basal diet of commercially available broiler stockfeed.

ACKNOWLEDGMENTS: University of Zimbabwe Research Board (Harare, Zimbabwe) is acknowledged.

CONFLICT OF INTEREST: None

FINANCIAL SUPPORT: Reagents used in this study were provided by the Biotechnology and Biochemistry Department at the University of Zimbabwe, Zimbabwe.

ETHICS STATEMENT: None

REFERENCES

1. Pan J, Xu H, Cheng Y. Recent Insight on Edible Insect Protein: Extraction, Functional Properties, Allergenicity, Bioactivity, and Applications. Foods. 2022;11:1-21.
2. Pham DT, Ninh NT, Hoang TN, Pham CT, Nguyen LH, Tran TQ, et al. The Effectiveness of Oral Nutritional Supplements Improves the Micronutrient Deficiency of Vietnamese Children with Stunting. Arch Pharm Pract. 2020;11(1):7-13.
3. Al-Saeed AA, Almaqhawi A, Ibrahim S. Nutritional Supplements Intake by Gym Participants in Saudi Arabia: A National Population-Based Study. Int J Pharm Phytopharmacol Res. 2020;10(3):43-52.
4. Ella CW, Ousmane O, Tiatou S, Augustin NP, Pietra V, Basma E, et al. Evaluation of the Effectiveness of Cost-free Nutrition Programme on Children in Reo Health District, Burkina Faso. Int J Pharm Res Allied Sci. 2020;9(2):24-33.
5. Orkusz A. Edible Insects versus Meat—Nutritional Comparison: Knowledge of Their Composition Is the Key to Good Health. Nutrients. 2021;13(4):1207.
6. Costa S, Pedro S, Louren H. Evaluation of Tenebrio molitor larvae as an alternative food source. NFS J. 2020;21:57-64.
7. Valdés F, Villanueva V, Durán E, Campos F, Avendaño C, Sánchez M. Insects as Feed for Companion and Exotic Pets: A Current Trend. Animals. 2022;12(11):1450.
8. Kim SY, Park J, Lee YB, Yoon HJ, Lee KY, Kim NJ. Growth characteristics of mealworm Tenebriomolitor. J Sericult Entomol Sci. 2015;53(1):1-5.
9. Liu C, Masri J, Zhao J. Growth Performance and Nutrient Composition of Mealworms (Tenebrio Molitor) Fed on Fresh Plant Materials-Supplemented Diets. Foods. 2020;9(2):151.
10. Rumbos CI, Karapanagiotidis IT, Athanassiou CG. Evaluation of various commodities for the development of the yellow mealworm,

Tenebrio molitor. Sci Rep. 2020;10(1):11224.
11. Bordiean A, Krzyżaniak M, Aljewicz M, Stolarski MJ. Influence of Different Diets on Growth and Nutritional Composition of Yellow Mealworm. Foods. 2022;11(19):3075.
12. Shah AA, Totakul P, Matra M, Cherdthong A, Hanboonsong Y, Wanapat M. Nutritional composition of various insects and potential uses as alternative protein sources in animal diets. Anim Biosci. 2022;35(2):317-31.
13. Riekkinen K, Väkeväinen K, Korhonen J. The Effect of Substrate on the Nutrient Content and Fatty Acid Composition of Edible. Insects. 2022;13(7):590.
14. Yu X, He Q, Wang D. Dynamic Analysis of Major Components in the Different Developmental Stages of Tenebrio molitor. Front Nutr. 2021;8:689747.
15. Khan S, Khan RU, Alam W, Sultan A. Evaluating the nutritive profile of three insect meals and their effects to replace soya bean in broiler diet. J Anim Physiol Anim Nutr (Berl). 2018;102(2):e662-8.
16. Makkar HP, Tran G, Heuzé V, Ankers P. State-of-the-art on use of insects as animal feed. Anim Feed Sci Technol. 2014;197:1-33.
17. Ghaly AE, Alkoaik FN. The yellow mealworm as a novel source of protein. Am J Agric Biol Sci. 2009;4(4):319-31.
18. Raksakantong P, Meeso N, Kubola J, Siriamornpun S. Fatty acids and proximate composition of eight Thai edible terricolous insects. Food Res Int. 2010;43(1):350-5.
19. Megido RC, Poelaert C, Ernens M, Liotta M, Blecker C, Danthine S, et al. Effect of household cooking techniques on the microbiological load and the nutritional quality of mealworms (Tenebrio molitor L. 1758). Food Res Int. 2018;106:503-8.
20. Aguilar-Miranda ED, Lopez MG, Escamilla-Santana C, Rosa BAP. Characteristics of maize flour tortilla supplemented with ground Tenebrio molitor Larvae. J Agric Food Chem. 2002;50:192-5.
21. Kirk CK, Paul T, Melvin AL, Christopher CC. Increasing the calcium content of mealworms (Tenebrio molitor) to improve their nutritional value for bone mineralization of growing chicks. J Zoo Wildl Med. 2000;31(4):512-7.
22. Mente A, Donnell M, Yusuf S. Sodium Intake and Health: What Should We Recommend Based on the Current Evidence? Nutrients. 2021;13(9):3232.
23. Belluco S, Losasso C, Maggioletti M. Edible insect in a food safety and nutritional perspective: A critical review. Compr Rev Food Sci Food Saf. 2013;12:296-313.
24. Cromwell GL. Feeding swine. In: Livestock Feeds and feeding (4th ed). Prentice-Hall, Upper Saddle River, NJ, USA. 1998.
25. Benzertiha A, Kiero´nczyk B, Rawski M. Tenebrio molitor and ZophobasmorioFull-Fat Meals in Broiler Chicken Diets: Effects on Nutrients Digestibility, Digestive Enzyme Activities, and CecalMicrobiome. Animals. 2019;9:1-12.
26. Elahi U, Xu Chang-chun, Qi G. Insect meal as a feed ingredient for poultry. Anim Sci. 2022;35(2):332-46.
27. Filho MA, Pereira RT, Oliveira AB, Suckeveris SD, Burin AM. Nutritional value of Tenebriomolitor larvae meal for broiler chickens: metabolizable energy and standardized ileal amino acid digestibility. J Appl Poult Res. 2021;30(1):100102.
28. Shafique L, Abdel-Latif HR, Liu Q. The Feasibility of Using Yellow Mealworms (Tenebriomolitor): Towards a Sustainable Aquafeed Industry. Animals. 2021;11(3):811.
29. Ramos-Elorduy J, Avila E, Gonzalez A, Rocha H, Pino JM. Use of Tenebrio molitor (Coleopteratenebrionidae) to recycle organic wastes and as feed for broiler chickens. J Econ Entomol. 2022;95:214-20.
30. Oonincx DGAB, Laurent S, Veenenbos ME, van Loon JJA. Dietary enrichment of edible insects with omega 3 fatty acids. Insect Sci. 2020;27(3):500-9.
31. Takic M, Pokimica B, Petrovic-Oggiano G, Popovic T. Effects of Dietary α-Linolenic Acid Treatment and the Efficiency of Its Conversion to Eicosapentaenoic and Docosahexaenoic Acids in Obesity and Related Diseases. Molecules. 2022;27(14):44.