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Review Article

Mealworms *(Tenebrio molitor L.)* as a Substituent of Protein Source for Fisheries and Aquaculture: A Mini Review

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ABSTRACT

Development of aquaculture and fisheries depend on the availability of sustainable feed sources. Using insects is one new option that is gaining popularity. The high protein content, rapid growth and little environmental impact of yellow mealworms have made them an appealing solution. Mealworms contain a substantial protein content (47-64%), essential amino acids, energy-dense lipids, and vital micronutrients, making them a viable substitute for traditional protein sources in fisheries and aquaculture. Historically consumed in various cultures, Mealworms have gained attention for their economic and nutritional value. In aquaculture, they enhance fish growth, feed efficiency, and overall health. Studies have shown that incorporating mealworm meal into fish diets improves immune functions, growth performance, and liver health, although excessive inclusion may have adverse effects. The nutritional content of mealworms can be optimized by adjusting rearing conditions, diet, and developmental stage. The European Union's approval of mealworms for human consumption further validates their safety and potential as a sustainable protein source. This review emphasizes the nutritional benefits of mealworms as a substitute for fishmeal, addressing protein shortages and environmental concerns associated with traditional feed production. By integrating mealworms into aquaculture, we can significantly improve sustainability, economic efficiency, and global food security.

INTRODUCTION

Insects from phylum Arthropoda are the most abundant animals in the world.They can reproduce rapidly and have large populations, serving as the most valuable source for human benefits.Because of their high protein, fat, and mineral content, are seen as a potential source of food and ingredients that can improve the quality of a wide range of food products. Dicke M in 2018 and Sabri NS *et al.*, in 2023 highlighted insects can also produce other useful products such as wax, dyes, silk, and also honey, royal jelly, and propolis that have various nutritional and functional values [1, 2]. Liceaga AM *et al.*, in 2022 and van der Fels-Klerx HJ *et al.*, in 2018 highlighted the concept of insect eating, or entomophagy is gaining interest as sustainable and nutritious alternative to traditional food sources.People have been eating insects for thousands of years before they had the means to hunt or cultivate, particularly in warmer regions of the planet where they could always find a variety of insects [3,4].Van der Fels-Klerx HJ *et al.*, in 2018 emphasized in Asia, Africa, Latin America (including Mexico), and Australia, there are 2000 and above insect species are thought to be consumed.In many areas, insects constitute a common component of the human diet, with significant cultural and gastronomic significance [4]. However, in Europe and other industrialized countries, entomophagy is often viewed as nasty [4].Baiano A 2020 and Liceaga AM *et al.*, 2022 pointed out China, Mexico, India, and Thailand are the countries in which highest numbers of edible insects have been reported [5, 6].

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Baiano A *et al.*, in 2020 underlined the consumption of insects is rare or even taboo in Western nations, despite compelling evidence of entomophagy in both ancient and modern times [5]. Hartmann C *et al.*, in 2017 and Garofalo C *et al.*, in 2019 outlined a number of research studies and evaluations focused on the European perspective on edible insects highlighting the overlooked potential of eating insects and need to reduce meat consumption and replace it with other protein sources [6, 7].The insects are used due to shortage of proteins, food security, cultural traditions, and environmental factors and for medicinal importance because they contain high protein content compounds and rich in nutritional value for feed and food.Furthermore, the nutritional content of insect is much better than that of plants both in qualitative and quantitative manner.The practice of consuming insects (entomophagy) as a source of nutrition has a rich history with archaeological and ethnographic records indicating historical use of insects. The ancient civilizations such as Aztecs, Mayans, Chinese, Greeks and Romans and Cambodian incorporated crickets, mealworms, locusts, silkworms and grasshoppers into their diets. Olivadese M *et al.*, in 2023 and Costa-Neto EM *et al.*,in 2016 highlighted in Africa, termite mounds are harvested for food.In Asia, silkworm pupae and bee brood were consumed. In Latin America, ants and their eggs were eaten; and among Native Americans, grasshoppers and crickets were used as food source [8, 9].Insects are utilized for various reasons, including protein deficiency, food security concerns, cultural traditions, and environmental considerations.Furthermore, insects possess medicinal importance due to their high protein content and other valuable nutritional properties.The concept of insect eating is perceived differently in different religions and cultures.Eating bugs is approved or even promoted in some religions because they are a nutrient-rich food source that aligns with a respect for nature.Sabri NS *et al.*, in 2023 pointed out however other religious beliefs have dietary guidelines that limit or restrict the consumption of certain animals, including insects, based on concepts of cleanliness, purity or symbolic significance [2]. Chung AY *et al.*, in 2000 and Sabri NS *et al.*, in 2023 highlighted the concept of insect consumption in non-Muslim countries of Asia is mainly reported in Japan, China, the Lao People's Democratic Republic, Vietnam and Thailand. However, in Muslim majority nations like Indonesia and Malaysia, insect consumption is less common due to a lack of historical dietary practices and concerns about its halal status [10, 2]. Tenebrio molitor (TM), commonly known as Mealworm, is a member of the family Tenebrionidae, class insecta and phylum Arthropoda.TM's exoskeleton is composed of calcium carbonate and chitin. TM grows mostly through molting of exoskeleton. Although TM is found all over the world, it is primarily found in the Mediterranean Sea. Since yellow TM has four tarsal segments on their legs while other beetles have five, TM may be easily distinguished from other beetles. It has four life stages as egg, larvae, pupa and adult.In Eberle S *et al.*, in 2022 study decaying fruits, vegetables, bird nests, chicken coop litter, and other decomposing organic materials.It grows best in a gloomy environment [11]. Heidari-Parsa S *et al.*, in 2018 showcased adult TM are dark brown, and yellow mealworm larvae are honey yellow as shown in Figure 1 [12].

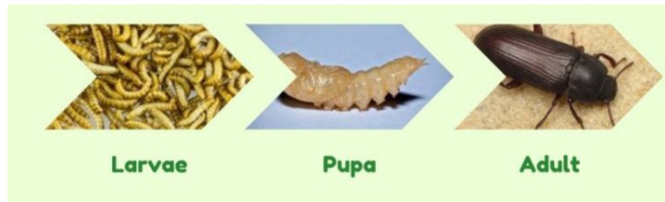

Figure 1: Physical Appearance of TM Life Stages

Melis R *et al.*, in 2018 explored their larvae are utilized as pet food for high nutritional qualities since they can readily develop on low nutrient trash [13]. Siemianowska E *et al.*, in 2013 discussed compared to huge animals, insects are better at converting plants into biomass. Insects have high nutritional value, take up less room, and eat less [14]. Growing Tenebrio larvae at home in a sterile container is simple. Its primary food sources at 28 degrees are carrots, lettuce, and other vegetables.It has the same protein content as soy and requires less land to produce (Cloudsley-Thompson, N.D.).The International Feed Industry Federation (IFIF) predicts that the world's population will surpass 10 billion by the year 2050.The food resources like meat from cows, poultry, pigs, etc. will never be sufficient for such large population. So, there would be other resources which will compensate the protein resources. Oonincx DG *et al.*, in 2012 demonstrated in recent years' entomophagy has been used as an alternate protein source because of its high nutritional values [15]. Veldkamp T *et al.*, in 2015 noted insects have all the essential amino acids, protein lipids and fatty acids which are useful for normal growth [16].Hong *et al.*,in 2020 indicated the larvae of TM are used in a powder form by freezing, chilling and drying. These procedures are done for maintain the nutrient composition [17]. Siemianowska E *et al.*, in 2013 presented many poor countries also use insects as a source of food due to their high nutritional content.The consumption level of insects as a food is less about 20% in Europe than other; such as in America it's 39% and in Africa is 30% [14].Grau T *et al.*, in 2017 identified the consumption of plant protein can be problematic for carnivorous species, so the protein from TM larvae is very effective for fishes.TM can also be supplemented to poultry and domestic birds feed [18].

TM as a Source of Protein for Fisheries

Due to increasing the population of the world it is estimated that consuming the animal protein is expending doubled

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than last some years.The consumption of protein is higher than its production because it is requirement in the feed of all the animals and human.In aquaculture fish is main source for human and other animals as a food and protein source. Dernekbaşi S highlighted the higher demand of fish oil and fish meal in aquaculture because these are basic food of aquaculture and having higher protein source and amino acids [19]. Aragão C *et al.*, in 2022 noted due to increasing demand of fish meal the number of fish decreasing worldwide.From some year's stakeholder is trying to find the proper source of amino acid and protein which can be used as a source of food for fish. In this way insects are promising to fulfill the requirements of proteins because they are almost free of cost, largely reproduce and give large amount of nutritional value [20].In recent years the production and expedition of farming the insects stand out as a basic protein source for mass production.Insects considered as large diversity of the world.In this way TM use as a protein source for all animals and humans.It is also estimated that dried yellow TM are safer and use as food for human.The European Union (EU) allowed yellow mealworm as food for human and these are the first insects that are used as a food in EU.Among these TM use as food source for both animals and human and are sustainable for environment.Now due to high demand of protein TM replaces the fish feed.These are also use as food for human. Nogales-Mérida S *et al.*, in 2019 presented according to this information insect are valuable as a protein source [21].The requirement of protein for omnivorous and carnivorous fish is higher than the herbivores and detritivores species.The requirement of protein for fish depends upon amino acid which is based on the requirement of corporal amino acid profile for each species.Many valuable proteins are abstracted from fish meat and fish oil.Due to this reason the requirement of fish is increasing which is reducing the population of fishes. Some plants and plant products are also used in place of fish meals but they are deficient in containing some amino acids as compared to other fish meal.The fresh leaves of Drumstick tree (Moringa oleifera) are used as diet for plant-eating fish such as tilapia, barbs, fancy carps, etc.The availability of amino acid for fish in insect's meal is alternative source of food. In aquaculture the TM use as a food because almost all the fishes eat them and obtain protein vitamins and fatty acids these are valuable for the growth of fishes.The amino acids which are essential for fish meal are arginine (Arg), histidine (His), isoleucine (Ile), leucine (Leu),methionine (Met), phenylalanine (Phe), threonine (Thr) and valine (Val).

Life Cycle of TM

Female TM produces eggs in dark shelter place and it has the ability to lay more than 300 eggs at a time and these eggs are hatched into larvae (mealworms) these larvae develop at different rates at different temperature. Temperature plays an important role in the growth of larvae.Its larvae can be grown at different temperatures from 20 degrees to 30 degrees but above this temperature its growth does not increase further.Its survival rate is maximum between 26 to 27 degrees. Larvae converted into pupa and then pupa is then transformed into an adult beetle as shown in Figure 2.

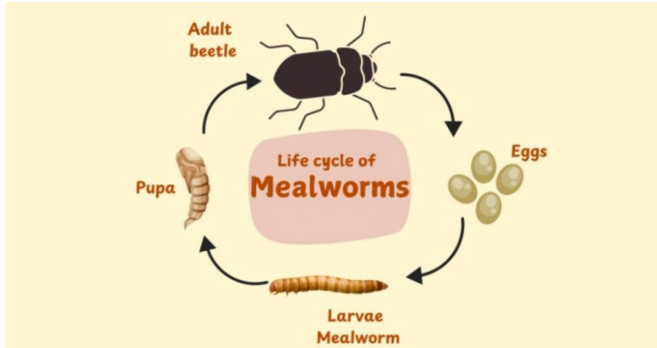

Figure 1: Life Cycle of TM

Nutritional Composition of TM

Ravzanaadii N *et al.*, in 2012 highlighted TM as a viable source of food in aquaculture and agriculture because a paradigmatic shift in the global food systems, yielding a great economic benefit and reducing environmental pressure associated with traditional feed sources. There is a great value of nutrition of TM especially as a protein supplier for domestic animals, fishes, plants and for human beings [22]. Bogusz R *et al.*, in 2024 noted TM act as a valuable resource for animal nutrition as it contains exceptional balance of bioactive compounds including micronutrients, macronutrients, vitamins and indispensable amino acids [23].

Table 1: Nutritional Composition of TM on Dry Matter basis [22]

TM Nutritional Composition	Dry Matter (%)
Proteins	55-60%
Fats	25-30%
Carbohydrates	10-15%
Vitamins	1.5-2.5%
Ash	3-5%
Fiber	5-10%
Essential Amino Acids	40-50%
Non-Essential Amino Acids	30-40%
Minerals	3-5%

The nutritional paradigm of yellow mealworms comprises a diverse array of nutrients, the concentrations of which can fluctuate in response to various factors such as ontogenetic stage, dietary regimen and somatic dimensions. Proteins (contain amino acids including valine, lysine, tryptophan, methionine, isoleucine, leucine, threonine, histidine, phenylalanine), Fatty acids (including oleic acid, stearic acid, palmitic acid, linoleic acid), minerals (calcium, phosphorus, iron, zinc, potassium,

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sodium, magnesium) and vitamins (including vitamin K, D3, A, E, B1, B12, B6, B1, B2) reveals its nutritional importance for food source.Ravzanaadii N *et al.*, in 2012 highlighted TM larvae constitute approximately 46%, adult 63%, exuvium 32% and excreta 18% protein content [22]. Noyens I *et al.*, in 2024 noted the excreta of TM even used in food recycling process as an additional supplement [24].The nutritional contents of the insects are found to be influenced by a number of factors such as diet, developmental stage and rearing environment.The temperature at which the insects were reared had a considerable impact on the larvae's fat content.Ghosh S *et al.*, in 2017 noted that the desired product from the insects by increasing or decreasing the factors that influence their nutritional content they contain [25].

Effect of TM Meal On Fish Growth

TM can be served as sustainable and effective alternative protein source for fisheries and aquaculture. Research has showed that replacing traditional fishmeal (FM) with TM meal is offering potential benefits for fish growth, health, and feed efficiency.A study conducted by Chen H *et al.*, in 2023 showed the effect of TM meal on juvenile largemouth bass growth performance, digestibility and hepatic health [26].The fish were fed with varying amounts of TM meal. The meal containing 24%TM had significantly higher weight gain rate, final body weight and specific growth rate. Appropriate replacement levels of fishmeal (FM) by TM meal can enhance the immune functions and antioxidant capacity in largemouth bass.However,high levels of FM substitution with TM meal can inhibit growth and can cause liver damage.The study suggests that TM is a feasible feed protein source for largemouth bass.Graph 1 represents the amino acid and nutritional composition of FM and TM as reported by Chen H *et al.*, in 2023, in which amino acids and nutritional composition are denoted on ordinate and their respective values in percentage are denoted on abscissa [26].Figure 1 illustrated the amino acid and nutritional composition of FM, highlighting its essential and non-essential amino acid profile along with key macronutrient and micronutrient contents. The figure provides a detailed breakdown of protein, carbohydrates, fats, vitamins, and minerals, emphasizing the nutritional value of FM. Essential amino acids such as lysine, leucine, and methionine are quantified, demonstrating their contribution to dietary requirements.Additionally, the figure compares these values with standard nutritional benchmarks, offering insights into the suitability of FM as a dietary protein source.This composition analysis plays a crucial role in evaluating the potential applications of FM in nutrition and health sciences.The amino acid and nutritional composition of fishmeal (FM), highlighting its protein content, essential amino acids, lipid profile, and micronutrient levels.This figure provides a comparative overview of FM's nutritional value, serving as a reference for evaluating alternative protein sources such as mealworms in aquaculture feed formulations (Figure 3).

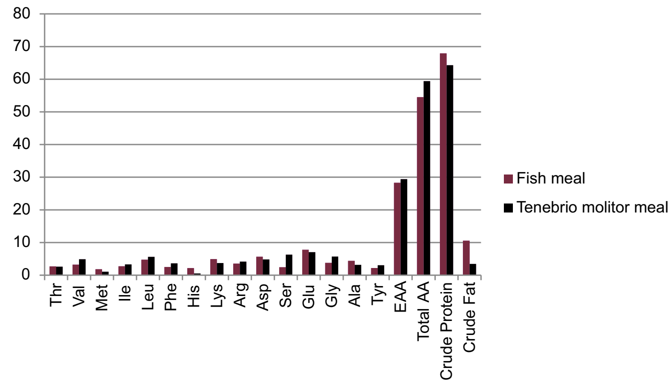

Figure 3: The Amino acid and Nutritional Composition of FM [26]

Substituting fishmeal with TM (mealworm) in fish diets can positively or negatively impact fish growth depending on the diet formulation and fish species Gu J *et al.*, in 2021 and Ido A *et al.*, in 2019 [27, 28].TM is rich in protein (50-60%), essential amino acids, and energy-dense lipids, making them a good alternative to fishmeal.However, they may lack certain amino acids like tryptophan and long-chain omega-3 fatty acids Zhang Z *et al.*, in 2022, which are crucial for fish health and growth Gu J *et al.*, in 2021 and Ido *et al.*, in 2019 [27-29].

Processing of TM Larvae

According to the International Platform of Insects for Food and Feed (IPIFF) has reported that insects, particularly TM larvae, are commonly processed for animal feed through slaughtering (heating or freezing) and post-slaughtering (drying and grinding) methods Hong J *et al.*, in 2020 [17]. For food safety and nutrient content preservation, these procedures are essential. Slaughtering process involves Blanching Vandeweyer D *et al.*, in 2017, Freezing, Chilling and Drying [30]. Blanching involves heating the larvae to kill vegetative cells Vandeweyer D *et al.*, in 2017 and prevent microbial growth during storage [30]. Freezing and chilling methods help in long-term storage and transportation. Drying is essential to reduce moisture content (around 68%) Kröncke N *et al.*, in 2019 to prevent enzymatic degradation, non-enzymatic degradation, and microbiological spoilage [31]. Common drying methods include oven drying Kröncke N *et al.*, in 2019, freeze-drying Bußler S *et al.*, in 2016, and microwave drying [31, 32]. Post-slaughtering process involves Grinding, Defatting and Hydrolysis.The dried larvae are ground into a fine powder for incorporation into animal feed. Defatting is the removal of excess fat to improve storage stability and prevent lipid oxidation.Methods include high-pressure pressing Thévenot A *et al.*, in 2018), organic solvent extraction, and supercritical CO2 extraction [33-35].Hydrolysis is the breaking down proteins into smaller peptides or amino

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acids to potentially improve digestibility and reduce anti-nutritional factors.

Schematic diagram illustrating the processing of Tenebrio molitor (TM) larvae for fish feed, detailing key steps such as harvesting, drying, grinding, and formulation. This diagram highlights the transformation of TM larvae into a nutrient-rich meal suitable for aquaculture, emphasizing its potential as a sustainable alternative to conventional fish feed ingredients (Figure 4).

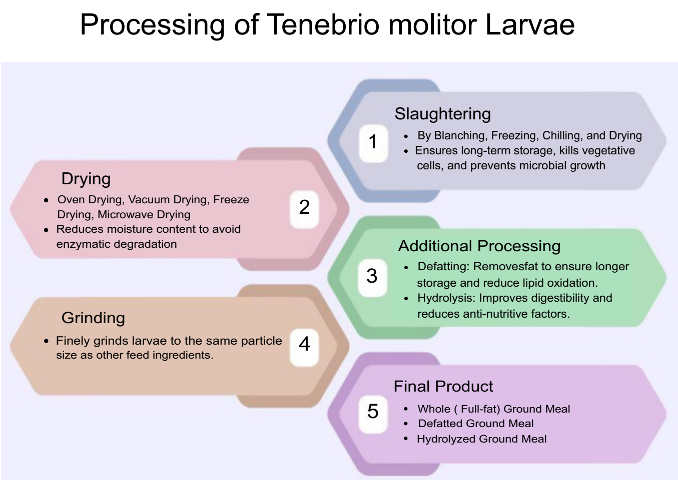

Figure 4: Schematic Diagram Showing Processing of TM Larvae for Fish Feed

CONCLUSIONS

In conclusion, mealworms present a sustainable and nutritionally rich alternative to traditional protein sources in aquaculture and fisheries. Their high protein content, essential nutrients, and minimal environmental impact make them an ideal substitute for fishmeal, addressing protein shortages and reducing reliance on conventional feed sources. Research has demonstrated their positive effects on fish growth, immunity, and feed efficiency, though careful formulation is necessary to prevent adverse outcomes. With growing global interest and regulatory approvals, incorporating mealworms into aquaculture can enhance sustainability, economic viability, and food security, paving the way for a more resilient and eco-friendly industry.

Authors Contribution

Conceptualization: MSK, MP, AS, AB, NS, HKY, MK
Methodology: MSK, MP, AS, AB, NS, HKY, MK
Formal analysis: MSK, MP, AS, AB, NS, HKY, MK
Writing, review and editing: MSK, MP, AS, AB, NS, HKY, MK

All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

All the authors declare no conflict of interest.

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