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A Review On Literary Dimensions Of Mealworm, *Tenebrio Molitor* L. (Coleoptera: Tenebrionidae)

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Abstract
Due to the forecasted overpopulation of the globe and increasing waste production, several insect species are mass produced for animal feeds, fish bait, or human consumption. The yellow mealworm, *Tenebrio molitor* L. (Coleoptera: Tenebrionidae), is one of the more-popular insects considered for this use. Our review identified that mealworms which thrive at temperatures between 25-28°C with peak larval growth at 70% relative humidity, exhibit a nutritional profile rich in essential amino acids, vitamins, and minerals while serving as a low-fat source. Their frass containing nitrogen, phosphorus, and potassium proves valuable for plant growth, and also induce tolerance to abiotic stress. Notably, mealworms showcase the remarkable ability to biodegrade petroleum-based plastics like polystyrene and polyethylene. Moreover, they can excrete or catabolize mycotoxins, displaying antifungal properties. They show medicinal potential including cardiovascular disease prevention due to the presence of angiotensin-converting enzyme (ACE), and antioxidative properties. Additionally, biodiesel production from dried mealworm larval biomass underscores their significance in sustainable fuel initiatives.

Keywords: *Tenebrio molitor* L., waste production, human consumption, frass, polystyrene degradation

INTRODUCTION

According to FAO (Food and Agriculture Organization), the world's undernourishment rate rose from 586,8 million in 2018 to 612,8 million in 2019, from 701,4 million in 2020 to 738,9 in 2021, and from 735,1 in 2022 to 735,0 in 2023 (FAO et al., 2023a). Despite the above, one-third of all food produced in the world is lost or wasted at various stages of the food chain (Bordiean et al., 2020), reducing the sustainability of our food systems. It is projected that the global population will reach around 9.7 billion by 2050, so the demand for animal-based food protein is expected to increase (Jajić et al., 2022). Also, by 2050, a 70% increase of the currently produced annual waste (2.3 billion tonnes in 2023) is expected 3.8 billion tonnes in 2050 (UNEP, 2024). For this reason, the possibility of utilizing nutrients (proteins, fats, vitamins) from sustainable sources such as insects is widely discussed (Bordiean et al., 2022). In view of climate change and limited food resources, edible insects provide a nutritious alternative for feed and food production (Bordiean et al., 2020), as insects can convert agricultural and food waste residues into protein of high biological quality (Bordiean et al., 2022), emit low levels of greenhouse gases (van Huis et al., 2013), reduces energy costs, and utilize less space (Toviho et al., 2023). As van Huis et al. (2013) encouraged mass production of insects for food and feed, insects for food and feed, there has been a growing movement globally and several startups have been established for mass production of insects as alternative protein sources (Ribeiro et al., 2018). Currently, there are many insect species that are being proposed for animal feeds, fish bait, or human consumption but among them the larvae of yellow mealworm (*Tenebrio molitor*) are one of the most popular insects (Montalbán et al., 2022; Ribeiro, 2018; Mancini et al., 2020).

The yellow mealworm (*T. molitor*), also known as mealworm, belongs to the order Coleopteran of the family Tenebrionidae ("darkling beetle"). *T. molitor* is a holometabolic insect (complete metamorphosis, four life stages as egg, larva, pupa, and adult (Fig. 1)) that probably originated in the Mediterranean, and nowadays, it is distributed worldwide due to colonization and trade (Moruzzo et al., 2021). This species is one of the largest stored-product beetles (adult body length between 12 and 20 mm), which are commonly found infesting stored agricultural products (considered a pest) (Silva et al., 2021), however, they are now being promoted as a beneficial insect. Mealworms are considered a profitable animal food source and are available in pet markets and stores. They are a more sustainable source of edible protein for humans than milk, chicken, pork, or beef, and are mass reared as feed for birds, reptiles, amphibians, and fish (Yang et al., 2018a; Moruzzo et al., 2021; Ghaly and Alkoai, 2009; Yang et al., 2019). Yellow mealworm can successfully replace fish or soy meal for livestock or fisheries. Mealworms can also be used to supplement the diets of poultry and other domestic birds (Grau et al., 2017). They are rich in vitamin D and have low gluten levels, making them a valuable dietary option for those seeking nutritional diversity and gluten-free alternatives.

Mealworms have emerged as a subject of extensive research due to their diverse applications. Recent research has found that mealworms are capable of biodegrading persistent petroleum based plastics including polystyrene and polyethylene in their guts (Yang et al., 2018b), suggesting that mealworms have powerful digestive systems and showcases their role in waste management. Studies have confirmed their nutritional value and resilience to harmful compounds like mycotoxins and pesticides, its potential as a substitute of oilseeds, making them promising for biodiesel production and environmental cleanup. Furthermore, mealworm frass has been investigated as a potent fertilizer.

FOSSIL RECORDS

The apparent absence of the mealworm beetles, *Tenebrio* spp. from Pharaonic deposits is possibly an indication of a non-African point of origin, despite the fact that *Tenebrio* sp. first emerges in Egypt at the Roman Mons Claudianus (Panagiotakopulu & van der Veen, 1997). There are fossil records of *T. molitor* L. and *T. obscurus* F. from modern-day Egypt and the former appears at Troy, Turkey all through the Bronze Age. The fossil records from the British Isles are of the later, suggesting a current dispersal from the Mediterranean region (Panagiotakopulu, 2001) and in recent times, it is distributed worldwide due to colonization and trade (Moruzzo et al., 2021). Mealworms are also known as European mealworm because of the many reports of its occurrence in Europe (Cotton, 1940).

BASIC BIOLOGY

The life cycle of yellow mealworms (egg to adult to egg (Fig. 1)) is 280 - 630 days, depending on ambient temperature, photoperiod, relative humidity and other factors (Makkar et al., 2014; Bordiean et al., 2020). Optimal rearing conditions for *T. molitor* larvae to ensure successful mass production have been reported in numerous studies. Mealworms thrive at a temperature of 25–28°C and relative humidity (RH) of ≥70% (the optimal RH range is 60–75%) (Bordiean et al., 2020), with an absolute minimum of 10°C and a maximum of 35°C. Temperatures <17°C inhibit embryonic development and temperatures >30°C increase death rates. The minimum and maximum lethal temperatures for exposure periods of 24 h are 7°C–8°C and 40–44°C (Ribeiro, 2018).

The females begin oviposition about a week after eclosion and continue it for one month (Kawasaki et al., 1975) produce an average of 250-500 eggs each which they oviposit singly or in small clusters attached to the substrate or the walls and floor of the containers in which they are present. When eggs are first laid they are covered with a sticky secretion that causes them to become quickly coated with particles of the food stuff in which they are deposited. Eggs are white, obling-oval and range in length from 1.7-1.8 mm and in width from 0.6-0.7 mm (Ghaly and Alkoaik, 2009). However, oviposition does not occur at temperatures below 14°C with an RH of 65%; even at the optimal temperature of 27°C in low humidity (20%), oviposition is significantly reduced due to the loss of body moisture by evaporation and subsequent death. The incubation period is influenced chiefly by the weather and lasts from 4 days to a week at normal spring or summer temperatures (26-30°C). With lower temperatures the incubation period may be lengthened to as much as 19 days (Cotton, 1940) but may take up to 34 d to hatch at 15°C. At 10°C and 12.5°C water absorption in eggs is reduced and embryological development halts. Whatever the temperature, extremely dry conditions of about 12% RH potentiate water losses from the eggs, culminating in death due to desiccation (Ribeiro, 2018).

Newly hatched larva is white in color and about 2 mm long which turns bright yellowish brown upon feeding. The larva is elongated cylindrical with 6 small legs right behind the head and 2 short horn-like appendages on the tips of the abdomen (Ghaly and Alkoaik, 2009). Duration of the larval stage varies from 57 days in controlled conditions (Weaver and McFarlane, 1990) to 629 days in ambient natural conditions (Cotton, 1927), with an average duration of 112-203.3 days (Damborsky et al., 2000). Larvae undergo several molts, varying from a minimum of 9 (Cotton, 1927) and to a maximum of 23 (Ribeiro, 2018).

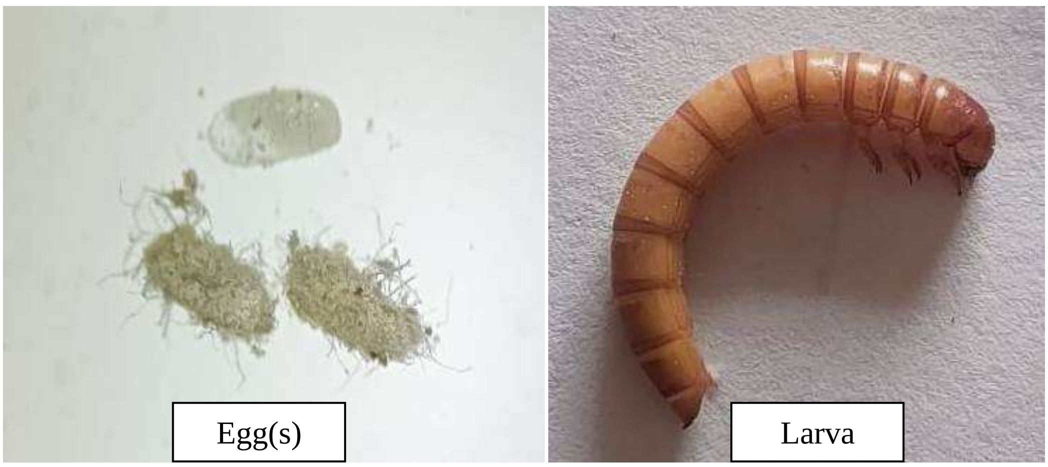
The growth rate of *T. molitor* larvae is highly dependent on moisture, with higher growth rates at 90–100% RH and even at 70% RH, but the rate slows at 30% RH and hardly occurs at 13% (Fraenkel, 1950). During times of extremely dry conditions, mealworm larvae may cease feeding and become inactive until RH rises to more-favorable levels (Ribeiro, 2018). The fully grown larvae change into c-shaped structure called as pupa, which is about 1 cm in length. Pupae are white, except for the tip of the caudal spine and the lateral appendages. As the pupae become older they change to yellowish brown (Cotton, 1927). They are soft, immobile and relatively unprotected due to the absence of a pupal case. The pupal stage lasts 6 to 20 days. Adults first emerge as whitish colored beetles with soft exoskeletons, which gradually harden and darken. In the adult stage (which lasts 16 to 173 days), mating and oviposition begin in about 3 days after emergence (Ribeiro, 2018) and is repeated at intervals throughout the life of the adults. (Damborsky et al., 2000).

Nutrient intake plays a central role in *T. molitor* life cycle, influencing development time, fertility, number of instars, survival rate, and the intensity and period of oviposition (Morales-Ramos et al., 2010; Morales-Ramos et al., 2013). Dietary protein and amino acids greatly influence *T. molitor* life cycle, with direct benefits for larval development time, survival, and weight gain. Supplementation of diets with protein, even in small percentages, has shown to increase the developmental rate of larvae, reduce the time for pupation and increases survival rates (Oonincx et al., 2015). *T. molitor* can survive under extremely dry conditions for extended periods of time, being able to obtain water from both the food ingested (even substances with low water content) and the atmosphere (Ribeiro, 2018).

The mating system of *T. molitor* includes both polygyny and polyandry. Males and females are drawn to each other by pheromones released by the other sex, and copulations happen fast—typically lasting for less than three minutes. Females that mate multiple times produce more eggs than females that mate only once. Also, females that mate with different males produce more eggs than females that mate with the same male an equal number of times. Mating behavior was also found to be influenced by the mass of the male beetle. Larger males are favored and tend to mate first, as opposed to smaller males (Worden & Parker, 2005).

Different pathogens and parasites, such as protozoa, tapeworms, and entomopathogenic microbes, can reside in *T. molitor* which can reduce the beetle's ability to survive and reproduce. *T. molitor* displays behavioral immunity when they consume the eggs of the tapeworm parasite *Hymenolepis diminuta*. This is demonstrated by the fact that the infected males develop an avoidance behavior for feces that contain the tapeworm, which lowers their likelihood of ever coming into contact with the tapeworm again (Vigneron et al., 2019). The female mealworm beetles develop a qualitative resistance through mate choice as they can assess a male's immunocompetence through pheromone signaling and select the more immunologically fit males as mates. This lessens the likelihood that the females will contract the infection from their partners which could result to pass on an enhanced level of immunocompetence to their offspring (Vigneron et al., 2019).

Another way mealworms can exhibit behavioral immunity is by limiting the detrimental effects of infections on their ability to reproduce. For instance, mealworm beetles sacrifice their own longevity and fitness to tolerate a high number of *H. diminuta* cysticercoids. However, the males produce better spermatophores with superior nuptial gifts, which are passed on to their mating females. This increases the fecundity of the females and increases the number of eggs that are fertilized (Vigneron et al., 2019).



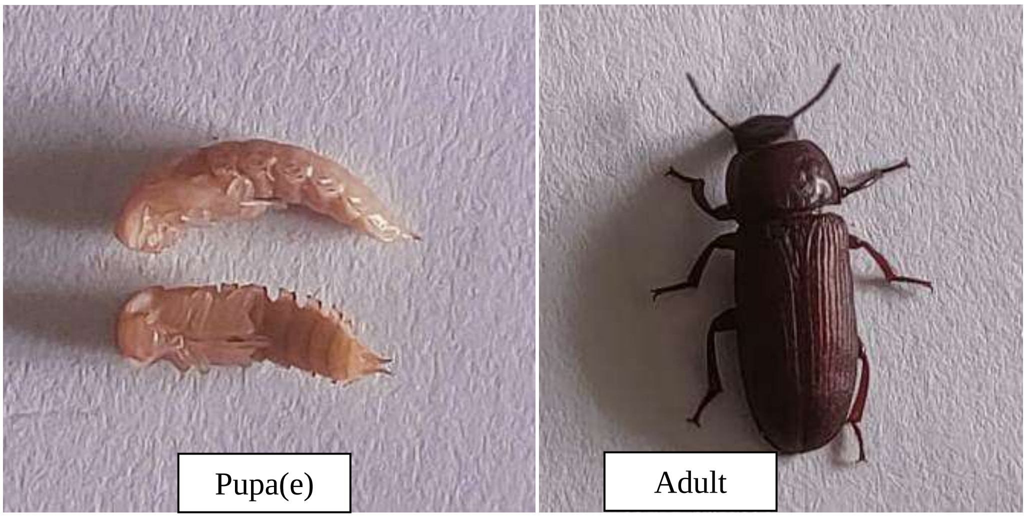


Fig. 1. Developmental stages of *T. molitor*

IMPORTANCE OF *T. MOLITOR*

1. Nutrients (Table 1):The nutritional composition of *T. molitor* varies according to their developmental stage (Shafique et al., 2021). Mealworms are rich in crude protein (about 47-60% of dry matter (DM) and about 31-43% of lipids (Shafique et al., 2021) with highest in adult and lowest in larvae. Due to the high protein content, further hydrolysis or enzymatic processing can produce large amounts of biological peptides that can also contribute to antioxidant properties (Zaini et al., 2023). The percentage of other nutrients is, fat 17-42.48% (Ribeiro et al., 2018) the ratio of omega-6/omega-3 (n-6/n-3) in the mealworm lipids (18:1) (Oonincx et al., 2020), carbohydrate 0.01 - 7.10% (the mealworm has the lowest percentage of carbohydrates among insects), crude fiber 5.00-20.22% (the most high in adults and the lowest in larvae), ash 2.36-4.3% (Zaini et al., 2023). *T. molitor* is a great source of essential amino acids (Shafique et al., 2021) and fatty acids - palmitic acid (9.33-23.7%), oleic acid (36.5-52.94%) and linoleic acid (3.8-33.58%) (Ada'mkova' et al., 2018). Precious minerals in mealworms are, 0.32-0.75 mg/g Ca, 1 .45-3.4 mg/g Mg, 5.37-13.45 mg/g P, 6.7-13.8 mg/g K, 0.025-1.76 mg/g S, o -0.13 mg/g Fe, 0.012-0.04 mg/g Cu and 0.082-0.145 mg/g Zn in dry mass (Ribeiro et al., 2018). There were four sources of calcium in the worm: 434.59, 484.39, 801, 14 and 1537.97 mg/kg for larvae, adults, in vitro and feces. However, the amount of calcium in waste and secretions indicates that waste recycling is beneficial in mealworms (Ravzanaadii et al., 2012).

Table 1: Percentage of various nutrients in mealworms (*T. molitor*)

Macronutrients	%age	TM Stage	References
Crude Protein	47-60%	Dry matter (DM)	Shafique et al., 2021
Fat	17-42.48%	Dry mass	Ribeiro et al., 2018
Crude Lipids	31-43%	Dry matter (DM)	Shafique et al., 2021
Crude Fiber	5.00 - 20.22%	Highest in adults, lowest in larvae	Zaini et al., 2023
Ash	2.36 - 4.3 %	Constant	Zaini et al., 2023
Moisture	2.43-7.25%	Larvae	Shafique et al., 2021
Calcium (Ca)	0.047-4.3%	Least in dried larvae and highest in fresh larvae	Shafique et al., 2021
Phosphorus (P)	0.69-7.8%	Least in dried larvae and highest in fresh larvae	Shafique et al., 2021

2. Food: *T. molitor* larvae have been used for a variety of food and feed purposes, from fish bait to animal feed for birds, lizards, snakes, amphibians, insects to human consumption (Ravzanaadii et al., 2012). For human consumption, mealworm larvae can be used fresh whole (Martin et al., 1976; Ghaly and Alkoaik, 2009) or as flour in feed, which can be used as supplement in pig and poultry and in aquaculture (Ribeiro et al., 2018). Dried Larvae can be used in place of nuts, raisins and chocolate chips in many cookie, bread or dessert recipes. Powdered larvae can also replace part of the flour in cakes or pie crust. Lightly thawed whole larvae can be added to sauces (Ghaly and Alkoaik, 2009). *T. molitor* can be regarded as a unique candidate that is suitable alternatives for fish meal in fish diets to achieve sustainability in aquaculture, because of its relatively high nutritional value (Shafique et al., 2021). It is one of the unique candidates as a potential protein source for possible FM (Fish Meal) replacement in aqua feeds (Shafique et al., 2021).

In BLSS (Bioregenrative Life Support System), mealworm food for astronauts could be prepared through lyophilization in order to maintain its nutritional value. Fermented straw, wheat bran, and vegetable leaves can be used to feed *T. molitor*, improving system closure and providing quality animal proteins for astronauts. Frass, the waste of *T. molitor*, can be used as a fertilizer on Earth and potentially applied to plant cultivation in space (Li et al., 2013).

Mealworms have a balanced protein and lipid composition, providing essential amino acids, vitamins, and minerals (Mancini et al., 2020; Jajić et al., 2022). Mealworm larvae, especially those raised on wheat, have a high protein (71% dry weight) and a low fat content (7% dry weight) particularly those reared on wheat bran (Jajić et al., 2022). Studies have found that gluten present in mealworms is less than 20 ppm which indicates mealworm food is gluten free (Mancini et al., 2020).

3. Fertilizer: The yellow mealworm (*T. molitor*) has been studied for its potential as a fertilizer and activation of plant defenses and studies have suggested mealworm frass could be a valuable fertilizer resource and plant defense inducer for sustainable agriculture (Blakstad et al., 2023). Insect frass usually contain chitin that can stimulate the plant immune system but when present in shorter oligomers (6-8 mer) (Li et al., 2020). The chitin found in the insect exoskeleton must likely be degraded (e.g. by soil microorganisms) before it can have an immune stimulating effect. Addition of mealworm exuviae to soil has shown to stimulate growth of chitinolytic bacteria, leading to degradation of chitin, and plant growth promoting *Rhizobacteria* (PGPR) (Bai, 2015). As a fertilizer, it has been shown that frass provides nutrients such as N, P and K and promotes the growth of plants). Plant-beneficial microorganisms present in mealworm frass are also involved to induce tolerance to abiotic stress like increased tolerance to salinity, drought and flooding in bean plants (Poveda et al., 2019).

4. Toxicity: After ingestion mealworms are able to excrete or catabolise mycotoxins, such as Aflatoxin B1 (AFB1) produced by *Aspergillus* fungi, Deoxynivalenol (DON) and Zearalelone (ZEN) produced by *Fusarium* (Bordiean et al., 2020). AFB1 can be 20 times lower than the legal limit in mealworms. DON levels in larvae are also below the detection limit highly concentrated diets. However, Zearolelone (ZEN) requires at least 24 hours of starvation before harvesting which reduces the remaining traces of ZEN and its metabolites (Bordiean et al., 2020). An antifungal peptide that shields *T. molitor* beetles from entomopathogenic fungus *Beauveria bassiana* infections as well as the host's infection development was examined by Maistrou et al. (2018). They concluded that Tenecin 3 exerted direct antifungal effects on *B. bassiana* and protected beetles against the infection.

5. Medicine: Studies have shown that mealworms contain less than 20 ppm of gluten. This indicates that mealworms are gluten-free and can be recommended for people with celiac disease. However, care must be taken as the risk of final contamination is non-zero and it is recommended to test mealworms for the presence of gluten (Mancini et al., 2020). Mealworms contain angiotensin-converting enzyme (ACE) inhibitors, so eating these insects can prevent heart disease (Mariod, 2020). The high protein content of mealworms may lead to the production of bioactive peptides through hydrolysis or enzymatic processing, which can enhance their antioxidant properties (Zaini et al., 2023). Mealworm larvae are also an excellent source of vitamin D. Oonincx et al. (2018) found that worms synthesize vitamin D through exposure to ultraviolet (UVb) light. Long-term exposure to UVB increases the synthesis of vitamin D2 and D3 up to a threshold of 6400 IU kg^{-1}. This study also found that vitamin D synthesis increases in response to higher levels of UVb radiation. Mealworm fiber is a complex carbohydrate. Dietary fiber lowers the risk of constipation, lowers cholesterol and regulates blood sugar levels. Minerals are important for bone growth and development, while vitamins improve the body's ability to fight infections. It also plays an important role in the production of antibodies. Antibodies strengthen immunity by fighting foreign substances that cause disease.

6. Biodiesel Production: The potential of mealworms as an oilseed substitute has been studied. Decayed vegetables were fed to mealworms, and after nine weeks, the grease was extracted to make biodiesel. From 234.8 g of dried beetle larval biomass, about 34.2 g of biodiesel was produced. Linolenic acid (19.7%), palmitic acid (17.6%), linoleic acid (16.3%), and stearic acid (11.4%) were the main fatty acids in YMB (Yellow Mealworm Beetle) biodiesel. The majority of the properties of the YMB biodiesel fed on decomposing vegetables, such as its ester content (96.8%), density (860 kg/m3), flash point (127 C), cetane number (58), water content (300 mg/kg), and methanol content (0.2%), were in compliance with standard EN 14214. A comprehensive analysis of social, economic and environmental impacts allows us to conclude that YMB can convert organic waste into electricity at a low cost (Zheng et al., 2013).

7. Degradation: Most petroleum-derived plastics are resistant to biological degradation (Otake et al., 1995). One of the most widely used plastics is polystyrene (PS), which accounts for 7.1% of annual plastic production and is used in a variety of applications, including eyeglass frames, plastic cups, egg trays, packaging, and building insulation. However, PS has become a major pollutant and source of microplastics. PS is currently known to be susceptible to rapid biodegradation in the gut of the yellow mealworm, the larval form of the mealworm, *Tenebrio* Linnaeus (Yanget al., 2018b). Since the 1950s, researchers have observed that beetles and larvae of the family Tenebrionidae can damage plastic packaging. In 2003, Chong-Guan Chen fed mealworms fed PS foam and suggested that PS is biodegradable (Sina, 2003). Using PS as the only carbon source, Ms. I-Ching Tseng (2009) isolated bacteria from the stomach of mealworms. In the mealworm gut, about half of the consumed PS carbon was transformed into CO_2. Isotopic analyses utilizing PS materials labeled with 13C have demonstrated that PS was mineralized to CO_2 and incorporated into lipids. The mealworm strain from Beijing nearly lost its ability to depolymerize PS and mineralize PS into CO_2 after being fed the antibiotic gentamycin, indicating that gut bacteria are involved in PS biodegradation. Additionally, studies have indicated that mealworms' intrinsic chewing and eating habits as well as their gut microbe-dependent oxidative digestive system contribute to the biodegradation of PS. Digestion of PS contributes to the energy requirements of mealworms, which can be improved by co-feeding nutrient sources like bran. The contributing gut microbial communities are diverse and subject to dietary changes (Yanget al., 2018b).

CONCLUSION AND FUTURE PERSPECTIVES

The nutritional requirements of *T. molitor* have been studied in some detail but large-scale production of such insect species could be improved by focusing on the exploitation of low-cost by-products as dietary components (Jajić et al., 2022). They are the versatile insects with great potential for sustainable food sources and environmental solutions. Rich in nutrition and protein, they have the potential to alleviate global food insecurity and lessen dependency on conventional animals. Their adaptability to many climes and minimal resource requirements make them a sensible option for future food production. Mealworms contain angiotensin-converting enzyme (ACE) inhibitors, which can prevent heart disease. Moreover, their capacity to consume organic waste offers chances for sustainable environmental practices and waste management. Their ability to biodegrade plastics, produce valuable enzymes, opens doors for innovative solutions in biotechnology and environment. Continued research into mealworm genetics, nutrition, and farming techniques will likely improve their efficiency and scalability. And incorporating mealworms into our food and ecosystem can lead us towards a future that will be more resilient and sustainable.

REFERENCES

1. Bai, Y. (2015). Ecological Functioning of Bacterial Chitinases in Soil. Universiteit Leiden (Dissertation).
2. Bordiean, A., Krzyżaniak, M. and Stolarski, M.J. (2022). Bioconversion Potential of Agro-Industrial Byproducts by *Tenebrio molitor*—Long-Term Results. *Insects,* 13(9): 810.
3. Bordiean, A., Krzyżaniak, M., Stolarski, M.J., Czachorowski, S. and Peni, D. (2020). Will Yellow Mealworm Become a Source of Safe Proteins for Europe? *Agriculture,* 10(6): 233.
4. Cotton, R.T. (1927). Notes on the Biology of the Meal Worms, *Tenebrio molitor* Linne and *T. obscurus* Fab*. Annals of the Entomological Society of America,* 20(1): 81-86.
5. Cotton, R.T. (1940). Mealworms (No. 195). US Government Printing Office (Book).
6. Damborsky, M., Bar, P.S.T. and Oscherov, M.E. (2000). Ciclo De Vida De *Tenebrio molitor* (Coleoptera, Tenebrionidae) En Condiciones Experimentales. *Comun. Cient. y Tecnol.* UNNE 6: 35-38.
7. Food Agriculture Organization of the United States (FAO) (2023). Hunger and Food Insecurity. Accessed on February 2024. https://www.fao.org/hunger/en/
8. Fraenkel, G. (1950). The Nutrition of the Mealworm, *Tenebrio molitor* L. (Tenebrionidae, Coleoptera). *Physiological Zoology*, 23: 92-108.
9. Ghaly, A.E. and Alkoaik, F.N. (2009). The yellow mealworm as a Novel Source of Protein. *American Journal of Agricultural and Biological Sciences,* 4: 319-331.
10. Grau, T., Vilcinskas, A. and Joop, G. (2017). Sustainable Farming of the Mealworm *Tenebrio molitor*for the Production of Food and Feed. *Zeitschrift für Naturforschung C,* 72(9-10): 337-349.
11. Jajić, I., Krstović, S., Petrović, M., Urošević, M., Glamočić, D., Samardžić, M., Popović, A. and Guljaš, D. (2022). Changes in the Chemical Composition of the Yellow mealworm (*Tenebrio molitor* L.) Reared on Different Feedstuffs. *Journal of Animal and Feed Sciences*, 31(2): 191-200.

12. Kawasaki, H., Sato, H. and Suzuki, M. (1975). Structural Proteins in the Egg Envelopes of the Mealworm Beetle, *Tenebrio molitor*. *Insect Biochemistry,* 5(1): 25-34.
13. Li, K., Xing, R., Liu, S. and Li, P. (2020). Chitin and Chitosan Fragments Responsible for Plant Elicitor and Growth Stimulator. *Journal of Agricultural and Food Chemistry,* 68(44): 12203-12211.
14. Li, L., Zhao, Z. and Liu, H. (2013). Feasibility of Feeding Yellow mealworm (*Tenebrio molitor*L.) in Bioregenerative Life Support Systems as a Source of Animal Protein for Humans. *Acta Astronautica*, 92(1): 103-109.
15. Maistrou, S., Paris, V., Jensen, A.B., Rolff, J., Meyling, N.V. and Zanchi, C. (2018). A Constitutively Expressed Antifungal Peptide Protects *Tenebrio molitor* During a Natural Infection by the Entomopathogenic Fungus, *Beauveria bassiana*. *Developmental & Comparative Immunology,* 86: 26-33.
16. Makkar, H.P., Tran, G., Heuzé, V. and Ankers, P. (2014). State-of-the-art on use of insects as animal feed. *Animal Feed Science and Technology*, 197: 1-33.
17. Mancini, S., Fratini, F., Tuccinardi, T., Degl'Innocenti, C. and Paci, G. (2020). *Tenebrio molitor* Reared on Different Substrates: Is it Gluten Free? *Food Control,* 110: 107014.
18. Mariod, A.A. (Ed.) (2020). African Edible Insects as Alternative Source of Food, Oil, Protein and Bioactive Components. *Springer Nature,* 314p.
19. Mohd, Zaini, N.S., Lim, E.J., Ahmad, N.H., Gengatharan, A., Wan-Mohtar, W.A.A.Q.I. and Abd Rahim, M.H. (2023). The Review of Cooking, Drying, and Green Extraction Methods on General Nutritional Properties of Mealworms and Locusts. *Food and Bioprocess Technology,* 16(9): 1-15.
20. Montalbán, A., Sánchez, C.J., Hernández, F., Schiavone, A., Madrid, J. and Martínez-Miró, S. (2022). Effects of Agro-industrial Byproduct-based Diets on the Growth Performance, Digestibility, Nutritional and Microbiota Composition of Mealworm (*Tenebrio molitor* L.)*. Insects,* 13(4): 323.
21. Morales-Ramos, J.A., Rojas, M.G., Shapiro-Ilan, D.I. and Tedders, W.L. (2010). Developmental Plasticity in *Tenebrio molitor* (Coleoptera: Tenebrionidae): Analysis of Instar Variation in Number and Development Time under Different Diets. *Journal of Entomological Science,* 45: 75- 90.
22. Morales-Ramos, J.A., Rojas, M.G., Shapiro-Llan, D.I. and Tedders, W.L. (2013). Use of nutrient self-selection as a diet refining tool in *Tenebrio molitor* (Coleoptera: Tenebrionidae). *Journal of Entomological Science,* 48(3): 206-221.
23. Moruzzo, R., Riccioli, F., Espinosa Diaz, S., Secci, C., Poli, G. and Mancini, S. (2021). Mealworm (*Tenebrio molitor*): Potential and Challenges to Promote Circular Economy. *Animals,* 11(9): 2568.
24. Oonincx, D.G., Laurent, S., Veenenbos, M.E. and van Loon, J.J. (2020). Dietary Enrichment of Edible Insects with Omega 3 Fatty Acids. *Insect Science,* 27(3): 500-509.
25. Oonincx, D.G.A.B., van Broekhoven, S., van Huis, A. and van Loon, J.J.A. (2015). Feed Conversion, Survival and Development, and Composition of Four Insect Species on Diets Composed of Food Byproducts. *PLOS One,* 10(12): 1-20,
26. Oonincx, D.G.A.B., Van Keulen, P., Finke, M.D., Baines, F.M., Vermeulen, M. and Bosch, G. (2018). Evidence of Vitamin D Synthesis in Insects Exposed to UVb Light. *Scientific Reports,* 8(1): 10807.
27. Otake Yoshito, Tomoko Kobayashi, Hitoshi Asabe, Nobunao Murakami and Katsumichi Ono (1995). Biodegradation of Low Density Polyethylene, Polystyrene, Polyvinyl Chloride, and Urea

Formaldehyde Resin Buried under Soil for Over 32 Years. *Journal of Applied Polymer Science,* 56(13):1789-1796.

28. Panagiotakopulu, E. (2001). New Records for Ancient Pests: Archaeoentomology in Egypt. *Journal of Archaeological Science,* 28(11): 1235-1246.
29. Panagiotakopulu, E. and van der Veen, M. (1997). Synanthropic Insect Faunas from Mons Claudianus, A Roman Quarry Site in The Eastern Desert, Egypt. In (A. C. Ashworth, P. C. Buckland & J. P. Sadler, Eds) Studies in Quaternary Entomology—An Inordinate Fondness for Insects. *Quaternary Proceedings,* 5: 199-206.
30. Poveda, J., Jiménez-Gómez, A., Saati-Santamaría, Z., Usategui-Martín, R., Rivas, R. and García-Fraile, P. (2019). Mealworm Frass as a Potential Biofertilizer and Abiotic Stress Tolerance-Inductor in Plants. *Applied Soil Ecology,* 142: 110-122.
31. Ravzanaadii, N., Kim, S.H., Choi, W.H., Hong, S.J. and Kim, N.J. (2012). Nutritional Value of Mealworm, *Tenebrio molitor* as Food Source. *International Journal of Industrial Entomology,* 25(1): 93-98.
32. Ribeiro, N., Abelho, M. and Costa, R. (2018). A Review of the Scientific Literature for Optimal Conditions for Mass Rearing *Tenebrio molitor* (Coleoptera: Tenebrionidae). *Journal of Entomological Science,* 53(4): 434-454.
33. Shafique, L., Abdel-Latif, H.M., Hassan, F.U., Alagawany, M., Naiel, M.A., Dawood, M.A., Yilmaz, S. and Liu Q (2021). The Feasibility of Using Yellow Mealworms (*Tenebrio molitor*): Towards a Sustainable Aqua Feed Industry. *Animals,* 11(3): 811.
34. Silva, L.B., de Souza, R.G., da Silva, S.R., Feitosa, A.D.C., Lopes, E.C., Lima, S.B.P., Dourado, L.R.B. and Pavan, B.E. (2021). Development of *Tenebrio molitor* (Coleoptera: Tenebrionidae) On Poultry Litter-Based Diets: Effect on Chemical Composition of Larvae. *Journalof Insect Science* 21(1): 1-7.
35. Toviho, O.A., Imane, M., Tünde, P. and Péter, B. (2023). Effect of Duckweed (*Spirodelapolyrhiza*)-Supplemented Semolina on the Production Parameters and Nutrient Composition of Yellow Mealworm (*Tenebrio molitor*). *Agriculture,* 13(7): 1386.
36. UN Environment Programme (UNEP) (2024). Global Waste Management. Outlook 2024. Accessed on 27, March, 2024.
37. Vigneron, A., Jehan, C., Rigaud, T. and Moret, Y. (2019). Immune defenses of a beneficial pest: the mealworm beetle, *Tenebrio molitor*. *Frontiers in Physiology,* 10: 138.
38. Weaver, D.K. and McFarlane, J.E. (1990). The Effect of Larval Density on Growth and Development of *Tenebrio molitor*. *Journal of Insect Physiology,* 36: 531-536.
39. Worden, B.D. and Parker, P.G. (2005). Females prefer noninfected males as mates in the grain beetle *Tenebrio molitor*: evidence in pre-and postcopulatory behaviours. *Animal Behaviour,* 70(5): 1047-1053.
40. Yang, S.S., Brandon, A.M., Flanagan, J.C.A., Yang, J., Ning, D., Cai, S.Y., Fan, H.Q., Wang, Z.Y., Ren, J., Benbow, E., Ren, N.Q. and Wu, W.M. (2018a). Biodegradation of Polystyrene Wastes in Yellow mealworms (Larvae of *Tenebrio molitor* Linnaeus): Factors Affecting Biodegradation Rates and the Ability of Polystyrene-Fed Larvae to Complete Their Life cycle. *Chemosphere,* 191: 979-989.
41. Yang, S.S., Wu, W.M., Brandon, A.M., Fan, H.Q., Receveur, J.P., Li, Y., Wang, Z.Y., Fan, R., McClellan, R.L., Gao, S.H. and Ning, D. (2018b). Ubiquity of polystyrene digestion and biodegradation within yellow mealworms, larvae of *Tenebrio molitor* Linnaeus (Coleoptera: Tenebrionidae). *Chemosphere,* 212: 262-271.

42. Yang, S.S., Zhang, Y., Zhou, H.M., Ji, X.Y., He, L., Xing, D.F., Ren, N.Q., Ho, S.H. and Wu, W.M. (2019). A Novel Clean Production Approach to Utilize Crop Waste Residues as Co-Diet for Mealworm (*Tenebrio molitor*) Biomass Production with Biochar as Byproduct for Heavy Metal Removal. *Environmental Pollution,* 252: 1142-1153.
43. Zheng, L., Hou, Y., Li W., Yang S., Li Q. and Yu Z (2013). Exploring the Potential of Grease from Yellow mealworm Beetle (*Tenebrio molitor*) as a Novel Biodiesel Feedstock. *Applied Energy,* 101: 618-621.