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Tenebrio Molitor: Investigating the Scientific Foundations and Proteomic and Peptidomic Potential

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Abstract

The introduction of a new food group represents a significant challenge, both from a technical and cultural perspective. The consumption of insects itself is quite complex when exploring new protein sources in nutrition. From a technical standpoint, considering the suggestion of using the adult phase of *Tenebrio molitor* as food, two sensory aspects must be addressed as a disadvantage: texture, due to its high chitin content (23%), and appearance (a living being beetle-like). However, its high protein content (50%) is an attractive aspect, even more when considering its larvae, which have an even higher protein value (58%). In addition to its high protein content, the larvae also have high fat values (30%). These parameters support the proposition that *T. molitor* larvae represent a promising matrix for obtaining a high-quality protein ingredient. Furthermore, its approximate composition indicates that a simple and low-cost technology can be used to obtain a protein concentrate without generating environmental waste, requiring only a press to remove the fat. This makes it a superior matrix compared to those used for plant-based alternatives. For instance, consider pulse beans. The technology used for these pulses is labor-intensive and destructive. For example, using six tons of beans (bean yield rate per hectare) for protein extraction will result in waste representing 75% of the total bean yield and a value of 25% for protein yield. This waste generated will represent a great environmental and agronomic aggression. Then it can be concluded that the use of larvae is a fact, but in-depth proteomics and peptidomics studies are necessary. This work presents a literature review of what has been done worldwide on this subject over the past ten years. The available information is confusing and lacks systematization.

Keywords

Larva, *Tenebrio molitor*, Alternative Protein Food, Proteomics, Peptidomics

1. Introduction

The growing global demand for proteins has raised concerns due to both population growth and changing dietary patterns that must be adjusted to address this challenge. Studies indicate that by 2050, the need for new proteins will represent an answer for sustainable food production [1]. To tackle this demand, researchers from various fields are exploring alternative protein sources, whether of animal or plant origin. Simultaneously, both food production technologies and agricultural practices are being improved to increase protein availability. However the most popular and actual solution, is concerned to the use of pulses (grains of legume) to extract protein with the aim to produce of protein concentrate. It is important to emphasize, that legume belongs to the alimentary group that contains highest amount of protein. The technology used for extract protein from pulses (beans, pea, lentil, chickpea and soy) is a labor-intensive and destructive process. For example, using six tons of beans (bean yield rate per hectare) for protein extraction will result in waste representing 75% of the total six tons used and a value of 25% for protein yield of protein concentrate. Moreover, it is important to call attention to the fact that this legume has a protein of low quality, as a consequence of its deficiency in methionine. Going further, the waste generated will represent a great environmental and agronomic aggression. Thus this plant-based program is not a solution to attend this demand. Looking forward, insects may represent a great solution, but not in its adult phase. To introduce Tenebrio molitor (the T. molitor beetle) as a new food group, it is essential to consider the sensory challenges that may affect consumer acceptance. Two notable disadvantages are: 1) Texture—Due to its high chitin content (23%), T. molitor can have a tough or unpleasant texture, especially when consumed whole or in minimally processed forms. 2) Appearance—Its resemblance to a live beetle may cause visual aversion or rejection, posing a significant barrier to cultural and sensory acceptance. These factors should be taken into account during product development, ideally by using processed forms (such as flours or extracts) that minimize these drawbacks. Additionally, food education strategies and sensory marketing can help promote familiarity and gradual acceptance. Despite of the fact, its high protein content (50%) is an attractive aspect. So, larvae of *T. molitor* emerge as great solution by its higher protein value (58%) (Oliveira *et al.*, 2024). This matrix is excellent for be processed. A low cost technology, requiring only a press to remove the fat, associated with an intelligent process will permit a production of two high quality ingredients (fat and protein concentrate), without any environmental pollution (**Figure 1**).

Scientific research on *T. molitor* is not limited to its nutritional value. Recent studies have focused on proteomic and peptidomic analyses, without yet a definitive conclusion on the structural chemical analysis of these molecules, particularly those found in the larval stage of this insect. These investigations could represent significant potential for the application of new proteins and bioactive peptides in various fields, including human nutrition, animal feed, bioprocesses, and even the cosmetic and pharmaceutical industries. The strategy for structural characterization can be conducted indirectly through the structural definition of the proteins by fragments obtained by mass spectrometry with further structure forecast by artificial intelligence databases (**Figure 2**).

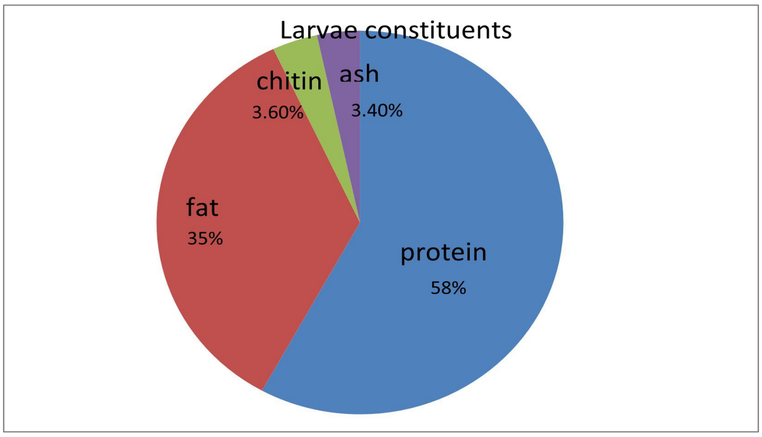

Figure 1. Diagram of constituents present in larvae of *T. molitor* that show the potential of using a low cost technology of extraction for separating fat and protein by mechanical pressing.

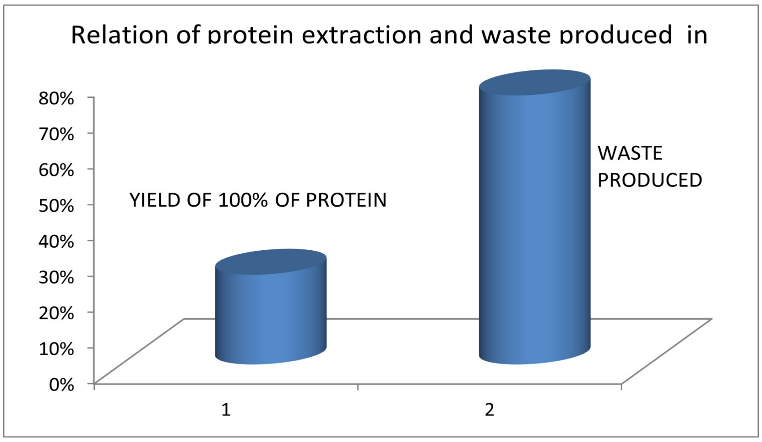

Figure 2. Percentage, in tons, of protein that can be extracted from beans and waste produced. It was calculated using six tons of beans that represent its yield per hectare. This is the plant-based solution for obtaining protein from pulses.

2. The Need for New Protein Sources

Once again, global population growth and increasing dietary demands, combined with the environmental impacts of traditional livestock farming, make it a priority to seek alternatives that can propose new protein models with nutritional quality similar to that of red meat [2]. This search also encompasses the management of conventional animal production, which presents sustainability challenges, including the need for large amounts of water and the reduction of greenhouse gas emissions, factors that contribute to the climate crisis [3].

The larva of *T. molitor* has especially valued due to its high protein content, which can reach up to 58% on a dry basis, comparable to traditional animal protein sources, such as lean meat (80%) and eggs (54%) [4] (**Figure 3**). Additionally, *T. molitor* larvae are rich in lipids, making them a nutritionally promising source.

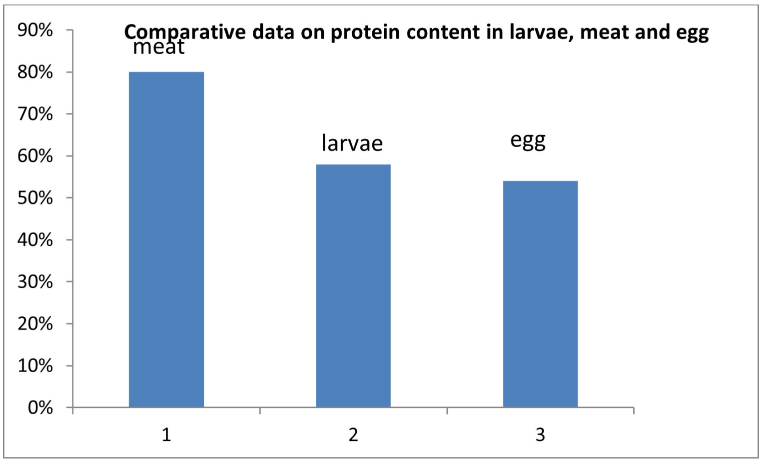

Figure 3. Values in percentage of protein (dry basis) in conventional foods that show the potential of larvae to be used an alternative protein for food ingredient production.

The nutritional value of *T. molitor* protein is also significant. Research indicates that its proteins are rich in essential amino acids, including leucine, lysine, and methionine, which are often limiting in plant protein sources (Micha *et al.*, 2017). This makes *T. molitor* larvae a potentially complete protein source for human and animal diets, especially in contexts where conventional food sources are scarce.

3. Biochemical and Nutritional Properties of *Tenebrio molitor*

The chemical composition of proteins in *T. molitor* differs from those found in conventional foods. The proteins in this insect's larvae are predominantly globulins (widely distributed proteins in the plant kingdom, especially in legume seeds, such as beans, peas, lentils, and chickpeas). It can be suggested that these larvae contain proteins similar to the myofibrillar proteins present in the musculature of animals, as the larvae also move and are composed of globulin-like proteins [5]. It is escribed that *T. molitor* larvae have sufficient strength to move using legs, suggesting that their muscle structure may be similar to that of vertebrate animals [6].

Moreover, studies on the proximate composition of *T. molitor* larvae show that they are an excellent source of minerals such as phosphorus, calcium, iron, and zinc, which are essential nutrients for human health [7]. These minerals are often deficient in diets based mainly on plant foods, making insects an attractive option for nutritional supplementation (**Figure 1**).

Regarding lipids, *T. molitor* larvae contain a significant amount of unsaturated fatty acids, particularly omega-3 and omega-6 fatty acids, which are essential for cardiovascular health [2]. The presence of these fatty acids, combined with high-quality protein, makes *T. molitor* a nutritionally balanced and efficient food source.

4. Challenges and Nutritional Considerations

Despite its high nutritional value, the use of *T. molitor* as food source faces some challenges. Firstly, the cultural acceptance of insect consumption varies widely from one region to another. In many parts of the world, especially in the West, eating insects is still viewed with some hesitation, which may limit the adoption of this alternative food source. However, in various cultures across Asia, Africa, and Latin America, insect consumption is traditional and widely accepted [6].

Another significant challenge is the need to establish clear regulatory guidelines for insect consumption. While the European Union has approved the use of *T. molitor* larvae as food for humans, there are still many issues to be addressed regarding food safety, particularly concerning the potential allergenicity of proteins present in the insect. Studies have shown that some proteins found in *T. molitor* larvae may not be fully digested, potentially leading to adverse reactions in individuals with allergies [8].

However, research on the digestibility of *T. molitor* proteins is still in its early stages. Some studies indicate that *T. molitor* has two major proteins, such as those of 75 kDa and 85 kDa, are they are fully digested in the human gastrointestinal tract, which does not limit the insect's nutritional effectiveness [9] preventing any suggestion of a toxicological effect from these proteins. Allergenicity is also a concern, requiring further research to identify and mitigate potential health risks. This is another research area that needs to be addressed.

Furthermore, large-scale production of *T. molitor* requires the development of efficient and sustainable farming systems. Insect farming demands strict control of environmental conditions such as temperature, humidity, and feed to ensure stable and high-quality production. Although insects, in general, are more efficient in converting feed into protein compared to vertebrate animals, the necessary infrastructure for large-scale production still needs improvement.

5. Challenges and Contributions to Future Proteomics and Peptidomics Studies

This review presents the latest scientific data described for *T. molitor*. By organizing the available data, conclusions should be drawn regarding the potential use of this alternative food source in the form of flour or as a proteic and fat ingredient.

Firstly, it is evident that Asian researchers are the most engaged in validating this invertebrate as a potential nutrient source (proteins, fats, and minerals), highlighting its high antioxidant properties (polyphenols and peptides), as well as molecules with technological properties (texture, emulsifying capacity) or technological applications (enzymatic technology and bioprocessing).

In the past 10 years, 12 publications on *T. molitor* have been observed, with two emphasizing nutritional quality studies, including mineral content, proximate composition, vitamins, and digestibility [10]-[12], mostly using *T. molitor* larvae as the study material. Regarding protein-focused research, there is a balance between functional-technological aspects, as demonstrated by increased antioxidant and anti-inflammatory capacity in tofu made with *Tenebrio molitor* larvae [13] and improved technological quality of ice cream when formulated with *T. molitor* larvae flour [10].

A nutritional study on *T. molitor* using protein digestibility techniques found that the two major proteins in *T. molitor* larvae flour one of 75 kDa and another of 45 kDa were fully digested [11]. Results at this molecular research have already controversy [11], describe that the larvae have two major proteins of 75 and 45 kDa and [9] shows two proteins of 75 and 85 kDa. However, total digestibility of the proteins is shown [11] what indicate the potencial of using those larvae for production of an ingredient of high quality. This evidence supports the claim that *T. molitor* could be a safe alternative protein source with a production process featuring sustainable characteristics.

From a chemical standpoint, a high solubility of proteins in alkaline pH was described. This factor is crucial because solubilization in an alkaline medium is a key step preceding the production process of protein concentrates [14]. Treatment of *T. molitor* flour with proteases was used as a method for extracting polyphenols bound to proteins, demonstrating a viable process for using polyphenols as a food ingredient with excellent antioxidant capacity [15] and [16].

Most publication is worried in producing peptides by using enzymatic technology. However, the use of this approach represents only a tool for the production of peptides from the protein matrix present in the meal of *T. molitor* larvae, with the sole purpose of being a database of scientific studies, without any prospect of technological application for the production of drugs [17]-[24]. The ongoing pursuit of sustainability can be further expanded. It has been demonstrated the feasibility of using adult insect feces in the bioprocessing of protease production by fungi [14].

Among these 12 studies conducted across Asia, Europe, and South America, it is noteworthy that North America has shown no interest in the subject. **Table 1** indicates that no research group worldwide is currently working on closing the cycle of proteomic and peptidomic studies in *T. molitor* and this a necessary condition for validating this insect larva as an alternative food ingredient source.

6. Environmental Impact and Sustainability

The production of *T. molitor* also offers significant environmental benefits. Compared to conventional meat production, insect farming requires far fewer resources, such as water, space, and feed. Studies show that the carbon footprint associated with insect production is considerably lower, making them a sustainable food alternative, particularly in a scenario of climate change and resource scarcity [20].

Additionally, insects can be fed organic waste, such as food scraps or non-edible plant materials, which can help reduce food waste and alleviate the pressure on agricultural resources. This makes *T. molitor* farming a solution not only for food security but also for waste management and reducing the environmental impact of food production.

Table 1. Distribution of research about protein of *T. molitor* studies among scientists of three differen continentes (Asian, European and South American) in the last ten years.

Ano	País	Autor	Fase da Metamorfose	Insecto	Aspecto Tecnológico e Funcional	Proteína/Fibra Alimentar	Perspective of Use
2024	Korea	[20]	Larva	*T. molitor*	Proteic extraction (0.25 M NaOH/hydrolisis alcalase)/functional peptides/antioxidant/ anti-inflamatory agents	-	Bioactive peptide
2024	Brasil	[11]	Adult	*T. molitor*	Nutricional aspects/ digestibility protein isolate	Protein of quality-	Scientific knowledgement
2024	Spain	[19]	Adult	*T. molitor*	Immunonutrition/anti-inflamatory agents/cellular biology	Quitosan/ dietary fiber	Peptídeos-scientific knowledgement
2023	Czech republic	[10]	Larvae	*T. molitor*	Technological Aspects/ice cream	-	Technological function
2023	Korea	[21]	Larvae	*T. molitor*	Protein isolate/protein hydrolysate/biological tests	-	Peptides-scientific knowledgement
2022	China	[22]	Adult	*T. molitor*	Protein isolate/protein hydrolysate/	-	Peptides-scientific knowledgement
2022	Korea	[13]	Adult	*T. molitor*	Protein isolate/protein hydrolysate/Tofu fortified/Digestibility/ antioxidant activity	-	Peptides scientific knowledgement
2020	Korean	[23]	Larvae	*T. molitor*	Protein hydrolysate/antioxidant activity hepatoprotective	-	Peptides scientific knowledgement
2022	Italian	[17]	Larvae	*T. molitor*	Protein concentrate (pH 7.4)/protein hydrolysate/ gastrointestinais enzymes/antihypertensive activity	-	Peptidomic of protein hydrolysate scientific knowledgement
2019	Korean	[18]	Larvae	*T. molitor*	Protein concentrate obtido em diferentes pHs/Atividade anti-inflamatória e nutricional	-	-
2020	Spain	[19]	Adult	*T. molitor*	Protein hydrolysate/ comercial enzymes	-	Peptidomic antihypertensive activity
2024	Spain	[14]	Adult	*T. molitor*	Quitin/Fermentation for protease production	-	-

7. Conclusions and Future Perspectives

T. molitor; larvae represents a promising food alternative to meet the growing demand for protein in the future. Its high protein and fat content associated with a low cost technology may represent a great solution for production of high quality food ingredients. Collaboration between scientists, regulatory agencies, and the industry will be essential to ensure that this larvae can be produced safely and sustainably, without compromising public health or the environment.

In a world where food security and sustainability are becoming increasingly urgent, *T. molitor* could be one of the pillars of a more efficient and eco-friendly global food system. The adoption of larvae of insects as a protein source could not only meet the nutritional needs of a growing population but also promote the transition to a more sustainable and less resource-dependent food production model.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] FAO (2018) The Future of Food and Agriculture: Trends and Challenges. FAO.

[2] Van Huis, A., *et al.* (2013) Edible Insects: Future Prospects for Food and Feed Security. FAO Forestry Paper 171.

[3] FAO (2016) The State of Food and Agriculture: Climate Change, Agriculture and Food Security. FAO.

[4] FAO (2013) Edible Insects: Future Prospects for Food and Feed Security. Food and Agriculture Organization of the United Nations.

[5] Micha, R., *et al.* (2017) Global Food Trade and the Risk of Foodborne Diseases. *The Lancet*, **390**, 2210-2221.

[6] Belluco, S., Losasso, C., Maggioletti, M., Alonzi, C.C., Paoletti, M.G. and Ricci, A. (2013) Edible Insects in a Food Safety and Nutritional Perspective: A Critical Review. *Comprehensive Reviews in Food Science and Food Safety*, **12**, 296-313. https://doi.org/10.1111/1541-4337.12014

[7] FAO (2003) Agricultural Trade and Proverty: Can Trade Work for the Poor? Food and Agriculture Organization of the United Nations. https://www.fao.org

[8] Neves, D. (2021) Tenebrio Molitor: A Promising Alternative Protein Source for Food Security. *Journal of Insect Food and Feed*, **7**, 5-16.

[9] Zhang, W., *et al.* (2020) The Digestibility and Allergenicity of Edible Insect Proteins: A Review. *Food Research International*, **137**, Article ID: 109606.

[10] Zielinska, E., Pecová, M. and Pankiewicz, U. (2020) Impact of Mealworm Powder (*Tenebrio molitor*) Fortification on Ice Cream Quality. *Sustainability*, **15**, Article 16041.

[11] Oliveira, L.A., Pereira, S.M.S., Dias, K.A., Paes, S.D.S., Grancieri, M., Jimenez, L.G.S., *et al.* (2024) Nutritional Content, Amino Acid Profile, and Protein Properties of Edible Insects (*Tenebrio molitor* and *Gryllus assimilis*) Powders at Different Stages of Development. *Journal of Food Composition and Analysis*, **125**, Article ID: 105804. https://doi.org/10.1016/j.jfca.2023.105804

[12] Yan, X., Laurent, S., Hue, I., Cabon, S., Grua-Priol, J., Jury, V., *et al.* (2023) Quality of Tenebrio Molitor Powders: Effects of Four Processes on Microbiological Quality and Physicochemical Factors. *Foods*, **12**, Article 572. https://doi.org/10.3390/foods12030572

[13] Oh, E. and Kim, Y. (2020) Influence of Mealworms (*Tenebrio molitor* Larvae) and Their Protein Derivatives on the Structural and Rheological Properties of Tofu. *Food Hydrocolloids*, **147**, Article ID: 109399.

[14] Muñoz-Seijas, N., Fernandes, H., Outeiriño, D., Morán-Aguilar, M.G., Domínguez, J.M. and Salgado, J.M. (2024) Potential Use of Frass from Edible Insect Tenebrio Molitor for Proteases Production by Solid-State Fermentation. *Food and Bioproducts Processing*, **144**, 146-155. https://doi.org/10.1016/j.fbp.2024.01.002

[15] Anusha, S. and Negi, P.S. (2023) Characterization and Techno-Functional Properties of Tenebrio Molitor Larvae Protein Concentrate. *Food Bioscience*, **54**, Article ID: 102882. https://doi.org/10.1016/j.fbio.2023.102882

[16] Gonzalez-de la Rosa, T., Montserrat-de la Paz, S. and Rivero-Pino, F. (2024) Production, Characterisation, and Biological Properties of Tenebrio Molitor-Derived Oligopeptides. *Food Chemistry*, **450**, Article ID: 139400. https://doi.org/10.1016/j.foodchem.2024.139400

[17] Brai, A., Immacolata Trivisani, C., Vagaggini, C., Stella, R., Angeletti, R., Iovenitti, G., *et al.* (2022) Proteins from Tenebrio Molitor: An Interesting Functional Ingredient and a Source of ACE Inhibitory Peptides. *Food Chemistry*, **393**, Article ID: 133409. https://doi.org/10.1016/j.foodchem.2022.133409

[18] Joe, M., Smith, A. and Park, J. (2019) Protein Concentrate Obtained at Different pH Levels and Its Anti-Inflammatory Activity from *Tenebrio molitor*. *Journal of Insect Science*, **19**, 1-10.

[19] Rivero Pino, F., Pérez Gálvez, R., Espejo Carpio, F.J. and Guadix, E.M. (2020) Evaluation of *Tenebrio molitor* Protein as a Source of Peptides for Modulating Physiological Processes. *Food & Function*, **11**, 4376-4386. https://doi.org/10.1039/d0fo00734j

[20] Oonincx, D.G.A.B., van Itterbeeck, J., Heetkamp, M.J.W., van den Brand, H., van Loon, J.J.A. and van Huis, A. (2010) An Exploration on Greenhouse Gas and Ammonia Production by Insect Species Suitable for Animal or Human Consumption. *PLOS ONE*, **5**, e14445. https://doi.org/10.1371/journal.pone.0014445

[21] Quah, Y., Tong, S.R., Bojarska, J., Giller, K., Tan, S.A., Ziora, Z.M., Esatbeyoglu, N. and Chai, T.T. (2020) Bioactive Peptide Discovery from Edible Insects for Potential Applications in Human Health and Agriculture. *Molecules*, **28**, Article 1233.

[22] Tan, J., Yang, J., Zhou, X., Hamdy, A.M., Zhang, X., Suo, H., *et al.* (2022) Tenebrio Molitor Proteins-Derived DPP-4 Inhibitory Peptides: Preparation, Identification, and Molecular Binding Mechanism. *Foods*, **11**, Article 3626. https://doi.org/10.3390/foods11223626

[23] Cho, H. and Lee, S. (2020) Novel Hepatoprotective Peptides Derived from Protein Hydrolysates of Mealworm (*Tenebrio molitor*) *Food Research International*, **133**, Article ID: 109194. https://doi.org/10.1016/j.foodres.2020.109194

[24] Pino, F.R., de la Rosa T.G. and de la Paz, S.M. (2024) Edible Insects as a Source of Biopeptides and Their Role in Immunonutrition. *Food & Function*, **15**, 2789-2798.