Nutritional Value of *Tenebrio molitor*

Subjects: Food Science & Technology
Contributor: Konstantina Kotsou , Theodoros Chatzimitakos , Vassilis Athanasiadis , Eleni Bozinou , Christos G. Athanassiou , Stavros I. Lalas

Tenebrio molitor larvae, commonly known as mealworms, as they are a rich source of nutrients and can be reared with relatively low resource input.

Tenebrionidae | edible insects | food additive | food products | nutritional enrichment

1. Introduction

The exploration of alternative food sources for human consumption has garnered significant attention due to several compelling factors, with most of them revolving around overpopulation and the high nutritional value of these novel food sources. This ongoing issue of overpopulation, which has been a topic of concern in the research community since 1997 [1], naturally correlates with an increasing demand for conventional protein sources, namely, meat and fish [2][3][4][5]. The expansion of livestock farming, driven by this escalating demand, poses the risk of encroaching on previously uncultivated land, exacerbating the issue of land use, considering that 75% of arable land is currently dedicated to livestock activities [6][7]. Moreover, the livestock sector is a major contributor, accounting for 14.5% of total anthropogenic greenhouse gas emissions [8], raising concerns about the environmental impact of this sector, which is likely to escalate with an increase in livestock units [9]. In the context of fish as a key source of protein, numerous fish species are endangered worldwide as a consequence of overfishing, pollution, coastal development, climate change and other anthropogenic actions [10]. An example is *Chondrichthyes*. The *Chondrichthyes* species is in danger, since 32.6% (391 out of 1199 species) are threatened with complete extinction due to overfishing [11]. This overexploitation of marine resources has resulted in the degradation of several marine habitats [11][12][13]. Given these ecological and sustainability concerns surrounding conventional protein sources, the scientific community has shifted its focus toward identifying alternative, sustainable sources of protein. Among these, insects have emerged as one of the most promising options [14][15][16][17][18].

Insects exhibit distinct advantages from economic and ecological standpoints. They require considerably less space, minimal water (relying primarily on moisture), and reduced feed to complete their biological life cycle compared to traditional protein sources [19][20][21][22]. However, it is noteworthy that the concept of insects as a food source is not entirely novel. Recent archaeological evidence from Tanzania suggests that insects played a crucial role in the nutrition of early humans, dating back 1.8 million years [23]. Additionally, historical depictions, such as those found in the Artamila caves in northern Spain (3000–9000 BC), portray the collection of bee nests and larvae, further highlighting the historical significance of insect consumption [24]. Despite this historical practice, insect consumption has declined significantly over time and is now primarily narrowed to traditional practices in certain regions like Southeast Asia and Australia [25][26]. In Europe, insect consumption remains relatively rare, largely due to "neophobia" surrounding insect consumption in any form [27][28][29][30]. Nevertheless, as of 2021, three insect species have received approval for safe human consumption by the European Parliament and Council [31]. In particular, on 12 November 2021 they authorized the placing on the market of frozen, dried, and powdered forms of *Locusta migratoria* Linnaeus (Orthoptera: Acrididae) [32], on 1 June 2021 the placing on the market of dried *Tenebrio molitor* Linnaeus (Coleoptera: Tenebrionidae) larvae as a novel food [33] and, most recently, on 5 January 2023, the frozen, paste, dried and powder forms of *Alphitobius diaperinus* Panzer (Coleoptera: Tenebrionidae) larvae (lesser mealworm) [34].

One of the approved species, *Tenebrio molitor* Linnaeus (Coleoptera: Tenebrionidae), is particularly noteworthy for its potential to be more readily accepted by consumers, especially in Europe [35][36][37][38]. For instance, Europeans tend to find the larvae of *T. molitor* more appealing than alternatives like cockroaches or ants [39]. Moreover, the rearing of *T. molitor* shows great promise in the rapidly expanding, global, edible insect market, where it is already being widely produced as feed for fish and poultry [40][41][42][43].

A comparative analysis of the rearing of *T. molitor* and *Alphitobius diaperinus* Panzer (Coleoptera: Tenebrionidae) reveals several advantages of the former. *T. molitor* larvae complete their development and growth in a shorter time frame, boasting a higher survival rate and greater weight compared to *A. diaperinus* [44]. Specifically, the survival rate of *T. molitor* larvae is as high as 98.8%, while that of *A. diaperinus* ranges from 88 to 95%. Additionally, the weight of *T. molitor* larvae is substantially greater, compared to the weight of *A. diaperinus* larvae [45][46][47]. This disparity is expected, given that *T. molitor* is larger than *A. diaperinus* at all stages of development [48][49]. When comparing the rearing of *T. molitor* to that of *Locusta migratoria* Linnaeus (Orthoptera: Acrididae), it becomes evident that *T. molitor* rearing is both faster and more straightforward. The development of *T. molitor* larvae is completed in just 2–3 months, whereas *L. migratoria* larvae require 2–4 months for their development [50][51][52]. This efficiency in rearing further highlights the potential of *T. molitor* as a viable and sustainable protein source for human consumption, particularly in regions where insect consumption is gaining recognition as an environmentally responsible dietary choice.

2. Nutritional Value of *T. molitor*

As is frequently mentioned, their high nutritional value is the reason that led researchers to extensively study the larvae of *T. molitor*. This species is, to this day, the main subject of research since it is characterized by its content of essential nutrients, including crude protein, essential amino acids (EAAs), fat, and essential fatty acids [24][53][54][55][56][57]. The quantification of the crude protein of *T. molitor* and its flour (dried and finely ground larvae) has received special attention. Due to this, several analytical methods have been used, such as the combustion (Dumas) method [56], Randall method [35], Kjeldahl method [58], elemental analysis method [59], Bradford method [60], and precipitation [61], yielding a variety of results, ranging from 36.8–75.1%. This variation can be attributed to the different rearing conditions of each *T. molitor* larvae. At this point, it is worth emphasizing that conventional animal, protein-rich foods, such as beef, chicken, and tuna, contain 21.4, 19.4 [62], and 22.7% crude protein [63], respectively, values that can easily be considered low compared to the protein content of *T. molitor* larvae. In **Table 1** the crude protein values contained in *T. molitor* larvae according to various surveys are presented.

Table 1. Nutritional value of *T. molitor* larvae according to the crude protein quantification method.

Composition of Dry Weight (%)			
Crude Protein	**Crude Fat**	**Ash**	**Ref.**
36.8	26.0	~1.0	[60]
46.4	32.2	2.9	[35]
47.0	29.6	2.6	[56]
51.0	ne *	ne	[59]
60.2	19.1	4.2	[58]
75.1	ne	ne	[61]

* ne: not examined.

Histidine (His), isoleucine (Iso), leucine (Leu), lysine (Lys), methionine (Met), phenylalanine (Phe), threonine (Thr), tryptophan (Trp), and valine (Val) are nine amino acids that cannot be synthesized by mammals and they must be obtained through food consumption. Therefore, they are called dietarily essential, indispensable nutrients or essential amino acids (EAAs) [64]. *T. molitor* larvae contain large amounts of Leu, Val, and Lys but low amounts of His, Met, and Trp EAAs, with Trp rarely occurring in these insects [55]. Similarly, to crude protein, EAA concentrations are influenced by the rearing conditions of the *T. molitor* larvae, temperature, humidity, feed substrate and rearing region [65][66]. For instance, Lys quantities in *T. molitor* larvae can range from 1.6 to 5.8%, Thr quantities can range from 1.3 to 4.3%, Met quantities can range from 0.6 to 2.2% and Trp quantities can range from 0.02 to 1.9% [35][42][43][44][45]. More details for the quantities of the EAAs are presented in **Table 2**.

Table 2. Amino acid composition (mg/g of dry weight) of *T. molitor* larvae.

His	Iso	Leu	Lys	Met	Phe	Thr	Trp	Val	Ref.
0.8	1.3	2.2	1.6	0.6	1.3	1.3	0.3	2.2	[67]
1.5	3.6	3.4	2.9	0.7	1.6	1.8	nd *	2.4	[57]
2.6	2.8	4.8	1.8	1.4	1.4	2.9	1.9	4.0	[43]
2.8	6.5	6.2	5.3	1.2	3.2	3.3	0.02	4.5	[68]
3.1	4.0	7.3	5.8	2.2	1.8	4.3	0.7	5.3	[69]

* nd: not detected; His: histidine; Iso: isoleucine; Leu: leucine; Lys: lysine; Met: methionine; Phe: phenylalanine; Thr: threonine; Trp: tryptophane; Val: valine.

The second most plentiful nutrient in the composition of *T. molitor* larvae is crude fat [70], which exhibits variability in values depending on the content of other nutrients and the processing method [55]. Predominantly, these larvae contain about 27% fat, whereas the percentage was found to range from 19.1 to 32.2% [56][57][58][59][60]. In **Table 1**, a detailed presentation of the crude fat values, with the corresponding crude protein content, is shown. In addition to EAAs, in *T. molitor* larvae, essential fatty acids (EFAs), such as linoleic acid (ω-6 group) and alpha-linolenic acid (ω-3 group) [71], are also detected [72]. Humans cannot produce these EFAs and thus must be obtained through the diet they are based on. The fatty acid composition of *T. molitor* larvae is presented in **Table 3**. As far as linolenic acid (C18:2 ω-6) is concerned, it is present in high amounts in *T. molitor* larvae, ranging from 11.5 to 48.1%. In contrast, as far as the content of alpha-linolenic acid (C18:3 ω-3) in larvae is concerned, it covers a range of values, from 0.2 to 2.3%. Furthermore, considerable quantities of fatty acids such as myristic acid (C14:0), palmitic acid (C16:0), palmitoleic acid (C16:1), and ω-9 oleic acid (C18:1) are also detected [38][42][45][46][47].

Table 3. Fatty acid composition (%) of *T. molitor* larvae.

C14:0	C16:0	C16:1	C18:1	C18:2 (ω-6)	C20:0	C18:3 (ω-3)	∑ SFA	∑ UFA	Ref.
2.1	18.8	0.5	28.6	48.1	0.6	0.2	22.5	77.5	[58]
2.1	17.2	1.9	43.8	29.4	nr *	2.3	21.0	79.0	[62]
2.3	21.4	0.1	39.1	27.3	1.4	0.1	31.6	nr	[65]
4.3	21.1	1.9	52.9	11.5	0.5	0.2	33.2	nr	[66]
5.0	19.1	1.7	49.9	18.1	0.1	0.4	28.6	nr	[67]

* nr: not referred.

Crude ash constitutes one more important aspect of *T. molitor* larvae, which is tested in all studies investigating the nutritional value of *T. molitor* larvae. Crude ash refers to the total of all mineral elements such as phosphorus (P), calcium (Ca), sodium (Na), and magnesium (Mg) [73]. The crude ash as presented in **Table 1** ranges from about 1.0 to 4.2% [56][57][58][59][60] and is also affected by the composition of the other nutrients, crude protein, and crude fat. Regarding, the minerals contained in *T. molitor* larvae were identified and quantified in a number of studies. In particular, the P content of larvae has recorded values up to about 1.0% [74], Ca content up to 0.5% [58], Na content up to 0.4% [57], Mg content up to 1.6% [58] and potassium (K) content up to about 1.0% [57]. In addition, *T. molitor* larvae contain up to 100.02 mg/kg of iron (Fe), up to 117.4 mg/kg, of zinc (Zn), and 20.0 mg/kg of copper (Cu) [74].

References

1. Wallace, B. The Multidimensional Nature of Population/Environmental Problems. Polit. Life Sci. 1997, 16, 224–226.

2. Béné, C.; Barange, M.; Subasinghe, R.; Pinstrup-Andersen, P.; Merino, G.; Hemre, G.I.; Williams, M. Feeding 9 Billion by 2050–Putting Fish Back on the Menu. Food Secur. 2015, 7, 261–274.
3. Boyd, C.E.; McNevin, A.A.; Davis, R.P. The Contribution of Fisheries and Aquaculture to the Global Protein Supply. Food Secur. 2022, 14, 805–827.
4. Van Bavel, J. The World Population Explosion: Causes, Backgrounds and -Projections for the Future. Facts Views Vis. ObGyn 2013, 5, 281–291.
5. Henchion, M.; Hayes, M.; Mullen, A.M.; Fenelon, M.; Tiwari, B. Future Protein Supply and Demand: Strategies and Factors Influencing a Sustainable Equilibrium. Foods 2017, 6, 53.
6. Foley, J.A.; Ramankutty, N.; Brauman, K.A.; Cassidy, E.S.; Gerber, J.S.; Johnston, M.; Mueller, N.D.; O'Connell, C.; Ray, D.K.; West, P.C.; et al. Solutions for a Cultivated Planet. Nature 2011, 478, 337–342.
7. Le Mouël, C.; Forslund, A. How Can We Feed the World in 2050? A Review of the Responses from Global Scenario Studies. Eur. Rev. Agric. Econ. 2017, 44, 541–591.
8. Caro, D. Greenhouse Gas and Livestock Emissions and Climate Change; Elsevier: Amsterdam, The Netherlands, 2018; Volume 1, ISBN 9780128126882.
9. Van Der Zijpp, A.; Wilke, P.; Carsan, S. Sustainable Livestock Intensification the Role of Livestock in Developing Communities: Enhancing Multifunctionality; UJ Press: Johannesburg, South Africa, 2008; pp. 123–150.
10. Copping, A.E.; Hemery, L.G.; Viehman, H.; Seitz, A.C.; Staines, G.J.; Hasselman, D.J. Are Fish in Danger? A Review of Environmental Effects of Marine Renewable Energy on Fishes. Biol. Conserv. 2021, 262, 109297.
11. Dulvy, N.K.; Pacoureau, N.; Rigby, C.L.; Pollom, R.A.; Jabado, R.W.; Ebert, D.A.; Finucci, B.; Pollock, C.M.; Cheok, J.; Derrick, D.H.; et al. Overfishing Drives over One-Third of All Sharks and Rays toward a Global Extinction Crisis. Curr. Biol. 2021, 31, 4773–4787.e8.
12. Coleman, F.C.; Williams, S.L. Overexploiting Marine Ecosystem Engineers: Potential Consequences for Biodiversity. Trends Ecol. Evol. 2002, 17, 40–44.
13. Lachs, L.; Oñate-Casado, J. Fisheries and Tourism: Social, Economic, and Ecological Trade-Offs in Coral Reef Systems; Springer: Berlin/Heidelberg, Germany, 2020; ISBN 9783030203887.
14. Patel, S.; Suleria, H.A.R.; Rauf, A. Edible Insects as Innovative Foods: Nutritional and Functional Assessments. Trends Food Sci. Technol. 2019, 86, 352–359.
15. Egas-Montenegro, E.; Ordo, R. International Journal of Gastronomy and Food Science Edible Insects: A Food Alternative for the Sustainable Development of the Planet. Int. J. Gastron. Food Sci. 2021, 23, 100304.

16. Guin, R.P.F.; Florença, S.G.; Boustani, N.M.; Chuck-hern, C.; Sari, M.M.; Ferreira, M.; Costa, C.A.; Cardoso, A.P.; Tarcea, M.; Correia, P.M.R.; et al. Are Consumers Aware of Sustainability Aspects Related to Edible Insects? Results from a Study Involving 14 Countries. Sustainability 2022, 14, 14125.
17. Florença, S.G.; Guin, R.P.F.; Gonçalves, F.J.A.; Jo, M.; Ferreira, M.; Costa, C.A.; Correia, P.M.R.; Cardoso, A.P.; Campos, S. The Motivations for Consumption of Edible Insects: A Systematic Review. Foods 2022, 11, 3643.
18. Ha, N.I.; Mun, S.K.; Im, S.B.; Jang, H.Y.; Jeong, H.G.; Kang, K.Y.; Park, K.W.; Seo, K.S.; Ban, S.E.; Kim, K.J.; et al. Changes in Functionality of Tenebrio molitor Larvae Fermented by Cordyceps militaris Mycelia. Foods 2022, 11, 2477.
19. Premalatha, M.; Abbasi, T.; Abbasi, T.; Abbasi, S.A. Energy-Efficient Food Production to Reduce Global Warming and Ecodegradation: The Use of Edible Insects. Renew. Sustain. Energy Rev. 2011, 15, 4357–4360.
20. Krongdang, S.; Phokasem, P.; Venkatachalam, K.; Charoenphun, N. Edible Insects in Thailand: An Overview of Status, Properties, Processing, and Utilization in the Food Industry. Foods 2023, 12, 2162.
21. Siddiqui, S.A.; Shah, M.A.; Centoducati, G. Prospects of Edible Insects as Sustainable Protein for Food and Feed—A Review. J. Insects Food Feed. 2023, 1, 4588.
22. van Huis, A. Edible Insects Contributing to Food Security? Agric. Food Secur. 2015, 4, 1–9.
23. Van Huis, A. Edible Insects Are the Future? Proc. Nutr. Soc. 2016, 75, 294–305.
24. Kouřimská, L.; Adámková, A. Nutritional and Sensory Quality of Edible Insects. NFS J. 2016, 4, 22–26.
25. Ojeda-Avila, T.; Woods, H.A.; Raguso, R.A. Effects of Dietary Variation on Growth, Composition, and Maturation of Manduca sexta (Sphingidae: Lepidoptera). J. Insect Physiol. 2003, 49, 293–306.
26. Bjørge, J.D.; Overgaard, J.; Malte, H.; Gianotten, N.; Heckmann, L.H. Role of Temperature on Growth and Metabolic Rate in the Tenebrionid Beetles Alphitobius Diaperinus and Tenebrio molitor. J. Insect Physiol. 2018, 107, 89–96.
27. Mancini, S.; Moruzzo, R.; Riccioli, F.; Paci, G. European Consumers' Readiness to Adopt Insects as Food. A Review. Food Res. Int. 2019, 122, 661–678.
28. Piha, S.; Pohjanheimo, T.; Lähteenmäki-Uutela, A.; Křečková, Z.; Otterbring, T. The Effects of Consumer Knowledge on the Willingness to Buy Insect Food: An Exploratory Cross-Regional Study in Northern and Central Europe. Food Qual. Prefer. 2018, 70, 1–10.

29. Moruzzo, R.; Mancini, S.; Boncinelli, F.; Riccioli, F. Exploring the Acceptance of Entomophagy: A Survey of Italian Consumers. Insects 2021, 12, 123.
30. van Huis, A.; Rumpold, B. Strategies to Convince Consumers to Eat Insects? A Review. Food Qual. Prefer. 2023, 110, 104927.
31. Żuk-Gołaszewska, K.; Gałęcki, R.; Obremski, K.; Smetana, S.; Figiel, S.; Gołaszewski, J. Edible Insect Farming in the Context of the EU Regulations and Marketing—An Overview. Insects 2022, 13, 446.
32. Commission Implementing Regulation (EU) 2021/1975 of 12 November 2021 Authorising the Placing on the Market of Frozen, Dried and Powder Forms of Locusta Migratoria as a Novel Food under Regulation (EU) 2015/2283 of the European Parliament and of the Council and Amending Commission Implementing Regulation (EU) 2017/2470. Off. J. Eur. Union L402 2021, 1975, 10.
33. Commission Implementing Regulation (EU) 2021/882 of 1 June 2021 Authorising the Placing on the Market of Dried Tenebrio molitor Larva as a Novel Food under Regulation (EU) 2015/2283 of the European Parliament and of the Council, and Amending Commission Implementing Regulation (EU) 2017/2470. Off. J. Eur. Union L194 2021, 882, 16–20.
34. Commission Implementing Regulation (EU) 2023/58 of 5 January 2023 Authorising the Placing on the Market of the Frozen, Paste, Dried and Powder Forms of Alphitobius Diaperinus Larvae (Lesser Mealworm) as a Novel Food and Amending Implementing Regulation (EU) 2017/2470. Off. J. Eur. Union L5 2023, 58, 10–15.
35. Moruzzo, R.; Riccioli, F.; Espinosa Diaz, S.; Secci, C.; Poli, G.; Mancini, S. Mealworm (Tenebrio molitor): Potential and Challenges to Promote Circular Economy. Animals 2021, 11, 2568.
36. Bordiean, A.; Krzyżaniak, M.; Stolarski, M.J.; Czachorowski, S.; Peni, D. Will Yellow Mealworm Become a Source of Safe Proteins for Europe? Agriculture 2020, 10, 233.
37. Tzompa-Sosa, D.A.; Moruzzo, R.; Mancini, S.; Schouteten, J.J.; Liu, A.; Li, J.; Sogari, G. Consumers' Acceptance toward Whole and Processed Mealworms: A Cross-Country Study in Belgium, China, Italy, Mexico, and the US. PLoS ONE 2023, 18, e0279530.
38. Gkinali, A.-A.; Matsakidou, A.; Vasileiou, E.; Paraskevopoulou, A. Potentiality of Tenebrio molitor Larva-Based Ingredients for the Food Industry: A Review. Trends Food Sci. Technol. 2022, 119, 495–507.
39. Fischer, A.R.H.; Steenbekkers, L.P.A. All Insects Are Equal, but Some Insects Are More Equal than Others. Br. Food J. 2018, 120, 852–863.
40. Mancuso, T.; Pippinato, L.; Gasco, L. The European Insects Sector and Its Role in the Provision of Green Proteins in Feed Supply. Qual. Access Success 2019, 20, 374–381.

41. Sogari, G.; Amato, M.; Biasato, I.; Chiesa, S.; Gasco, L. The Potential Role of Insects as Feed: A Multi-Perspective Review. Animals 2019, 9, 119.
42. Thévenot, A.; Rivera, J.L.; Wilfart, A.; Maillard, F.; Hassouna, M.; Senga-Kiesse, T.; Le Féon, S.; Aubin, J. Mealworm Meal for Animal Feed: Environmental Assessment and Sensitivity Analysis to Guide Future Prospects. J. Clean. Prod. 2018, 170, 1260–1267.
43. Selaledi, L.; Mbajiorgu, C.A.; Mabelebele, M. The Use of Yellow Mealworm (T. Molitor) as Alternative Source of Protein in Poultry Diets: A Review. Trop. Anim. Health Prod. 2020, 52, 7–16.
44. van Broekhoven, S. Quality and Safety Aspects of Mealworms as Human Food; Wageningen University and Research: Wageningen, The Netherlands, 2008; Volume 12, ISBN 9789462575714.
45. Toviho, O.A. Nutrient Composition and Growth of Yellow Mealworm (Tenebrio molitor) at Different Ages and Stages of the Life Cycle. Agriculture 2022, 12, 1924.
46. Hosen, M.; Khan, A.R.; Hossain, M. Growth and Development of the Lesser Mealworm, Alphitobius Diaperinus (Panzer) (Coleoptera: Tenebrionidae) on Cereal Flours. Pak. J. Biol. Sci. 2004, 7, 1505–1508.
47. Rumbos, C.I.; Bliamplias, D.; Gourgouta, M.; Michail, V.; Athanassiou, C.G. Rearing Tenebrio molitor and Alphitobius diaperinus larvae on seed cleaning process byproducts. Insects 2021, 12, 293.
48. Rumbos, C.I.; Karapanagiotidis, I.T.; Mente, E.; Athanassiou, C.G. The Lesser Mealworm Alphitobius Diaperinus: A Noxious Pest or a Promising Nutrient Source? Rev. Aquac. 2019, 11, 1418–1437.
49. Mariod, A.A.; Mirghani, M.E.S.; Hussein, I. Tenebrio molitor Mealworm. In Unconventional Oilseeds and Oil Sources; Mariod, A.A., Mirghani, M.E.S., Hussein, I., Eds.; Academic Press: San Diego, CA, USA, 2017; pp. 331–336.
50. Gomaa, K.F.S. Evaluation of Five Pearl Millet Ecotypes Susceptibility to the Nymphal Instars of Migratory Locust. Trop. Drylands 2017, 1, 57–63.
51. Rumbos, C.I.; Karapanagiotidis, I.T.; Mente, E.; Psofakis, P.; Athanassiou, C.G. Evaluation of Various Commodities for the Development of the Yellow Mealworm, Tenebrio molitor. Sci. Rep. 2020, 10, 11224.
52. Dreyer, M.; Hörtenhuber, S.; Zollitsch, W.; Jäger, H.; Schaden, L.M.; Gronauer, A.; Kral, I. Environmental Life Cycle Assessment of Yellow Mealworm (Tenebrio molitor) Production for Human Consumption in Austria—A Comparison of Mealworm and Broiler as Protein Source. Int. J. Life Cycle Assess. 2021, 26, 2232–2247.

53. Zielińska, E.; Baraniak, B.; Karaś, M.; Rybczyńska, K.; Jakubczyk, A. Selected Species of Edible Insects as a Source of Nutrient Composition. Food Res. Int. 2015, 77, 460–466.

54. Jantzen da Silva Lucas, A.; Menegon de Oliveira, L.; da Rocha, M.; Prentice, C. Edible Insects: An Alternative of Nutritional, Functional and Bioactive Compounds. Food Chem. 2020, 311, 126022.

55. Hong, J.; Han, T.; Kim, Y.Y. Mealworm (Tenebrio molitor Larvae) as an Alternative Protein Source for Monogastric Animal: A Review. Animals 2020, 10, 2068.

56. Benzertiha, A.; Kierończyk, B.; Kołodziejski, P.; Pruszyńska–Oszmałek, E.; Rawski, M.; Józefiak, D.; Józefiak, A. Tenebrio molitor and Zophobas Morio Full-Fat Meals as Functional Feed Additives Affect Broiler Chickens' Growth Performance and Immune System Traits. Poult. Sci. 2020, 99, 196–206.

57. Ravzanaadii, N.; Kim, S.-H.; Choi, W.-H.; Hong, S.-J.; Kim, N.-J. Nutritional Value of Mealworm, Tenebrio molitor as Food Source. Int. J. Ind. Entomol. 2012, 25, 93–98.

58. Heidari-Parsa, S.; Imani, S.; Fathipour, Y.; Kheiri, F.; Chamani, M. Determination of Yellow Mealworm (Tenebrio molitor) Nutritional Value as an Animal and Human Food Supplementation. Arthropods 2018, 7, 94–102.

59. Boulos, S.; Tännler, A.; Nyström, L. Nitrogen-to-Protein Conversion Factors for Edible Insects on the Swiss Market: T. molitor, A. domesticus, and L. migratoria. Front. Nutr. 2020, 7, 89.

60. Kotsou, K.; Chatzimitakos, T.; Athanasiadis, V.; Bozinou, E.; Rumbos, C.I.; Athanassiou, C.G.; Lalas, S.I. Enhancing the Nutritional Profile of Tenebrio molitor Using the Leaves of Moringa oleifera. Foods 2023, 12, 2612.

61. Gkinali, A.; Matsakidou, A.; Paraskevopoulou, A. Characterization of Tenebrio molitor Larvae Protein Preparations Obtained by Different Extraction Approaches. Foods 2022, 11, 3852.

62. Siulapwa, N.; Mwambungu, A.; Lungu, E.; Sichilima, W. Nutritional Value of Four Common Edible Insects in Zambia. Int. J. Sci. Res. 2012, 3, 2319–7064.

63. Aberoumand, A.; Baesi, F. The Nutritional Quality and Contents of Heavy Elements Due to Thermal Processing and Storage in Canned Thunnus tonggol Fish Change Compared to Fresh Fish. Food Sci. Nutr. 2023, 11, 3588–3600.

64. Jensen, I.J.; Bodin, N.; Govinden, R.; Elvevoll, E.O. Marine Capture Fisheries from Western Indian Ocean: An Excellent Source of Proteins and Essential Amino Acids. Foods 2023, 12, 1015.

65. Adámková, A.; Mlček, J.; Adámek, M.; Borkovcová, M.; Bednářová, M.; Hlobilová, V.; Knížková, I.; Juríková, T. Tenebrio molitor (Coleoptera: Tenebrionidae)—Optimization of Rearing Conditions to Obtain Desired Nutritional Values. J. Insect Sci. 2020, 20, 24.

66. 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, 48–56.
67. Wu, R.A.; Ding, Q.; Yin, L.; Chi, X.; Sun, N.; He, R.; Luo, L.; Ma, H.; Li, Z. Comparison of the Nutritional Value of Mysore Thorn Borer (Anoplophora chinensis) and Mealworm Larva (Tenebrio molitor): Amino Acid, Fatty Acid, and Element Profiles. Food Chem. 2020, 323, 126818.
68. Ao, X.; Yoo, J.S.; Wu, Z.L.; Kim, I.H. Can Dried Mealworm (Tenebrio molitor) Larvae Replace Fish Meal in Weaned Pigs? Livest. Sci. 2020, 239, 104103.
69. Yoo, J.S.; Cho, K.H.; Hong, J.S.; Jang, H.S.; Chung, Y.H. Nutrient Ileal Digestibility Evaluation of Dried Tenebrio molitor. Asian Australas. J. Anim. Sci. 2018, 32, 387.
70. Dreassi, E.; Cito, A.; Zanfini, A.; Materozzi, L.; Botta, M.; Francardi, V. Dietary Fatty Acids Influence the Growth and Fatty Acid Composition of the Yellow Mealworm Tenebrio molitor (Coleoptera: Tenebrionidae). Lipids 2017, 52, 285–294.
71. Di Pasquale, M.G. The Essentials of Essential Fatty Acids. J. Diet. Suppl. 2009, 6, 143–161.
72. Lawal, K.G.; Kavle, R.R.; Akanbi, T.O.; Mirosa, M.; Agyei, D. Enrichment in Specific Fatty Acids Profile of Tenebrio molitor and Hermetia illucens Larvae through Feeding. Futur. Foods 2021, 3, 100016.
73. Ali, M.Y.; Sina, A.A.I.; Khandker, S.S.; Neesa, L.; Tanvir, E.M.; Kabir, A.; Khalil, M.I.; Gan, S.H. Nutritional Composition and Bioactive Compounds in Tomatoes and Their Impact on Human Health and Disease: A Review. Foods 2021, 10, 45.
74. Ghosh, S.; Lee, S.M.; Jung, C.; Meyer-Rochow, V.B. Nutritional Composition of Five Commercial Edible Insects in South Korea. J. Asia Pac. Entomol. 2017, 20, 686–694.