

'Insects as Food and Feed: If You Can't Beat Them, Eat Them!' – To the Magnificent Seven and Beyond

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Abstract

The objective of this special issue is to highlight the current state of research in the field of insects as food and feed, but also other aspects on the exploitation of insect farming. In this editorial, we make a short introduction of the topic of the special issue, briefly present the contributions that are collected in it and offer some thoughts on the future research priorities and challenges that should be addressed. Regarding insect farming, there are additional applications, such as fertilizer, health-promoting products, and cosmetics, that can be produced and utilized, that go far beyond food and feed production.

Key words: alternative nutrient source, circular economy, insect farming, insects as food and feed, sustainability

This special issue of the *Journal of Insect Science* constitutes one of the first issues of the journal for the year 2021. The publication of this special issue coincides with the beginning of a new year, which is expected to be a year of pivotal developments and advances for the insect farming sector. The exploitation of insects as food and feed was originally proposed as a means to address two major current challenges for human population. First, the need to produce adequate food for a continuously growing world population without expanding agricultural land. According to 'The State of Food Security and Nutrition in the World' report (FAO et al. 2019), more than 10% of the world human population suffered from hunger in 2018, with the numbers of undernourished people in hunger having increased for three consecutive years. Insect consumption has been proposed as a feasible means for reducing malnutrition and food insecurity in developing countries (Tao and Li 2018). However, being highly nutritious and containing considerable amounts of protein, fat, vitamins, and minerals (Finke 2015), dietary inclusion of insects could provide more than just survival. Currently, more than 2 billion people, mainly in Asia, Africa, and South America, cover part of their dietary needs with insects (Ramos-Elorduy 2009, Van Huis 2019). However, the road is still long to claim that insects have also acquired a noteworthy position in Western diets. Significant steps have been made towards this direction though, the latest being the approval for human consumption of larvae of the yellow mealworm, *Tenebrio molitor* L. (Coleoptera: Tenebrionidae), by the European Food Safety Authority (EFSA 2021). Specifically, the EFSA panel on Nutrition, Novel Foods, and Food Allergens recently concluded that the consumption of *T. molitor* larvae, either as dried insects or in the form of powder, does not raise any safety concerns when used as an ingredient of various food products (e.g., snacks, energy bar, biscuits,

and pasta) up to specific levels. In fact, EFSA (2021) clearly illustrates the low allergenic risks from *T. molitor* consumption, which is not much different than other animal-based commodities. This first EU-wide approval for insect-based products is expected to be a milestone for the sector that will hopefully have a snowball effect and speed up the authorization of other insect-derived novel foods. Interestingly, but not surprisingly, this EU support towards insect utilization for food and feed has triggered different research and commercial initiatives in non-EU areas, which is clearly illustrated in the list of articles that are published in this special issue, where 6 out of 11 research papers come from non-EU countries (United States, Thailand, Brazil, and Mexico).

The second issue that could be addressed by the exploitation of insects as a nutrient source is the necessity to develop alternative feed materials for animal production and aquaculture, which is even more challenging, as it is directly related with food production. In this context, 75% of our food comes from a handful of sources, which is not more than 12 plant and five animal species (<http://www.fao.org/docrep/007/y5609e/y5609e02.htm>), so any changes in feed prioritization could have an effect on food availability. Insect inclusion in terrestrial animal and fish diets could decrease the dependency on currently used critical feeds, such as soybean meal and fishmeal, the use of which has not always been cloudless. For instance, soy production is one of the leading drivers of tropical deforestation in South America (Barona et al. 2010), whereas the high global demand for fishmeal due to the continuous growth of the aquaculture sector has led to overfishing and reduction of natural fish stocks (Tacon et al. 2010). Moreover, the demand for this feedstuff also by other sectors, such as the pet food industry, could result in a supply shortage and price increase (Tacon and Metian 2008).

More than a feeding

The overall idea towards the exploitation of insect farming in EU was historically started mainly as a feed alternative over the use of imported soya, i.e., to foster the development of alternative feed material and to decrease EU dependency on critical imported feed material, where there is no full control of the growing conditions (De Visser et al. 2014). Hence, in terms of the insect use as feed, significant progress has been achieved during the last few years. The approval of insect protein in aquafeeds in EU has provided a breakthrough in the exploitation of insects as feed. EU Regulation 2017/893 established a framework for the use of seven insect species as components of compound aquafeeds. At the time of writing this editorial, the EU Commission has intensified its efforts to come to an agreement with the Member States regarding the authorization of the use of insects in poultry and swine diets. The green light for the expansion of the use of insects to the poultry and swine industry in the EU is expected to be given in 2021.

As research was developing towards the direction of food and feed evaluation, there were novel insights of insect farming that were considered as worthy of further investigation, which are not directly related with consumption. In this context, the potential of insect frass as a fertilizer and a plant growth- and development-promoter has been lately identified, further enhancing the characterization of insect farming as a clear circular economy paradigm (Houben et al. 2020). However, further research is warranted to fully unfold the potential of this waste stream of insect production to an efficient, sustainable alternative of conventional fertilizers (Berggren et al. 2019). Moreover, this 'bio-fertilizer' cannot currently cover the market's needs, and thus, can be used only in small-area applications. It is generally expected though that the increase of insect production will cause a concomitant increase in the insect-based fertilizer production, and cover many more application scenarios in agriculture and food science.

Another ambitious field of research for the insect sector is the utilization of insects as a source of animal health-promoting compounds. Current evidence proves that several categories of insect-derived substances (e.g., peptides, chitin, chitosan lauric acid, etc.) can exert an antimicrobial and/or prebiotic effect on livestock animals consequently promoting animal health (Gasco et al. 2018, Mouithys-Mickalad et al. 2020). The currently available results from relevant studies are quite encouraging, as insects show promise that could be utilized to increase animal immune responses against a wide range of pathogens in animal production and aquaculture (Ido et al. 2015, 2019; Ji et al. 2016; Islam and Yang 2017; Sprangers et al. 2018). The use of insect-derived functional feed ingredients to promote animal health could indirectly contribute to the reduction of antimicrobials in animal rearing and is fully aligned to the goal for the reduction of antimicrobial usage in animal production and aquaculture (by 50% in EU-level by 2030), which have been associated with the prevalence and spread of drug-resistant pathogens (Van Boeckel et al. 2015, Lulijwa et al. 2019). Additionally, several insect-derived components have strong potential to be used by the cosmetic industry for the production of a wide variety of products and applications (Verheyen et al. 2018). Finally, due to the ability of insects to grow on organic side-streams and wastes, insect production could be easily integrated with current organic waste management practices (Da Silva and Hesselberg 2020, Surendra et al. 2020). Apart from organic waste, recent studies have demonstrated that several insects such as *T. molitor* and the superworm, *Zophobas morio* L. (Coleoptera: Tenebrionidae), can biodegrade and mineralize various types of plastics, such as polystyrene or polyethylene

(Brandon et al. 2018, Yang et al. 2020), indicating their potential for plastic waste management. Based on the above, it becomes evident that insect farming can cover many aspects in the industrialized world, and perhaps only a small portion of insect uses has been revealed so far.

To the Magnificent Seven... and beyond

EU Regulation 2017/893 gave the green light for the utilization of seven insect species, and it would not be accurate to put all cultivated insects under the 'umbrella' of insect farming. These species were *T. molitor*, the lesser mealworm, *Alphitobius diaperinus* (Panzer) (Coleoptera: Tenebrionidae), the black soldier fly, *Hermetia illucens* (L.) (Diptera: Stratiomyidae), the common housefly, *Musca domestica* L. (Diptera: Muscidae), and a few Gryllidae (Orthoptera): the house cricket, *Acheta domesticus* (L.), the banded cricket, *Grylodes sigillatus* (Walker) and the field cricket, *Gryllus assimilis* (F.). From the literature available so far, *T. molitor* and *H. illucens* seem to be by far the most thoroughly investigated species towards this direction (Fig. 1). However, from the insect Order range indicated in the catalog above, it becomes evident that many species can be further examined for this purpose, which vary in their biology, metamorphosis, life cycle, and food preferences.

There are thousands of insect species that are already consumed by humans in different geographic zones (Ramos-Elorduy 2009, Van Huis 2013, Jongema 2017). At the same time, there are plenty of insect species that are naturally consumed by farmed animals and fish, especially in semi-intensive farms, where fowl, such as broilers, are in often contact with different insect species (Józefiak et al. 2016). Based on this, more work is needed to examine the suitability of additional species to the catalog of insects that are suitable for commercial applications. One approach is to start with species that are relative to those included in the EU Regulation 2017/893. *Zophobas morio* is presented in this special issue as a possible candidate for this purpose.

Need for Speed

Despite the promising expectations that the EU Regulation 2017/893 provided and the impression that this will soon go beyond aquaculture, this next step did not occur until now. The

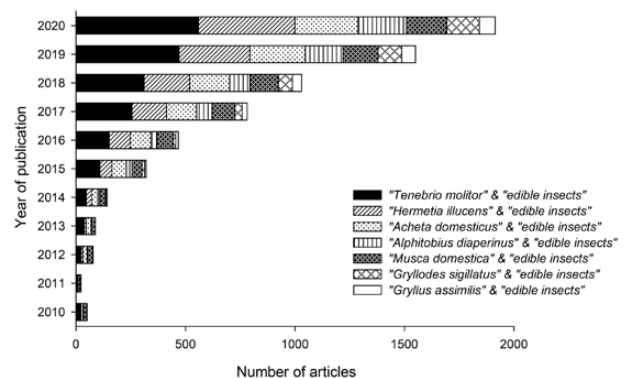


Fig. 1. Number of published articles per annum indexed by Google Scholar matching the search queries '*Tenebrio molitor*', '*Hermetia illucens*', '*Acheta domesticus*', '*Alphitobius diaperinus*', '*Musca domestica*', '*Grylodes sigillatus*', '*Gryllus assimilis*' and 'edible insects', shown per year of publication (2010–2020) (Date of Google Scholar search: 11 February 2021).

expansion of insect use from fish to farm animals like chicken or pigs seems to be a rather ‘long jump’ than just an expansion of the information that is currently available. Moreover, the inclusion of insects in feed in the poultry and swine industry at the EU level may, and is expected to, cause regulatory changes in the pipeline that may facilitate the development of insect farming, with apparent positive projections. Nevertheless, currently, this acts mostly as a limitation marketwise, as the final insect production cannot be channeled to animal production as a whole. Apparently, EU regulations for insect farming are much stricter than other places, while raw materials must fulfill very specific requirements (Lähteenmäki-Uutela et al. 2017). Still, further developments of insect farming are expected to be particularly beneficial for numerous countries around the world, which have the capacity of reduced production costs (Onsongo et al. 2018). Prioritization of the substances that can be utilized in this production chain is a key issue of major importance that should be seriously planned at the transnational level. The authorization in EU of specific materials of animal origin, such as former foodstuffs containing meat and fish or catering waste, which are both set as priorities by the International Platform of Insects for Food and Feed (IPIFF 2019), could be a substantial step towards this direction. The re-introduction of valuable resources in the economic circuit and the valorization and up-cycling through bioconversion to insect protein of a wider spectrum of low-cost side-streams and food waste will extensively boost the sustainability profile of the insect sector and will be fully aligned with circular economy strategies that are forcefully promoted in the European Union (European Commission 2014, 2020).

Consumers’ acceptance is still a ‘black box’, despite first evidence of positive results in different countries (Verbeke et al. 2015, Wilkinson et al. 2018, Llagostera et al. 2019, Domingues et al. 2020). Consumers are a big driver of the development of the sector; however, most of the studies available for acceptance are mainly based on questionnaires investigating the ‘willingness’, rather than on sensory analysis with actual food samples (Wendin et al. 2019, Mishyna et al. 2020). Strengthening the latter is critical, because insect products are eventually linked with an extremely large variety of final commodities, such as egg, milk etc. The work of Petersen et al. (2020) presented in this special issue, who run taste-test surveys with insect-based products (cricket powder brownie) contributes to this direction.

Contributions to This Special Issue

All these challenges and research priorities are, to a large extent, mirrored in the contents of this issue. Despite its title, the idea behind this article collection was beyond the ‘food and feed’ approach, as we also wanted to collect new data on waste management, rearing protocols, alternative insect species, as well as nutritional and economic aspects, from different parts of the world. This was to one extent achieved by the papers published, which address various aspects of the topic of this special issue. The first contribution to this special issue is a paper by Bawa et al. (2020) on the diet effects on the nutritional composition and growth parameters of *A. domesticus*. This species is one of the mostly farmed insect species in Thailand, whereas it is one of the species that can be included in aquafeeds in EU. Gold et al. (2020) describe one protocol to produce viable, sterile *H. illucens* larvae that can be used to study the impact of the insect microbiome

on the larval development. In another protocol described in this paper, the authors present a novel method to collect diet residue-free frass from individual *H. illucens* larvae as a tool to estimate their nutrient requirements. The work of Mattison et al. (2020) deals with the potential allergic reactions to the consumption of insect-based foods and the risks that this may pose to consumers. Particularly, they report that the arginine kinase of termites, which are regularly consumed in several parts of the world, may act as an allergen to persons with shellfish, cockroach or other arthropod allergies. Two of the contributions explore the use of novel substrates as insect feed, addressing one of the research priorities as defined by IPIFF (2019). Specifically, Riudavets et al. (2020) investigated the suitability of organic agro-industrial byproducts for the rearing of the Mediterranean flour moth, *Ephestia kuehniella* (Zeller) (Lepidoptera: Pyralidae), *T. molitor*, and *H. illucens*, whereas Galassi et al. (2021) studied the effect of organic side-streams from agro-food industries on larval biomass production, development time, nutritional composition and microbiota of *H. illucens* larvae. Another research topic of high interest is the exploitation and reuse of insect rearing residues, which was directly addressed by Gärtling et al. (2020). In their paper, the authors evaluated the efficiency of three different byproducts of *H. illucens* rearing, i.e., frass, larval skins, and dead adult flies, for maize fertilization. Working with the same insect species, Yang and Tomberlin (2020) compared the life-history traits of *H. illucens* larvae at bench-top and industrial scale regarding survival, biomass production and waste conversion, and highlight the significance of scale effect when evaluating the industrial value of research results. The ability to manipulate insect nutritional values by altering rearing conditions was studied by Adámková et al. (2020), who demonstrated the effect of temperature and diet on the nutrient composition of *T. molitor* larvae. Similarly, Silva et al. (2021) evaluated the development and nutrient composition of *T. molitor* larvae fed poultry litter-based diets. In the last two research contributions, Pino Moreno et al. (2020) investigated commerce-wise the edible insect species in the state of Morelos in Mexico, whereas Petersen et al. (2020) evaluated the current university student perceptions of entomophagy in the United States (University of Minnesota) running taste-tests surveys. Moreover, they developed a learning lesson plan to assess student attitudes and concomitantly educate them on entomophagy. Finally, in the review paper of Rumbos and Athanassiou (2021), the currently available information on *Z. morio* is presented collectively in order to highlight the potential of this insect species as a nutrient source for food and feed.

Closing Remarks

Insects can provide a sustainable, efficient, and reliable solution to the challenges that the food and feed system faces and facilitate the transition to circular farming systems in agriculture and more environmentally friendly food systems that will provide social and economic sustainability. As the interest on insect farming for food and feed production grows exponentially, given the broader urge for sustainable agricultural and food systems, scientific research on various aspects of insect production is an essential component in guiding improvements in this field. This special issue aims to contribute to the overall debate on the topic and trigger further discussions within the scientific community. Some ‘pests’ may not be ‘pests’ after all, but highly beneficial agents for human nutrition.

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