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# Edible insects in mixed-sourced protein meals for animal feed and food: An EU focus

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ABSTRACT

Despite insects being nutritious and a sustainable protein source, entomophagy is not widely accepted by Western consumers. After EFSA's positive risk assessment report, few species can be legally farmed and processed in the EU under measures set out in Novel Foods regulation 2015/2283. This review summarizes scientific progress in the applications of insects as feed and complementary proteins in foods during the past five years including legislative frameworks covering this trajectory. Despite numerous opportunities presented, insects farming still faces challenges such as gaps in legislative policies, high initial R&D costs, and high costs involved in Life Cycle Assessment. As with other novel foods, insect production requires new value chains and attention to standardization, food safety-related issues, certification for mass production, and consumer acceptance. Therefore, the roles of public sector, scientific community, local authorities, and legislative bodies are extremely important in increasing awareness of sustainability implications and benefits of insects as food and feed.

## 1. Introduction

Despite ongoing attempts to achieve the sustainable development goal of 'zero hunger', there were 828 million malnourished people globally in 2021, 46 million more since 2020 and 150 million added since the outbreak of the COVID-19 pandemic according to the Food and Agriculture Organization (FAO, 2022). Food security and safety is also under increasing pressure because of intensive farming practises' unsustainable demands on land and water. The current food production model relies heavily on livestock to feed the population, especially in industrialised countries. Livestock farming (namely cattle, swine, and poultry) is responsible for almost 15% of global greenhouse Gas (CHG) emissions and consumption of massive natural resources (O'Mara, 2011). The production of protein from livestock is extremely resource and nutritionally inefficient. According to recent estimates, meat accounts for 18% of the protein produced, although as the world population reaches 9.8 billion, as expected by 2050, the need for livestock protein would rise by up to 90% (Xu et al., 2021). Additionally, the recent conflict in Ukraine endangering the food supply chain, disrupting agricultural practices and transportation of crops and further worsens the problem of food security.

Even with the increased awareness of anthropogenic climate change and the need to embrace a sustainable approach across all our activities only a small number of people willing to adopt a different, climate friendly diet. Due to various cultural stereotypes, global meat production and consumption has been steadily increasing for the last 60 years with detrimental effects on the environment, human health, and the welfare of animals (Sans & Combris, 2015). To limit or to reduce instead of limit meat consumption and promote healthy and sustainable diets with a balanced protein content, effective consumption-side intervention techniques are required. Therefore, there is a need for a more dependable and sustainable system of protein production, resilient to many of the side-effects on the ongoing food security crisis (Reynolds et al., 2019).

The adoption of edible insects in human diet and animal feed could represent a promising option due to the many advantages that could lead to a more sustainable food system. Insect proteins are gaining importance in the feed sector, as the requirement of food including seafood

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and meat is increasing with the increase in human population. Recent studies reported the potential use of insects in different types of animal feed, such as aquaculture (Alfiko et al., 2022), pigs (Hong & Kim, 2022), poultry (Abd El-Hack et al., 2020) and even ruminants (Toral et al., 2022). Regarding entomophagy, the practice of eating insects, is not as widely accepted in Western societies although common in many tropical countries (e.g., East Asian, and African) where certain species of insects grow to large sizes, are abundant and relatively easy to harvest year-round. This may be due to a variety of factors, including cultural and personal preferences, lack of familiarity with insects as a food source, and a perceived 'gross factor' associated with consuming insects (Toti et al., 2020).

However, there has been increasing worldwide interest in the potential for insects to serve as a sustainable and nutritious alternative protein source. This is due in part to the environmental and nutritional benefits of insects as a food source, as well as the potential to address issues related to food security, sustainability and growing public awareness of animal welfare. The high feed conversion efficiency of insects, decreased greenhouse gas emissions, reduced water and land consumption, and the use of insect-based bioconversion as a commercially viable method of decreasing food waste are some of environmental advantages associated with raising insects for food (Hyland et al., 2017; Campbell et al., 2020; Vinci et al., 2022). In 2021, the European Food Safety Authority (EFSA) published its positive risk assessment on an 'insect-based food' application for consumption of certain insect species and paved the way for their official approval within the EU. Under the Novel Food Regulation (European Union [EU] Reg 2015/2283), novel foods that include some specific insect species (namely *Acheta domesticus*, *Tenebrio molitor* larva, *Locusta migratoria*, and *Alphitobius diaperinus*) have been currently authorised. This critical and required step in the EU and other countries in the world, allowed the first food products containing insects to appear in the market (Lähteenmäki-Uutela et al., 2021). These products are often marketed as a more sustainable and environmentally friendly alternative to traditional animal source of proteins.

Despite the potential benefits of insects as a food or feed source with regards to their protein content and overall composition as seen in the next section, there are also some drawbacks to consider. One concern is the potential for insect-borne diseases to be transmitted to humans. Because insects are vectors for the transmission of pathogenic microorganisms (bacteria, parasites, moulds, and yeasts), it is crucial to ensure the microbiological safety of edible insects, e.g., by heat treatments, as food safety and the shelf life of a food are determined by a food's total microbial load (Garofalo et al., 2017). Arthropods can also induce allergic reactions, due to the tropomyosin (contained also in shellfish and house dust mites), arginine kinase, glyceraldehyde 3-phosphate dehydrogenase, hemocyanin-derived proteins they contain (Ayuso et al., 2002). Notably, the EFSA Scientific Committee (2015)) concluded that the consumption of the evaluated insect proteins may potentially lead to allergic reactions, especially in people with pre-existing allergies to crustaceans, dust mites and molluscs. Additionally, allergens from the feed (e.g., gluten) may end up in the insect that is consumed. With regards to the microbial risk from the production and consumption of insects as food however, EFSA found the microbial risk of edible species was comparable to that of other animal protein sources (EFSA, 2015).

In the recent years, the topic of developing novel food systems containing edible insects, or their protein, has grown in scientific interest while legislation continues to evolve to include these changes. In their literature review, Delgado and colleagues described the EU authorisation progress to date up until 2022, highlighting the risk assessment carried out by the EFSA, the different risks related to safety and the opportunities presented for consumers and businesses (Delgado et al., 2022). Although, the current review paper has also an EU focus, progress in the legislation framework up until the end of 2023 will be discussed, as well as the state-of-the-art of methodologies, and applications developed for insect proteins in aquafeed, animal feed and in insect-complementary foods including in the combination of insect proteins with other proteins in the recently published works. Another element that will be critically evaluated is the opportunities and challenges of insect farming for the commercial sector after the recent legislation developments.

## 2. Insect proteins as complementary protein

### 2.1. Animal feed

One of the major problems facing the poultry industry is a food supply that will contain all the dietary components needed for rapid growth within a short period of time (Oyegoke et al., 2006). Soybean meal, the major protein source, is supplied together with fish meal, which covers the amino acid (AA) deficiency associated with vegetable proteins. However, these two feed sources have problems, which make insects an increasingly attractive feed option for poultry (Makinde, 2015). Insect protein includes essential AA (lysine, methionine, and leucine) which are limited in protein vegetable origin. High protein levels (40–44%) and AA profiles are better than soymeal and are even like fish meal. In general, both free-range poultry and wild birds consume pupal, larval, and adult developmental stages of insects but in small quantities of 2–15% range. The most used insect species in animal feed are the black soldier fly, the yellow mealworm and the common housefly larvae and the possibilities to feed insect proteins to certain animal species are unlocked, thanks to the lifting of the EU 'feed ban' rules. Insect-derived proteins are now allowed for use in pig or poultry feed since the 7th of September 2021 (International Platform of Insects for Food and Feed, International Platform of Insects for Food & Feed IPIFF, 2022) however, insect-derived proteins cannot be included in ruminants diet as per EU regulation (EU Reg 2015/2283).

The wild birds and free-range poultry naturally consume insect species from the order Orthoptera. It has been observed that arginine and methionine in *Acheta domesticus* improved the feed conversion ratio in poultry feed which was later supported by multiple researchers as seen in Table 1**.** Thus, positive results have been noted when 15% of grasshopper (*Acridia cinerea*) (Wang et al., 2007) cricket *(Anabrux simplex)/ Gryllus testaceus* (Wang et al., 2005) meal has been included in the meal fed to broiler chicken.

Most of the experimental diets fed to poultry consisted of black soldier fly in Order Diptera. It has been seen that piglets feeding on conventional diets and diets supplemented with black soldier fly meal resulted in non-significant effect on blood profile as well as gut and histological profile (Biasato et al., 2019). In addition, a similar result of no changes on gut and blood profile was observed when rabbits were fed with black soldier fly fat and yellow mealworm oil (Gasco et al., 2019). Moreover, it has been observed that when pigs consumed 4–8% full fat black soldier fly pre-pupae meal along with their conventional meals resulted in their increased mucosal immune homeostasis by alternating bacterial count and their metabolites (Yu et al., 2019).

Similarly for ruminants such as goats, black soldier fly and its by-products such as frass is mostly used in insect meal as a substitute for fattening rations, milk replacers and creep feeds. These are prominently used for meeting the requirements of lauric acid and lactic acid bacteria as former serves the function of the anti-bacterial effect while latter is used as a substitute for antibiotic growth promoter (Astuti & Wiryawan, 2022). Positive results have been seen while using insects as whole for feeding goats however, utilisation of insect frass for the same cause limited digestion of organic matter, dry matter, total digestible nutrients, and nitrogen free extract (Astuti & Wiryawan, 2022; Renna et al., 2022). Officially, ruminants cannot be given an insect-based diet, according to the EU Regulation (EU Reg 2015/2283).

### 2.2. Aquafeeds

Considering the scarcity of wild fish and crustaceans, the only way to

 

**Table 1**
Insect proteins as complementary protein in the experimental diets for aqua- and animal feed.

| Insect | Inclusion (%) | % protein content in diet | References |
|---|---|---|---|
| **Supplemented with fish meal** | | | |
| Black soldier fly (*Hermetia illucens*, L.) | 33–100 | 38–39 | Belghit et al. (2019) |
| | 18.5–37.5 | 50.20–50.87 | Caimi et al. (2020)) |
| | 10–50 | 39.98–40.27 | Cardinaletti et al. (2019) |
| | 10–30 | 49.03 – 49.88 | Terova et al. (2019); Terova et al. (2019) |
| | 10–60 | - | Gaudioso et al. (2021) |
| | 14.5–29 | 18.1 | Vongvichith et al. (2020) |
| | - | 39 | Li et al. (2020) |
| | 25–75 | 4.76–5.66 | Fawole et al. (2020) |
| | - | 50–51 | Huyben et al. (2019) |
| | - | 56.01 | Fisher et al. (2020) |
| | 10–30 | 49.3–50.6 | Guerreiro et al. (2020) |
| | 20 | 46.1–55.4 | Basto et al. (2020) |
| House cricket *(Acheta domesticus)* | 15 | 47.18 | Estévez et al. (2022) |
| Yellow Mealworm (*Tenebrio molitor*) | 50 | 41–54 | Antonopoulou et al. (2019) |
| | 20 | 56.3–68.9 | Basto et al. (2020) |
| | 5–20 | 43.07–44.25 | Chemello et al. (2020) |
| | 5–25 | 48.5 | Rema et al. (2019) |
| | - | 30.95–34.13 | Tubin et al. (2020) |
| | - | 47 | Hoffmann et al. (2020) |
| *Locusta migratoria* meal | 20 | 24.2 | Basto et al. (2020) |
| Black soldier fly (*Hermetia illucens*, L.) and yellow mealworm (*Tenebrio molitor*) | 18 | 43–44 | Melenchón et al. (2022) |
| | - | 16.3 | Gasco et al. (2019) |
| *Nauphoeta cinerea* meal, *Zophobas morio* larvae meal, *Gromphadorhina portentosa* meal. (NOT APPROVED FOR ANIMAL FEED) | 10 | 31.30–36.29 | Fontes et al. (2019) |
| *Gryllus assimilis* meal *Tenebrio molitor* larvae meal | 10 | 31.30–36.29 | Fontes et al. (2019) |
| **Supplemented with animal feed** | | | |
| Black soldier fly (*Hermetia illucens*, L.) | - | - | Biasato et al. (2019) |
| | 3–9 | 20.1–24.8 | Gariglio et al. (2019) |
| | 7.3–14.6 | | Moniello et al. (2019) |
| | 10–15 | 19.5–20 | Dalle Zotte et al. (2019) |
| | 10 | 80.6–87.0 | Cullere et al. (2019) |
| | 25–100 | 18.5–19.2 | Mbhele et al. (2019) |
| | 11–55 | 43.90 | Onsongo et al. (2018) |
| | 4–8 | 14.53 | Yu et al. (2019) |
| | - | 27.2 | Sypniewski et al. (2020) |

meet the growing demand for animal protein is aquaculture. Aquaculture depends mostly on the steady supply of the fishmeal along with the soyabean and meat meal. Fishmeal is the major constituent in the fish feeds commercially contributing to 60–70% of total aquaculture production cost (Daniel, 2018).

To ensure sustainable and profitable aquaculture production, alternative protein sources such as plant-based components (soybean, cereal or oil seeds) and insect proteins are gaining popularity. Due to the presence of anti-nutritional factors and incompatible fatty acid and amino acid profiles, plant based alternative protein sources are not suitable for aquaculture despite having similar protein content as fish meal (Daniel, 2018). Moreover, plant-based protein sources have higher requirements in terms of land, energy, water, and feed than compared to plant based alternative protein sources. Therefore, insect meals are a more suitable alternative for aquaculture and in some cases with compatible chemical composition (e.g., diptera protein has a similar amino acid profile to that of fish meal). The crude lipid in insects ranges from 8.5% to 36% while their fatty acid profile depends on their developmental stage and the substrates as a source of nutrients (Barraso et al., 2014; Henry et al., 2015). Insects have extremely small amounts of docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA), and omega-3 compared to fish meal however, this can be altered by using substrates while insect breeding or feeding with fish offal (Henry et al., 2015). Although there are less than 20% of carbohydrates in insects in the form of chitin, which is quite indigestible to fish, recent studies showed that chitin acts as an immune-stimulatory. Chitin, a polysaccharide in the exoskeleton of insects, has shown potential as an antimicrobial and for boosting immune system functioning, making it a promising alternative to antibiotics (Food and Agriculture Organization FAO, 2017). In recent years, studies (Table 1) have been carried out to analyse the effect of either partially including insect meals in the fishmeal or entirely replacing the fishmeal with insect meal on the nutritional value, culture methods or large-scale farming of fishes.

For instance, Karapanagiotidis et al. (2023) investigated the effect of both full fat and defatted *H. illucens* prepupae meal on feed intake, growth and nutrient content of Gilthead seabream. The outcomes exhibited that both the feed intake and the fat content in the feed are crucial for substituting fishmeal with *H. illucens* prepupae meal for Gilthead seabream. The authors concluded that Gilthead seabream resulted in higher acceptance of defatted *H. illucens* prepupae meal than that of full type prepupae meal. Moreover, the defatted prepupae meal would be more suitable to substitute fishmeal for Gilthead seabream in terms of highest growth, highest feed consumption, and unaltered nutrient composition.

### 2.3. Human food

As seen in Table 2, the most common insect species are silkworm pupae (*Bombyx mori)*, crickets (*Acheta domesticus*), mealworm (*Tenebrio molitor*) and locust (*Locusta migratoria)* that has been included as one of the ingredients in producing food such as bread, muffins, pasta and extruded snacks for feeding around 2 billion people worldwide (González et al., 2019; Zielińska et al., 2021; Ali & Ali, 2022).

The consumption of insects as food for humans are much less explored compared to that for animals and fish. The major reasons of limited use of insects in human food are less acceptance by the human population especially in Western regions and another reason is allergens present in insects. Though any food such as shellfish, peanuts or milk can cause severe allergic reactions in susceptible individuals however, being insects as new source of food results bit of nervousness among human population. The primary compounds in insects leading to allergenic reactions in certain human population are glycoprotein nature of hyaluronidase and phospholipase A. However, the severity of insect-based allergy can be reduced using food processing techniques such as hydrolysis and fermentation, which are yet to be explored (Castro et al., 2018). The whole insects are dried and grinded and used in the food

**Table 2**
Inclusion of insect proteins as complementary ingredient in value-added products for human consumption.

| S. No | Insects (% inclusion) | Supplement | Protein diet content (%) | Sensory analysis | References |
|---|---|---|---|---|---|
| 1 | *Acheta domesticus, Bombyx mori, Brachytrupes portentosus, Gryllus assimilis, Gryllus bimaculatus, Locusta migratoria* | Wheat flour | 5–50 | Not studied | Benes et al. (2022) |
| 2 | *Acheta domesticus* (house cricket) | Sourdough fermented with *Lactobacillus plantarum* strain | 72.60 | Not studied | Vasilica et al. (2022) |
| 3 | *Tenebrio molitor* and crickets *Gryllodes sigillatus* (2–10%) | Muffins | 11.18–14.25 | Yes (taste, overall acceptability) | Zielińska et al. (2021) |
| 4 | Mealworm *Tenebrio molitor*/buffalo worm *Alphitobius diaperinus*/ cricket *Acheta domesticus* (10%) | Wheat bread | 16–27 | Yes (taste, texture, appearance) | Kowalski et al. (2022) |
| 5 | *Alphitobius diaperinus* (7.5%) | Pea (3.7%) and hemp (3.75%) protein for sponge cakes | 7–10 | Yes (characteristic odour, uncharacteristic odour and taste, inner colour, elasticity, crumby, hardness, adhesiveness, chewiness, sweetness) | Talens et al. (2022) |
| 6 | *Alphitobius diaperinus* and *Tenebrio molitor* (5–10%) | Wheat flour bread | - | Not studied | Igual et al. (2021) |
| 7 | *Tenebrio molitor* (10–15%) | Cornmeal-, corn gluten meal-, and soybean meal-based diets | - | Not studied | Biasato et al. (2019) |
| 8 | Cricket *(Gryllusbimaculatus)*(5–10%) | Millet flour for pasta | | Yes (taste, odour, appearance,consistency, and cooking properties) | Jakab et al. (2020) |

products in the form of insect powders. This dried and powdered insect, or insect powders are texturally like plant derived powders such as grain flours (Brogan et al., 2021) resulting in the term insect flour. Spray-drying is another technique to obtain insect powder, and specifically, the one produced from crickets shows both nutritional and antioxidant activities and no toxic effect on cellular viability and pro-inflammatory activity were detected (Ruggeri et al., 2023). The effects of insect meal on the quality attributes of the protein rich muffins by replacing wheat flour with 15% of *Locusta migratoria* and *Tenebrio molitor* insect meal to make muffins. Muffins having *L. migratoria* yielded 12.91% protein content while those with *T. molitor* yielded in 36.56% fat content. The study concluded that muffins with mealworm had higher acceptability score than that with grasshopper. Moreover, muffins fortified with insect meal exhibited less dense structures along with the lower specific volume than the standard muffins resulting to be effective ingredient in enhancing the nutritional content of the bakery products (Çabuk, 2021).

## 3. Barriers and opportunities

### 3.1. Contributions to sustainability

Insects farming has been reported as more sustainable compared to conventional meat livestock. The results obtained in a recent study showed that the value chain for producing a protein from mealworm is less impactful on the ecosystem, in terms of nitrogen produced, the potential for soil acidification, and on global warming, than producing an equal amount of protein from pork. In addition, it uses lower mineral and fossil resources, which makes the insect production system suitable also in poor realities where protein demand is growing (Vinci at al., 2022). Insects are a potential protein source which could contribute to freeing up land to grow crops for direct consumption by the human populace and lead to a concomitant increase in food security. Insect production reduces significantly the land needed for protein production comparing the hectares for the same quantity of protein from pigs, chickens, and cattle livestock (Raheem et al., 2019), contributing, together with vertical farming practices, to fighting biodiversity losses (IPIFF, 2022). In addition, it implements sustainable practices in agriculture, since it doesn't require pesticides, antibiotics, or growth hormones (IPIFF, 2022) and it contributes to a real circular food system. Table 3 shows the feed stocks for insect production and target animal species according to IPIFF (2022). The cross marks indicates that specific feedstocks are not permitted to be used as a substrate during the insect production (i.e., former foodstuffs, catering waste). Moreover, the dried or frozen whole insects (not milled) are not allowed to be included in the diet of fish, poultry and pig. Derler et al. (2021) provided an overview on by-products, which have already been fed to *Tenebrio molitor* and suitable for its farming and Kuan et al. (2022) discussed the applicability of *Hermetia illucens* and *Zophobas morio* in food and plastics. Local insect farming can reduce the dependence on expensive and imported feed, particularly important for small-scale livestock farmers (Chia et al., 2019) and on externally derived fertilizers (Beesigamukama et al., 2022). Considering all these aspects, edible insect farming and consumption could have an important role in food security and to promote

**Table 3**
General acceptance of feed stocks for insect production and target animal species (adapted from IPIF, 2022).

| Feed stocks | | Target species | | | | |
|---|---|---|---|---|---|---|
| ✓ | Vegetal substrates | | Protein | Fat | Live* | Whole insects (dried or frozen, not milled) |
| ✓ | Former foodstuffs: vegetal, eggs and dairy | Companion animals | ✓ | ✓ | ✓ | ✓ |
| ✗ | Former foodstuffs: meat and fish | Fish | ✓ | ✓ | ✓ | ✗ |
| ✗ | Catering waste and slaughterhouse products | Poultry | ✓ | ✓ | ✓ | ✗ |
| ✗ | Animal manure | Pig | ✓ | ✓ | ✓ | ✗ |

* permitted.

zero hunger (Bao & Song, 2022). Besides these many advantages, wider adoption is dependent of the legislation framework and consumer attitude.

### 3.2. Legal framework and implications

Firstly, legal regulations are the essential prerequisite to develop insect farming and effective marketing of edible insect-based foods. From 2015, in which the production and marketing of insects as food in Europe is regulated by Novel Food Legislation (EU Reg 2015/2283), legislation is progressing rapidly (Delgado et al., 2022). As of June of 2023, 23 applications have been submitted, covering 7 insect species, 6 applications have been authorised. 7 applications have been granted a Positive Assessment by the EFSA (Table 4).

Six edible insect products are already authorised as novel food, including four insect species: *Acheta domesticus* (house cricket), *Tenebrio molitor* larva (yellow mealworm), *Locusta migratoria* (migratory locusts), and *Alphitobius diaperinus* (lesser mealworm). Currently, other 8 novel food applications on edible insects are being assessed by the EFSA, including at least 2 additional insect species: *Hermetia illucens* larvae (black soldier fly) and *Apis mellifera* male pupae (honeybee drone brood) (IPIFF, 2022). Moreover, since September 2021, the possibilities to feed insect proteins to certain animal species are unlocked, thanks to the lifting of the EU 'feed ban' rules. EU authorises the use of insect proteins originating from the above insect species in feed for aquaculture, poultry, and swine animals.

However, despite the progress, there still are some gaps in regulation associated with policy making, legislative solutions, standardization and certification of mass-produced edible insects, including interdisciplinary regulations that address the production of edible insects integrating food sciences, agriculture, animal production, conventional medicine, forestry, and socioeconomic and environmental sciences; microbiological concerns and management of insect diseases; genetic modifications for specific traits; safety of insect-based foods in case of products derived from insects that are fed with organic waste; functionality and shelf life of insect-based foods; health benefits for consumers, including the digestibility, toxicity, allergenicity of insect-based products; long-term impact of insect protein consumption on human and animal health; introduction of universal standards and certification requirements for edible insect farming and industrial production; and logistics operation. (Żuk-Gołaszewska et al., 2022).

### 3.3. Consumer behaviour and attitude

Behavioural interventions and tools are necessary to change the consumer perspective and to promote entomophagy in Western countries (Bao & Song, 2022). A case study conducted last year in Finland, through a consumer survey and expert interviews, recognizes four pathways to increasing the use of edible insects in countries without tradition of entomophagy: i) producing a variety of insect-based food products, especially processed food in a familiar form in which insect are not recognized as such; ii) producing edible insect food products remaking the possibility to replace greenhouse gas emission-intensive animal proteins; iii) focusing on the price, taste, and availability of insect-based food products; and iv) using insects in animal feed. They suggest that technological progress is expected to decrease the price of insect-based foods, but at the same time, the increased use of edible insects faces challenges related to eating habits, contradictory perceptions about the sustainability implications of insect farming, and the availability of insect-based products (Halonen et al., 2022). Moreover, the acceptance of edible insects depends on some positive motivators, including not only concerns about sustainability, but also desire to try new foods and curiosity (Florença et al., 2022). Processing edible insects increases consumer acceptance as are already used in the production of

**Table 4**
Insect species and the various forms approved by the European Commission under the Regulation (EU) No. 2015/2283) for animal and food production.

| Insect species | EFSA's Risk Assessment | EC Decision/ Approval | Human food *Approved forms* | Animal feed *Poultry, Aquaculture and Swine Production* |
|---|---|---|---|---|
| *Tenebrio molitor* larva | Positive opinion published on 13th of January 2021 (dried);Positive opinion published on the 25th of August 2021andPositive opinion published on 1st of June 2023 (UV-treated powder) | EC Implementing Regulation authorising its commercialisation entered into force on the 22nd of June 2021 (dried);EC Implementing Regulation entered into force on the 1st of March 2022andRegulation No 2001/999 (Annex IV) amended by the Regulation 2017/893 (Annex II) for feed | frozen, dried and powder | Hydrolysed proteins, proteins, live insects and insect fats |
| *Locusta migratoria* | Positive opinion published on the 2nd of July 2021 | EC Implementing Regulation entered into force on the 3rd of December 2021 | frozen, dried and powder | Hydrolysed proteins, proteins, live insects and insect fats |
| *Acheta domesticus* | Positive opinion published on the 17th of August 2021 (dried, ground, and frozen)and 13th of May 2022 (partially defatted powder) | EC Implementing Regulation entered into force on the 24th of January 2023 (dried, ground, and frozen) and24th of January 2023 (partially defatted powder) andRegulation No 2001/999 (Annex IV) amended by the Regulation 2017/893 for feed | frozen, dried, full fat powder and partially defatted powder | Hydrolysed proteins, proteins, live insects and insect fats |
| *Alphitobius diaperinus* larva | Positive opinion published on the 4th of July 2022 | EU Implementing Regulation entered into force on the 26th of January 2023andRegulation No 2001/999 (Annex IV) amended by the Regulation 2017/893 (Annex X) for feed | frozen, paste, dried and powder | Hydrolysed proteins, proteins, live insects and insect fats. |
| Musca domestica | N/A | Regulation No 2001/999 (Annex IV) amended by the Regulation 2017/893 (Annex X) for feed | Not approved | Hydrolysed proteins, proteins, live insects and insect fats |
| Hermetia illucens | Application terminated on 12th of September 2022 (refined fat);Application terminated on 10th of March 2023 (Dried defatted powder)andOngoing Risk Assessment (meal as a novel food) | | Not approved | Hydrolysed proteins, proteins, live insects and insect fats |
| Gryllodes sigillatus | Withdrawn on 22th of April 2022 | Regulation No 2001/999 (Annex IV) amended by the Regulation 2017/893 (Annex X) for feed | Not approved | Hydrolysed proteins, proteins, live insects and insect fats |
| Gryllus assimilis | N/A | Regulation No 2001/999 (Annex IV) amended by the Regulation 2017/893 (Annex X) for feed | Not approved | Hydrolysed proteins, proteins, live insects and insect fats |
| Bombyx mori | N/A | Authorisation of the use of processed animal proteins (PAPs) in aquaculture, poultry and pig feed | Not approved | Processed proteins |

various types of bread, pasta, chips, protein bars and other products in the rapidly growing insect industry (Jeong & Park, 2020).

Finally, flavour is directly correlated to the potentially acceptability of insect-based food products, that is nowadays under investigation, e.g., with the study of volatile compounds, that directly influence the aroma (Żołnierczyk & Szumny, 2021). Some processing techniques, such as defatting, or fermentation could be also useful to remove or reduce unpleasant odours specific for some insects (Perez-Santaescolastica et al., 2022).

### 3.4. Opportunities and challenges of the insect farming for Small and Medium-sized Enterprises

Novel food authorisation is the first step needed for an agricultural and food manufacturer willing to enter the sector to place a new product on the market. It is important to consider that presenting a scientific dossier to European Commission is not an easy task, particularly for a Small and Medium-sized Enterprise (SME). Research and Development (R&D) expenses represent a real challenge from the very beginning. Investors, even if focused on pre-seed start-ups, are usually looking for traction, which cannot be robust until the sector start growing, and more products become available on the market. However, this phenomenon is an oxymoron, since, currently, the volumes of insect foods available are still low, and the costs of those novel food are relatively high. For this reason, more product availability on the market and product technological innovation, boosted by novel food procedure, will help segmentation, lower costs, and product differentiation.

In farm-to-fork value chains of an SME insect farm, sustainability can have a significant role in the rearing activities, although, a complete Life Cycle Analysis of the entire process is one of the main challenges and objective for the sector (FAO, 2021). As rearing and transforming insects, as most of the food technological processes, are energy intensive. Green and renewable sources, together with circular economy activities, have a key role to determine genuine sustainable claims for the entire production chain (United Nations, 2015). Business model of a company aiming to sell insect-based Novel Food cannot exclude any channel, even if online sales seem to be the more common entry point. Having enough volumes and financial resources to enter large retailers might take some time, but it will represent the most effective segment growth. Honest and complete communication on the label should be essential for all the producers, to allow consumer informed and aware choice: insects must be clearly highlighted on labels, and no confusion between 'normal' food and 'insect based' novel food need to be in place (Pölling et al., 2017).

Novel Food Regulation allows, case by case, different percentages of use of the Novel Food in different food categories. It is possible to indicate the presence of insects within a food product through insect-related nutritional claims on the label. The higher the percentage of authorised novel food, the easier it is for the consumer to associate the nutritional beneficial properties of the food to the presence of the insect-based ingredient. Normally, there is a very low amount of insects in the ingredient list, this does not imply any relevant impact on the nutritional profile, but it just allows to report the claim on the label.

A company entering the sector needs to consider the proper preparation of the product launch with an appropriate stakeholder management approach and a consumer centric business model. Part of the political reluctance towards this niche sector might be overcame if local authorities recognise that new insect farms not as competitors for traditional farmers and local production. In fact, insect farming might economically help traditional farmers adding extra revenues to their models, might encourage innovation and new products in local agri-food industry, might build national expertise in processing and cooking this new ingredient. Insect based novel food should not be positioned as a mere alternative to other traditional meat sources, but they can gain broader consensus, if positioned as they are an innovative alternative food to increase variety in a balanced and healthy diet (Bessa et al., 2018; Cajas-Lopez & Ordoñez-Araque, 2022).

## 4. Conclusions

There is no denying that there is a global protein gap caused by the continuous population rise, the global food crisis, and the rising demand for high-quality alternative protein. This should motivate and support the growth of the edible insect market. It is evident that a variety of animal and fish feed are currently being reformed with some inclusion of insect protein. Under a continuously evolving legal framework, farmers and consumers shows positive attitude, mostly motivated by the increased awareness of sustainability implications and benefits. Despite this, there are still few limitations, regarding the adoption of insects in certain animal feeds, primarily for safety reasons, such as ruminants, and the acceptance in human food in countries without entomophagy tradition, mainly related to perception of those.

In this trajectory, the roles of the public sector, scientific community, local authorities, and legislative bodies are extremely important. Our review indicated that governments should focus on well-structured communication campaigns with an aim to inform and educate consumers on the benefits of entomophagy, avoiding misleading information and not science-based communication. Education and marketing campaigns should also target farmers to promote the awareness that edible insects offer extra revenue models in addition or as an alternative to conventional livestock rearing.

On the legislative aspect, more Novel Food Authorisations will favour market growth in the EU. Food process innovation will boost higher volumes and product segmentation. Entry barriers are still high and new investments in the seed and pre-seed SMEs are crucial to increase number of companies entering the sector. Stakeholder management and engagement can help operators spreading the scientific evidence behind insect foods safety and beneficial effects.

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There are no conflicts of interests.

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