Sustainable food systems: EU regulatory framework and contribution of insects to the Farm-to-Fork strategy

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Abstract

The European Green Deal is a set of policy initiatives of the EU that aim to make Europe the first climate-neutral continent by 2050. Within this Deal, the ‘Farm-to-Fork’ strategy aims to accelerate the transition to a sustainable food system and to make food systems fair, healthy and environmentally-friendly. Insects contribute to the circularity of agriculture, and are ideal candidates to complement traditional sources of protein. The placement of insects on the EU food market needs to be authorized by the Commission following a risk assessment. To date, three insect species have been approved for their commercialization, while the use of insect proteins in feed is strictly regulated. Insect farming is an expanding industry in Europe, and more consumers are willing to try insect-based foods. To consolidate the insect market, it is also very important to assure the safety of eating insects. The European Food Safety Authority is the body in charge of assessing the microbiological and chemical risks related to the production and consumption of insects as food. Aside from the risks posed by contaminants or pathogens, insects consumed as food may be a threat for certain allergic consumers, who might develop an adverse reaction mainly due to a cross-reactivity to crustaceans and/or house dust mites.

In this review paper the European insects market is analysed, putting a special emphasis on the regulatory aspects and on the safety assessment. Moreover, an updated overview on the consumer acceptance is presented. Overall, the entry of insects into the EU market represents a great opportunity for the economic and ecological growth of the Community, however consumers need to be exhaustively informed and protected from the hazards that these novel products might cause.

Keywords: Novel Foods, European Legal Framework, Consumer Acceptance, Food Allergy
1 **Abbreviations**

2 EC: European Commission

3 EFSA: European Food Safety Authority

4 EU: European Union

5 FAO: Food and Agriculture Organization

6 GMO: Genetically Modified Organisms

7 IPIFF: International Platform of Insects for Food and Feed

8 NDA: Nutrition, Novel Foods and Food Allergens

9 PAP: processed animal protein

10 PUFA: polyunsaturated fatty acids

11 SDGs: sustainable development goals

12 SMEs: small and medium enterprises
1. Green Deal: Farm to Fork strategy

In 2019, the European Commission (EC) adopted the so-called “European Green Deal” (https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en), which provides the frame to make the European Union (EU), as part of Europe, the first climate-neutral continent by 2050. Its goal is a new, sustainable and inclusive growth strategy to boost the economy, improve people’s health and life quality, caring for the environment, but at the same time not leaving European citizens behind (Communication from the Commission, 2020). As part of the “Green Deal”, the Farm to Fork Strategy of the EU addresses as far as possible the challenges of a sustainable food system and will link healthy people, healthy societies and a healthy planet. It will also contribute to the Commission’s aims to achieve the United Nations’ Sustainable Development Goals (SDGs).

According to the United Nations’ SDGs, a shift towards a sustainable food system will provide environmental, health and social benefits as well as economic gains. The EU’s goals comprise three main aspects: i) ensuring that the food chain, including food production, transport, distribution, marketing and consumption has, at least, a neutral or even positive environmental impact. This should help to mitigate climate change and adapting to its impacts; ii) assuring food security, nutrition and public health – allowing everyone to have access to sufficient and nutritious food with higher standards of safety and quality; and iii) maintaining the affordability of food, while generating fairer economic revenues in the supply chain and promoting the competitiveness of the EU supply sector.

Alternative solutions to conventional sources for protein as food and for livestock need to be identified. According to the Food and Agriculture Organization (FAO), insects will become increasingly relevant as food and feed in this century due to the increasing cost of protein of animal origin, food insecurity, environmental pollution, earth population growth and growing demand for protein for food but also for feed purposes.

The EU’s Green Deal will affect feed for livestock in particular quite substantially. Feed derived from plant origin will be limited in the future due to competing interest with food production, reduced land availability and biofuel production. Insects and isolated proteins thereof represent one out of several
possibilities to overcome the shortage. In a report, FAO indicates that insects are a “highly nutritious and healthy food source with high fat, protein, vitamin, fibre and mineral content” (FAO 2013). Likewise, insects are preferred over large land animals because their farming consumes less land and water, and – depending on the feed source - their greenhouse emissions are remarkably lower (Garino, Zagon et al. 2019). Therefore, they constitute a suitable alternative source of proteins, enabling the shift towards healthier and more sustainable diets. While insect-based foods represent so far a niche product only, in the feed sector insects and their products are considered a valid alternative to the increasingly expensive fish meal and soy, particularly in aquaculture. The Farm to Fork strategy also highlights the role that insects could play in reducing food waste and in developing a “circular” economic system in the EU, more resilient and sustainable than current linear food production systems are (IPIFF 2020a).

2. The regulatory framework for insects as feed and food in the EU

The use of insects as food and feed in EU is regulated by a series of horizontal (non-specific) legislative requirements (Table 1). Insect producers must conform to EU environmental legislation in case they want to produce or import insects into the EU. Notably, in accordance with Regulation (EU) 1143/2014, “insect species and products shall not be protected or defined as an invasive alien species. Furthermore, the commercial use of certain exotic or endemic species may fall under the restrictions of the Nagoya Protocol, aiming to protect the biodiversity and ensuring adequate sharing of benefits if profiting from genetic resources from abroad (Regulation (EU) No. 511/2014). Depending on whether the end use of insects or their derived products is human or animal consumption, they are subject to different legislation

2.1 Legal framework for insects as feeds

known as ‘Feed ban’ or ‘TSE-Regulation’), opened the use of processed animal protein (PAP) derived from only seven insect species (*Acheta domesticus, Alphitobius diaperinus, Gryllus assimilis, Gryllodes sigillatus, Hermetia illucens, Musca domestica* and *Tenebrio molitor*) as feed for animals in aquaculture. Prions have been an important food safety concern in the last decades, however prion codifying genes have not been detected in insects, making them naturally prion free (Thackray, Muhammad et al. 2012). In 2021, in a second step, the authorization for insect PAP as feed was expanded to pig and poultry (Commission Regulation (EU) No. 2021/1372). In addition, PAP from silkworm (*Bombyx mori*) was added to the list of allowed insect species as feed for those animals. This seems consistent since *B. mori* exclusively feeds on mulberry leaves. The former seven authorized insects may have been listed because of their big commercial potential in Europe, as outlined in a risk assessment on feed and food insects of the European Food Safety Authority (EFSA 2021a). According to EFSA, additional releases seem to be probable in the future. Several provisions are binding for insect PAPs production. First, they have to be produced in approved processing plants exclusively dedicated to the production of insect PAP or under avoidance of cross contamination in case of derogation, which has to be authorized (Regulation (EC) No. 999/2001). Secondly, only materials belonging to category 3 according to Regulation (EC) No. 1069/2009 (fit for human consumption) shall be fed to farmed animals, which includes farmed insects, and the processing conditions at least must ensure efficient reduction of pathogenic bacteria (Regulation (EC) No. 1069/2009 and implementing Commission Regulation (EU) No. 142/2011). The restriction to category 3 materials clearly excludes rearing insects on organic side-streams like e.g. manure or digestive tract content (also stated in Regulation (EC) No. 767/2009 on the placing on the market and use of feed). Further feeding catering waste to farmed animals, with exemption to fur animals is forbidden (Regulation (EC) No. 1069/2009), whereas ‘former foodstuffs’, like unsold bakery products are allowed for feeding purposes as long as they are not consisting of or containing meat or fish. Insect PAP itself is ranked as an animal-by product of category 3 if serving as feeding stuff for other farmed animals. Irrespective of the overarching prohibitions given by the ‘TSE’-
Regulation and related regulations, any feed used in insect production must meet the same high-quality standards in terms of e.g. additives, contaminants and hygiene as required for any farmed vertebrates (Regulation (EC) No. 183/2005). Directive 2002/32/EC about undesirable substances in animal feed, highlights that harmful substances or contaminants might not overpass the maximum limits, while Regulation (EC) No. 1831/2003 on additives in animal nutrition specifies that only generic feed additives (i.e. their approval is not tailored to specific animal species) can be utilised as feed for insects. Furthermore, Commission Regulation (EU) No. 68/2013 provides a catalogue of feed materials with precise descriptions of single feed components. The voluntary use of this catalogue aims to support feed producers in their good manufacturing practice, fostering proper declaration. Interestingly, insect meals processed according to the animal-by-products rules (Regulation (EC) No. 1069/2009) are excluded, but materials from terrestrial invertebrates, alive or dead, whether technically treated or not, are part of the list (Commission Regulation (EU) No. 68/2013). In this context it has to be stressed, that only processed insect material shall be fed to aquaculture, pigs or poultry, but no living insects, as they are not regulated at EU level. Environmental uptake of living insects, e.g. by hens from organic free-range breeding, is tolerated due to natural behaviour and not covered by feed legislation. Last but not least, any new placing of the market of a feed material that is not listed in the European catalogue shall immediately be notified to the EC (Regulation (EC) 767/2009). For this purpose, a public register has been established (https://feedmaterialsregister.eu/), which notably already contains several entries for insects. Finally, insects are allowed as feed for pets (e.g., cats, dogs, birds or reptiles) and fur animals (e.g., mink).  

2.2 Legal framework for insects as food

Dedicated European-wide harmonized legislation on insects as food has been established in 2015 only with Regulation (EU) No. 2015/2283 replacing the former Novel Food Regulation (EC) No. 258/97 from 1997.
Since 1997, insects were, in general, considered to fall under the category (e) “consisting of or isolated from plants and food ingredients isolated from animals, except for foods and food ingredients obtained by traditional propagating or breeding practices and having a history of safe use” of the Novel Food Regulation. This was due to the fact that insects had not been used as food to a significant extent in the EU before 15th of May 1997, corresponding to the date the Regulation came into force. However, whole insects were not mentioned explicitly in this Regulation. Due to a request from the highest French administrative court, the Conseil d’État, in 2020 the European Court of Justice (EJC) ruled (ECJ, 2020) that whole insects did not fall under the above-mentioned category of the previous Novel Foods Regulation (EC) No 258/97.

This regulatory uncertainty on insects as novel foods resulted in heterogeneous legal interpretation and individual policies established in various European member states. Some member states, such as the Netherlands, Belgium, Austria and United Kingdom, considered whole insects not falling under the Novel Food Regulation, and consequently no specific restrictions were in place for rearing insects in these countries. Other countries, such as Italy, France, Ireland and Poland, did not permit instead in most cases the rearing of insects and the production of foods containing or consisting of insects, thus introducing a more restrictive policy on insects for human consumption (Lähteenmäki-Uutela, Marimuthu et al. 2021, Mancini, Sogari et al. 2022).

In order to harmonize the highly fragmented situation in the EU internal market and to equip it with competitive business operators to support the growth of the insect market from its early stages, the updated Novel Food Regulation No. 2015/2283 was adopted and came into force on 1st of January 2018. Insects are explicitly mentioned in the Considerandum number 8 of the Regulation (“the categories of food which constitute novel foods […] should cover whole insects and their parts”), and also the text in article 3 clearly indicates that insects fall under its scope: “food consisting of, isolated from or produced from animals or their parts, except for animals obtained by traditional breeding practices which have been used for food production within the Union before 15 May 1997 and the food from those animals has a history of safe food use within the Union”.

According to the new Novel Food Regulation, there are two possible pathways in place for the authorisation of edible insects: (a) a simplified notification procedure as “traditional food” to the EC, or (b) the general application procedure, more time consuming due to the need for a safety assessment by the European Food Safety Authority (EFSA, Parma, Italy). For the simplified procedure, applicants just need to demonstrate that the edible insect or parts thereof were “traditional” in a non-EU country and that it has a “history of safe use”, accompanied by data about composition and evidence of the continued use for at least 25 years in diets of a substantial number of consumers. However, this is only applicable in case the traditional way of processing will be commercialized; as soon as new steps or ways of servings are planned, the “traditional” pathway is blocked and a general application as novel food needs to be submitted. In case an authorisation is given, the generic use of that insect species is allowed in the EU without any individual protection for a single applicant. However, the general authorisation procedure includes the possibility for the authorisation holder to exclusively protect its specific insect product for at least five years. Commission Implementing Regulation (EU) No. 2017/2470 contains the list of insects authorized in EU as novel foods.

Apart from the Novel Foods Regulation, the most important pieces of Regulation affecting operators dealing with insects as food in the EU are the general food law (Regulation (EC) No. 178/2002) and the two food hygiene Regulations (Regulations (EC) No. 852/2004 and 853/2004). They apply to all insect producers who farm, process, handle or distribute insects for food or feed, enforcing them to register with and notify national competent authorities, comply with specific hygiene requirements and follow HACCP principles when implementing and maintaining their procedures.

3. Labelling and Controls

Insects authorised under the novel food regulation must follow the general labelling requirements established in Regulation (EU) No. 1169/2011. According to this regulation ‘labelling means any words, particulars, trademarks, brand name, pictorial matter or symbol relating to a food and placed
on any packaging, document, notice, label, ring or collar accompanying or referring to such food’.

The specific name of the insect, as well as its quantity within the food and, where pertinent, the conditions of use, must be indicated in the label. Regarding the risk of allergic reactions, Annex II of the 1169/2011 Regulation reports the list of the substances or products able to cause allergies or intolerances that are mandatorily indicated in the label. The list was last updated in 2013 and insects are not included so far. However, article 4 states that information on compositional ingredients that can be harmful to the health of particular groups of consumers are mandatory. In accordance to this principle, additional specific labelling requirements are included in the Commission Implementing Regulations (EU) No. 2021/882 and 2021/1975 for authorisation of the dried *T. molitor* larva and of the frozen, dried and powder forms of *Locusta migratoria*, respectively: all the foodstuffs shall include a statement that this particular ingredient might cause allergic reactions to consumers with identified allergies to crustaceans and similar products, and to dust mites. This statement shall be printed very close to the list of ingredients. It is foreseen that a very similar statement will also appear on the label of all the insect food products authorised in the near future.

The rules of the EU official controls are important for the governance of the European agri-food chain, defining the correct application of the laws across national borders. The import for insects as food from third countries depends on two sets of legislations, namely the Novel Food Regulation (EU) No. 2015/2283, for the authorisation of the insects as a novel food on the EU market, and a ‘package’ of EU Regulations setting out the conditions of import for animals and goods for human consumption. Both sets apply in parallel but that are independent of each other (IPIFF 2020c). The package of laws on import conditions directly affecting insects as food is formed by:

- Official Controls Regulation (EU) No. 2017/625: it addresses official controls and other official actions carried out to assure the application of the law regarding food and feed, regulations on animal health and welfare, plant health and protection. According to this regulation, Competent Authorities are in charge of performing official controls on all operators through all the stages of production, processing, distribution and use of animals,
goods, substances, materials or objects governed by agri-food chain rules. Animals, products
of animal origin, plants and other products and goods must be checked at borders before they
enter the EU. Moreover, guidelines for the designation of the laboratories performing
analyses, tests or diagnoses for official controls and the conditions to be designated are set
out. All official control laboratories must be accredited to EN ISO/IEC 17025.

- Commission Delegated Regulation (EU) No. 2019/625: defines the requirements for the entry
into EU market of animals as food and contains the only available definition of insects as food
in a legal document: insects are “food consisting of, isolated from or produced from insects
or their parts including any life stadia of insects intended for human consumption which are,
when applicable, authorised in accordance with Regulation (EU) 2015/2283”. When
importing insects as food there are some specific EU requirements, as well as hygiene
standards, to comply with. Moreover, the establishment producing the foods containing
insects must fulfil these requirements, and an official certificate must accompany each
consignment of animals and goods.

certificate model for the entry of insects proposed for human consumption into the European
Union.

- Commission Implementing Regulation (EU) No. 2021/405: in Annex XV of this Regulation,
the list of third countries authorised for the entry into the European Union of insects proposed
for human consumption is laid down. Currently the shortlist is formed by Canada,
Switzerland, South Korea, Thailand, and Vietnam and, since 31st of August 2021, UK
(excluding Northern Ireland). The regulation, applicable from 21st of April 2021, implies that
all the EU Member States applying the ‘transitional measure’, and hence allowing imports of
insects as food from third countries, will have to stop importing from countries not included
in the above-mentioned list. It is however foreseen by the EC to increase the number of
countries, provided that they make available sufficient data and information about the activities related to the insect production.

- Commission Implementing Regulation (EU) No. 2021/632: according to this regulation live insects are included into the list of “animals, products of animal origin, germinal products, animal by-products and derived products, composite products, and hay and straw that are subject to official controls at border control posts in accordance with Official Controls Regulation”.

4. Application as feed

The use of insects for feed purposes is a promising perspective in terms of replacing valuable protein and lipid sources of limited availability such as fishmeal or oil crops competing with food production. Furthermore, most consumers willingly accept feeding livestock on insects (Minh 2021), especially if the animals are naturally insectivorous like fish or poultry. Several aspects affect the possible use of insect PAP as animal feed. First, the nutritional value (e.g., amino and fatty acids composition, vitamins and trace elements) must be suitable for the needs of the respective species, since it triggers growth rate, animal health, fertility and survival. Anti-nutritional compounds on the other hand should be restricted to a minimum. Secondly, factors like palatability and digestibility, but also the mostly overlooked acceptance by the animals, are of importance.

Last but not least, the organoleptic properties of the products, accounting for consumer acceptance, as well as aspects of sustainability and environmental issues including life cycle assessments, will be decisive for the future meaning of insects from farm to fork. In this sense, the following subsections present a short overview on the main fields of feed application under consideration of advantages but also pointing to bottlenecks and restrictions.

4.1 Aquaculture
Aquaculture is a steadily growing food sector on a global scale. In 2018, fish and shellfish from aquaculture already accounted for 52% of all aqua food consumed (FAO 2020). Meals and oil from fish or crustaceans have a long tradition as a valuable protein and energy source. Due to its high protein content of 60 – 70%, fishmeal became the main protein source in aquaculture in the last decade (Shepherd and Jackson 2013).

In Europe, fishmeal is authorised for aquaculture as long as the ‘cannibalism ban’ is respected. This means that marine fishmeal can be fed to freshwater fish, but, for example, no rainbow trout meal shall go back to rainbow trout (Regulation (EC) No. 1069/2009, Article 11; “intra-species ban”). The world’s catches for commonly used fishmeal species (Barlow 2003) do not keep up with the increasing demand for protein-rich aquaculture feed, and, in addition to overfishing and quota, warming up of the oceans has a measurable impact on migration and reproduction habits of cold water species. Therefore, to protect the balance of the global aquatic ecosystems, the search for alternative protein sources is an inevitable future task. Against this background, terrestrial invertebrates as fishmeal replacer are increasingly considered.

The protein content and composition, apart from lipids as energy source, is the most decisive element for considering insects for feeding purposes. In this respect, the balanced amino acid composition of insects, is one of the most favourable features of insect meals. Considering the proximate analysis of seven of the eight insect species allowed in the EU for aquaculture (A. domesticus, A. diaperinus, G. assimilis, G. sigillatus, H. illucens and M. domestica), the available literature roughly reveals a crude protein content in a range from 50 – 70%. In contrast, the fatty acid profiles and contents in polyunsaturated fatty acids (PUFA) is more variable, which might be mainly due to the highly divergent feeding materials in the different studies. Fish oil, fishmeal or plant oil are still a valuable part of aquaculture diets. Hence, to make use of insects in aquaculture, the feed quality during rearing is of utmost importance. Since only feed grade materials are authorised and not any side streams or waste from agricultural production, the choice of materials for insect farming is limited.

4.2 Poultry and pig
The need for alternative sources of protein for poultry and swine feeding is, as well, very obvious. While meat demand and, hence, meat production is increasing worldwide, soybean is the main source of protein in animal feeding. However, soy cultivation for feed is related to climate-damaging effects such as deforestation, high use of resources, emission of greenhouse gases and land competition between feed and food (Weinrich and Busch 2021).

Same as in aquaculture, insects can be a valid sustainable alternative. Among the factors to consider when using insects as a feed there is the natural feeding habits of the animal. For instance, insects are part of the natural diet of poultry. The amino acidic and the nutritious profile is also important: overall, insects have acceptable nutrition properties but some species are deficient in histidine, lysine, and tryptophan, and so they need to be incorporated into the diet (Sánchez-Muros, Barroso et al. 2014).

The most studied species for poultry and swine feed are the black soldier fly (H. illucens), the yellow mealworm (T. molitor), and the common house fly (M. domestica). Many trial studies investigating the role of insects as a feed source primarily focus on digestibility, growth performance, health and microbiological considerations, and nutrient profile and nutrient utilization (Sogari, Amato et al. 2019). In 2019, Moula and Detilleux (Moula and Detilleux 2019) analysed 174 trials on insect feed to poultry, concluding that insects should only partially substitute traditional protein sources and should not be purely grasshoppers to assure the proper growth of the chickens. Same conclusion has been reached among studies focused on pigs, where insect products seem to be a good choice to partially substitute conventional protein sources in swine diets without unfavourably affecting growth performance, health and product quality. However, more consistent research is needed to reduce differences among studies (Veldkamp and Vernooij 2021).

5. Application as Food

Insects are the largest class of the phylum Arthropoda, they have been included in the human diet since prehistoric times (Kouřimská and Adámková 2016) and people throughout the world have
consumed insects regularly for millennia, since they have been among the primary food sources for many nations (Ferri, Federico et al. 2018; Hurd, Shertukde et al. 2019; Raheem, Carrascosa et al. 2019). The earliest citing of entomophagy dates back to biblical literature. Cicadas were a delicacy in Ancient Greece, and also the consumption of beetles in Ancient Rome and of grasshoppers in Ethiopia has been reported (van Huis, J. et al. 2013).

Nowadays, several hundred millions people around the globe include insects on their diet (van Huis, Halloran et al. 2022), and around 2000 species are eaten across 113 countries (Tao and Li 2018, Elhassan, Wendin et al. 2019) predominantly in Southeast Asia and the Pacific, in the sub-Saharan Africa, and in Latin America (Hanboonsong, Jamjanya et al. 2013, Pal and Roy 2014). The three most commonly eaten groups are beetles (Coleoptera), a taxonomic group containing almost 40% of all known insect species, caterpillars (Lepidoptera) and bees, wasps and ants (Hymenoptera). Other commonly consumed insects are the members of the Orthoptera (grasshoppers, locusts and crickets), of the Hemiptera (cicadas, scale insects, leaf and plant hoppers and true bugs), of the Blattodea (termites), of the Odonata (dragonflies), of the Diptera (flies), of the Mantodea (mantids) and few more (van Huis, J. et al. 2013; Jongema 2017).

From the nutritional point of view, the consumption of insects guarantees the intake of several valuable nutrients. Proteins in insects are abundant, varying between 40% and 75% of the dry weight, and characterized by a profile rich in essential amino acids (IPIFF 2018), which meets the necessities for the human diet and is comparable to other animal proteins (van Huis, J. et al. 2013). Usually, insects have high fat content, widely fluctuating from 2 to 62% (Williams, Williams et al. 2016). The profile of fatty acids is similar to that of animal fats and vegetable oils (Tzompa-Sosa and Fogliano 2017), with an important sum of unsaturated fatty acids and an omega-6/omega-3 ratio spanning from 1.2 and 2.7 (Mishyna and Glumac 2021). However, this and other nutritional parameters, such as vitamins, minerals, prebiotic fibres and bioactive peptides, are strongly influenced by the type of substrate used to feed them.
So far, very few types and species of insects have been considered for food purposes in the EU, namely some crickets (e.g., *A. domesticus*, *Gryllus* spp., *G. sigillatus*, *Teleogryllus testaceus*), grasshoppers (*L. migratoria*, *Schistocerca gregaria*, *Oxya* spp., *Melanoplus* spp., *Hieroglyphus* spp., *Acridia* spp.), mealworms (*T. molitor*, *A. diaperinus*, *Zophobas atratus*), flies (*H. illucens*), honey bee drones (*Apis mellifera*) and silkworms (*B. mori*). Some of these species are already on the market in Denmark, Belgium, the Netherlands and France, the most advanced countries in the production of insects for feed and food purpose at industrial level (Dossey, Morales-Ramos et al. 2016).

In Europe, entomophagy has always been sporadic, and the few examples of this practice were abandoned over the years. In Sardinia, the ripened cheese ‘Casu Marzu’ is normally produced by natural infestation, however controlled inoculation of maggots of the fly *Piophila casei* has also been attempted. The digestive action of these larvae causes an advanced level of fermentation and has a substantial impact on proteolysis (Mazzette, Colleo et al. 2010), which contributes to the generation of a rich bioactive peptide profile (Robinson, Nielsen et al. 2021). Similar cheeses containing alive insects larvae are manufactured in France and Germany, and some authors report of a soup containing adult cockchafer beetles from Alsace-Lorraine (Grabowski and Klein 2017). Aside from these few exceptional cases, entomophagy in Europe has only received attention very recently. The interest has grown in parallel with the progression of the ecological movements in this millennium, but it has undergone an acceleration due to the publication of the FAO forestry paper 171 (van Huis, J. et al. 2013), which encouraged new entrepreneurs entering in the business and catalysed the research at academic level. In Germany, every year since 2015 the Insecta Conference addresses multiple topics in insect production. On April 2017, a workshop on the future of insect farming was held in the UK involving approximately 100 representatives, including researchers from academia, start-up companies, NGOs and livestock feed suppliers (Ferri, Federico et al. 2018).
6. Insect market situation

According to some estimates, about 92% of edible insects are harvested and collected from the wild (Yen 2015). Insect farming can be extensive and intensive, and can be carried out indoor or outdoor. Most of the insects consumed by humans in developing countries are picked up by hand from the wild. In West African countries termites are the main feed employed in fish and poultry farming (PROteINSECT 2016). In some parts of Latin America, like the Oaxaca region in Mexico, the consumption of insects is normalized. In rural communities with limited access to other animal-based foods, insects constitute an important source of nutrients that nowadays also translates into an important source of economic value (Hurd, Shertukde et al. 2019). In China, where people have consumed edible insects for more than 20 centuries, insect farming is a well-established and advanced industry (Feng and Chen 2009, Feng, Chen et al. 2018). Millions of tons of dry mealworm larvae are produced every year for export as pet food. In China, another appreciated insect for producing feed is the house fly *M. domestica* (Ferri, Federico et al. 2018). Thailand, with over 50 species consumed throughout the year, is the largest consumer of edible insects globally, and it has more than 20,000 insect farms. Thailand is the world leader to breed insects for food and export, with an annual average production of 7,500 tons/year. The North-East, the humblest part of the country, where crops are tough to grow and raising cattle is difficult, is also the region where eating insects is most preferred (Meticulous Research 2020).

Compared to these countries, the insect market situation in Western Countries is completely different. Outside EU, only few species for commercialization as human food have been approved: *A. domesticus* (house cricket), adult *L. migratoria* (migratory locus) and *T. molitor* larvae (mealworms) in Switzerland (Sogari, Mora et al. 2019); and *A. domesticus*, *T. molitor* and *Zophobas morio* (super mealworm) in Australia. In the United States, insects are allowed for human consumption only when good manufacturing practices (CGMPs) are followed (Lähteenmäki-Uutela, Grmelová et al. 2017).
Although in western societies edible insects still represent a niche food market, insect farming is a developing industry across Europe. The trend of changing our dietary habits and the disposition of consumers to try insect-containing food is growing and it is positively supported by media coverage. Whole insects represent the highest market share (almost 25% of the marketed products), but the rising demand for high protein food for dietetic food, sports nutrition or food supplements open the way to alternative formulations, thus creating further opportunities for the insect sector. Insects can be processed into a paste or a granular powder to increase the protein content and the nutritional value of products like bars, snacks and pasta (IPIFF 2020b).

In 2019, the European insect food business operators traded around 500 tonnes of insect-based products on the European market, divided into whole insects, insect ingredients and products with edible insects incorporated (IPIFF 2018), with a calculated revenue of more than €600 million through investments, and with an expectation of more than €2.5 billion by the mid-2020s (IPIFF 2020b). Current estimates for the market of the insect-containing food products speak of a rapid growth in the next few years. Recent forecasts indicated the total production of insect protein to be used for food and feed in 2025 at over 1.2 million tonnes, reaching around 10% of share of total protein supply in the EU (Mancuso, Pippinato et al. 2019). Despite these encouraging numbers, the harmonisation of the legal framework for edible insects in the EU was only achieved recently thanks to the Novel Food Regulation. This have hampered the establishment of major insects’ production units, and insects still represent a very small niche market. The sector is currently composed almost exclusively of SMEs and start-up enterprises mostly located in the North of Europe and with restricted capacity. Most of them have fully integrated production steps, from farming until distribution of insect derived sub-products. According to a recent survey the preferred distribution channel is the E-commerce, and the most sold products are whole insects or insects meal, primarily Tenebrio molitor and Acheta domesticus (Pippinato, Gasco et al. 2020). Furthermore, marketing edible insects in Europe is still more expensive than meat (Rumpold and Schlüter 2013).
Insects in Europe can be consumed in a limited number of restaurants, including one in the European Parliament, or at public events such as cooking classes, television shows or trading fares, but there is a growing interest fed by the increasing number of farms and awareness campaigns led by traditional and social media. The situation is complicated by the varied regulatory framework, and some countries are reacting faster than others to the occupation of the market by these novel foods. In Table 2, a list of the most common insect species on the EU market, and their relative authorisation status as food or feed is presented.

In Germany, where the traditional diet is strongly meat-based, the awareness and interest towards entomophagy is growing (Grabowski, Grootaert et al. 2016). In the UK, an increasing number of companies sell insects in different forms, from bags of whole crickets, mealworms and grasshoppers to grilled house crickets and giant ants (Dossey, Morales-Ramos et al. 2016). In the Netherlands, since 2014, insects for human consumption have been produced, processed and sold in specialized shops or in the supermarket (Ferri, Federico et al. 2018). Beside many small manufacturers and regional players popping up on a weekly base, the key companies operating in the food insect market in Europe are EAP Group Agronutris from France, Deli Bugs Ltd. from UK and Protifarm Holding NV from the Netherlands, the latter recently bought by the French Ÿnsect, specialized in insect-based feeds (Meticulous Research 2020).

On 1st of June 2021 the EC adopted the Implementing Regulation (EU) No. 2021/882, which authorizes one food business operator, namely the French company Micronutris, part of the EAP Group which had requested this authorisation, to place dried *T. molitor* larvae on the EU market. Unless another applicant obtains authorisation for the same product, this company is the only authorised one for placing on the EU market this novel food for a five years period from the date the Regulation entered into force. The application filed to the Commission was received by EFSA for the safety assessment on 21st of March 2018. The scientific opinion on the safety of dried yellow mealworm (*T. molitor* larva) as a novel food pursuant to Regulation (EU) 2015/2283 was adopted on 24th of November 2020 and published in January 2021 (EFSA 2021a). After this first authorisation,
three more products from the same Dutch company Fair Insects BV (belonging to the Protix group), namely the frozen, dried and powder forms of *L. migratoria*, yellow mealworm (*T. molitor* larva) and *A. domesticus*, were authorised between the end of 2021 and the beginning of 2022. In total, 28 more applications were submitted to the Commission (2 of which have already been withdrawn by the applicant), 11 of which are currently under evaluation by EFSA (Table 3).

7. **Ecological footprint**

Even if a plausible and a convincing solution at the very first sight, insects farmed on organic matter represent an additional stage in the food chain. Hence, holistic analysis in terms of the economic and environmental balance compared to traditional sources are required. The entire chain from insects farmed as feed for poultry, pigs, or aquaculture comprises multiple steps, combining at least two independent life cycles, from the starting material for feeding the insects, which must be feed grade, to the farming conditions of the insects themselves, such as temperature, humidity and space. Each step has its own footprint of energy use, resources and emissions. Finally, the materials have to be converted into PAP in accordance with the law, e.g. requiring heating and drying steps (IPIFF 2021b).

Insects have the potential to convert non-used co-products and organic side streams from the agri-food industries into high value materials (IPIFF 2018). By converting low-value ingredients and materials with low ecological footprints into proteins, unexploited resources can find a new and alternative way back into the production flow, in accordance with the waste hierarchy principles (IPIFF 2019a). However, not all species can grow effectively when only these substrates are employed. According to the International Platform of Insects for Food and Feed (IPIFF), “up to a third of the food waste generated today could be suitable for insect farming before it is classified as ‘waste’” (IPIFF 2020a). Despite catering waste is not yet allowed by the European Commission, IPIFF suggests to explore the possibility for authorising it as insect feeding substrate. Recent studies
on the effects on feeding farmed insects with catering waste have shown no impact on the safety of 
the products or on the animal health (IPIFF 2020).

Insect farms have a reduced environmental footprint. The reason is that, compared to traditional 
sources of animal protein like livestock, insects are advantageous in terms of feed conversion rates, 
water usage, greenhouse gases emissions and environmental contaminants (van Huis, J. et al. 2013).
Moreover, farmed insects also produce insect larvae faeces (insect frass), a by-product recently 
authorized in EU by Commission Regulation (EU) No. 2021/1925, which have huge potential to be used as a fertilizer. Together with and interesting content of nitrogen, phosphorus and potassium, insect frass contains beneficial bacteria that act as plant growth microorganisms, improving the health of the plant and facilitating the absorption of nutrients (IPIFF 2019).

Thanks to these circular practices, insect farming is less dependent on finite natural resources (IPIFF 2020a).

8. Safety assessment of insects for food and feed purposes

According to Regulation (EU) No. 2015/2283, novel foods including insects will be authorised only if they comply with the conditions expressed in Article 7, namely if they do not pose a safety risk to human health, do not mislead the consumer, or are not nutritionally disadvantageous for the consumer. The risk assessment is carried out by EFSA based on a guidance describing the data needed to carry it out, beginning with the description of the novel food, the production process, the compositional analysis, the key parameters that characterise the identity, the proposed uses and their levels, and the anticipated intake (EFSA 2021e).

In 2015 EFSA published a scientific opinion on the risks of producing and consuming insects as food and feed (EFSA 2015) that assessed the microbiological, chemical and environmental risks, covering the main steps of the production process. In this opinion, it is concluded that for both biological and chemical hazards, the insect production methods, the substrate used for feeding them, the stage of
harvest, the species chosen, and also the methods used for further processing the insects have an impact on the possible presence of biological and chemical contaminants in insect food and feed products that might cause possible hazard of food safety. A similar conclusion was also drawn more recently by the EFSA Nutrition, Novel Foods and Food Allergens (NDA) Panel assessing the safety of *T. molitor*, *L. migratoria* and *A. domesticus* as novel foods (EFSA 2021a,b,c,d; EFSA 2022b).

Despite insects can be generally considered as safe, offering neutral or positive health outcomes (Stull 2021), they can eventually accumulate toxins from the environment they are farmed in. Collecting insects from the wild has a double negative impact, because not only the risk of contamination with pesticides and heavy metals increases, but also because the practice decreases the biodiversity (van Huis, J. et al. 2013). As an alternative to wild harvesting, the recent development of farming systems with a controlled environment and diet significantly improved the quality of these feed and food products (Mishyna and Glumac 2021). As a matter of fact, the level of contamination from chemical hazards in edible insects largely depends on the respective level present in the substrate used as feed for insects. The microbiological risk associated to the consumption of insects as food has been recently reviewed. Insects are generally consumed cooked, where the heating process usually inactivates microorganisms and thermo-labile toxins. Foodborne diseases reported after traditional consumption of insects are generally a consequence of ignoring these traditional food safety rules (Ferri, Federico et al. 2018). Pathogenic bacteria, as well as antibiotic-resistant microorganisms and/or antibiotic resistance genes can come from the feeding substrate, but their levels are comparable to other food items. Regular microbial monitoring of pathogens is therefore required, and their survival should be studied after subsequent processing steps (Van Huis 2019). While conventional animal feeds used as substrate for insect production present similar microbiological hazards of feed administered to other animals, insects fed on ruminant by-products need to be assessed to control the risks of prions (Ferri, Federico et al. 2018). The main risk associated to the ingestion of edible insects that does not depend neither on the rearing practices nor on the post-harvest processing, is the allergenic one and this safety issue will be discussed in the next subsection.
8.1 Allergenicity risk assessment

Hazards associated with insects for use in food and feed depend on feed, species, and production/processing conditions (Schlüter, Rumpold et al. 2017, Testa, Stillo et al. 2017). To date, little information is publicly available about the hazards associated with insects for use in food and feed. Interestingly, the scarce information available indicates that insect proteins can cause allergic reactions in humans and animals with allergy to other arthropods, such as crustaceans (e.g., shrimp, prawn and crab) and house dust mites, due to allergen cross-reactivity (de Gier and Verhoeckx 2018, Premrov Bajuk, Zrimšek et al. 2021). Cross-reactivity can be explained because many proteins occurring in currently consumed edible insects are phylogenetically-related to allergens widely dispersed in the different groups of arthropods (crustaceans, insects, mites) and molluscs, as it is the case of pan-allergens such as tropomyosin, enolase, alpha-actin or arginine kinase, among others (Barre, Caze-Subra et al. 2014). Besides pan-allergens, some proteins belonging to distinct protein families, including apolipophorin III, the chemosensory protein, the cockroach allergen-like protein, hexamerin, the larval cuticle protein, the receptor for activated protein kinase and the odorant binding protein, among others, have arisen as proteins very specific for edible insects (Barre, Pichereaux et al. 2021, He, Li et al. 2021). These proteins, missed or much less represented in other groups of arthropods, molluscs or nematodes, share well-conserved amino acid sequences and highly similar quaternary structures. Consequently, they have been recently proposed as probes for the specific detection of insect proteins added either intentionally as food ingredients or involuntarily as hidden allergens to food products in complement to other detection methods (He, Li et al. 2021).

Therefore, there is a need to assess their food safety, especially for people allergic to edible insects. Likewise, recently several anaphylactic reactions have been reported in Europe and America after consumption of certain insect species (i.e., yellow mealworm *T. molitor* and silkworm pupae *B. mori*) from individuals whose clinical history consisted exclusively of allergy to house dust mites (Beaumont, Courtois et al. 2019) or without any previous reported allergy (Gautreau, Restuccia et al. 2017), indicating that the consumption of insects may also induce primary sensitization in previously
non-allergic individuals (Garino, Mielke et al. 2020). This was confirmed in professional mealworm breeders sensitized after occupational exposure and showing allergic symptoms upon in food challenges with *T. molitor* (Broekman, Knulst et al. 2017). In light of above evidences, EFSA has recently recommended to better characterize the allergenic potential of insects consumed as food (EFSA 2021a). However, the lack of clinical studies focused on insects’ consumption and of reliable data about the prevalence of allergic reactions to insects and/or level of exposure makes the current risk assessment of insects as food or feed a complex challenge. In this context, the principles and guidelines of the Codex Alimentarius for the safety assessment of foods derived from modern biotechnology published in 2003 serve currently as basis for the allergenicity risk assessment strategies. As no single piece of information or experimental method provide enough evidence to predict allergenicity, the main approach for the safety assessment is based on a “weight-of-evidence” approach, where information of different nature is considered for the assessment of allergenicity (EFSA 2011). In the frame of the EU-COST action “Improving Allergy Risk Assessment Strategy for New Food Proteins (ImpARAS)”, this protocol has been re-evaluated for its applicability to novel food proteins (Verhoeckx, Lindholm Bogh et al. 2020). In this context, a bottom-up strategy that defines a priori the specific risk assessment needs for the investigation of any given novel protein’s cross-reactive allergenic potential has been recently proposed by building fit-for-purpose databases, ranking allergens according to allergenic potential and the subsequent development of targeted bioinformatics tools (Fernandez, Mills et al. 2021). When known allergenic structures are already present in the novel food, such as the case of several insect allergens, a comparative assessment can be performed, and the range of cross-reactivity explored. Important parameters to be evaluated are: the amino acid primary sequence homology to known allergens (through bioinformatics analysis), the secondary and tertiary structure (looking for conformational epitopes), and the ability to bind specific IgEs (through *in vitro* assays such as ELISA or immunoblot) and to elicit an immune response (checking the biological activity through *in vitro* or *in vivo* tests). For a comprehensive assessment, other parameters like thermal and chemical stability to food processing, as well as resistance to gastric
and duodenal digestion need to be carefully evaluated (Mazzucchelli, Holzhauser et al. 2018, De Marchi, Mainente et al. 2021, De Marchi, Wangorsch et al. 2021, Lamberti, Nebbia et al. 2021). Furthermore, the EFSA Genetically Modified Organisms (GMO) Panel has recently published a scientific opinion addressing, among other aspects, the identification of specific research needs to improve the allergenicity risk assessment of new proteins (EFA 2022a). This document has highlighted some potential gaps on allergenicity prediction which could indicate that some of the methods included in the current weight-of-evidence approach for the allergenicity risk assessment could not be easily applicable to complex mixtures of proteins that often make up whole foods, such as insects. Among other issues, the EFSA GMO Panel has recommended the consideration of the clinical relevance, route of exposure and potential threshold values of food allergens (if available), as well as the use of improved in silico analysis approaches based on more advanced bioinformatics tools that may better predict the risk of a novel protein to trigger allergic reactions. Likewise, the draft of a roadmap that (re)defines the allergenicity safety objectives and risk assessment needs will be required to address a series of key questions for risk assessors and risk managers (EFSA 2022).

9. Acceptance by consumers

Recent publications indicate that Western consumers are not yet prepared to substitute traditional meat with insects, towards which they remain largely averse. Very recently, a risk-benefit assessment was performed in the frame of the NovRBA-project (“Novel foods as red meat replacers—an insight using Risk Benefit Assessment methods”) with the aim of assessing the overall health impact of substituting red meat by the novel food house cricket. An evidence-based communication strategy was generated, which relied on a literature review of risk perceptions and acceptance of beef and insects as food. The aim of the strategy was to provide information on regional and sociodemographic differences in target groups, as well as possible cognitive and cultural barriers to consumption. The result of the literature review of risk perceptions and acceptance showed how food neophobia,
familiarity, state of food (processed vs. unprocessed), disgust, animal reminder, cultural differences, contextual information, sociodemographic characteristics and social norms and contexts were identified as likely to affect the consumption of edible insects (Boehm, Borzekowski et al. 2021). There is a considerable amounts of factors playing a role in the choice of selecting insects as alternative protein source. A very recent review has tried to tackle them one by one, with the aim of providing useful information for the design of marketing strategies and target group-oriented product development. The result was a complex picture of different and related key factors influencing consumers’ perceptions and acceptance (Kröger, Dupont et al. 2022). One of the reasons playing a major role in entomophagy avoidance is disgust, which seems to be the most prominent and immediate response to eating insects observed in Western societies (Ruby, Rozin et al. 2015, Hartmann and Siegrist 2016, La Barbera, Verneau et al. 2018, Jensen and Lieberoth 2019). According to recent interpretations, disgust is elicited because insects typically deviate from what consumers have internalized to be normal food (Koch, Bolderdijk et al. 2021). Another reason is fear, generally intended as fear of harming the body, of damaging the ego or emotions, of having an unpleasant eating experience, of social outcomes, (Baker, Shin et al. 2016), or simply fear of trying new unfamiliar things, also referred as food neophobia. However, according to some authors, food neophobia cannot be called into question when it comes to entomophagy, while cultural conditioning would be most likely at the base of declining insects. An empirical research on Italian consumers from 2019 demonstrated that when the ‘innovative ingredient’ cricket flour was not advertised in pizza, participants were willing to give it a try, while when it was revealed the pizza containing cricket flour was the least preferred option (Iannuzzi, Sisto et al. 2019). Therefore, cultural prejudice, and not neophobia, seem to be the rejection criterion (Ardoin and Prinyawiwatkul 2021). The thesis of cultural bias was supported also by the British entomologist Vincent M. Holt, who in 1885 argued in his small booklet titled “Why not eat insects?” that the only way to persuade the West to eating insects was to make them trendy, because prevailing customs were a powerful factor influencing Western society food habit (Holt 1885). Changing the behaviours and the secular habits of consumers is an
arduous undertaking, especially since so many tasty, cheap and convenient food options are accessible to Western citizens.

Among the different ways how to study consumers’ habits and preferences in food shopping, online surveys have progressively become a popular method, and they have been extensively employed for exploring the psychological drivers of consuming insect. Online surveys allow the investigator to engage consumers who might otherwise refuse more classical in-person evaluations. Moreover, they can reach a much larger number of respondents compared to telephone surveys (Thielen, Vermuyten et al. 2018) or mailing questionnaires (Schlup and Brunner 2018). Social media platforms are effective ways how to increase the visibility and the level of engagement (Cicatiello, Vitali et al. 2020, Zielinska, Zielinski et al. 2020). However, the characteristics of the subpopulation sampled should be carefully considered. Highly educated young adults showed to be more open to insects as foods compared to the general populations (Cicatiello, Rosa et al. 2016, Roma, Ottomano Palmisano et al. 2020).

The willingness to try an insect-containing food, which has been the predominant mean of evaluating disposition to entomophagy in the West, varies from study to study, but in general, what emerges is that Western consumers are not yet prepared to quit on meat for insects. Lammers and colleagues (Lammers, Ullmann et al. 2019) described neophobia, familiarity and previous insect consumption as traditional variables in Western entomophagy research representing the classical set of predictors used to model insect consumption likelihood, together with gender and disgust sensitivity. Best candidates for entomophagy in the West are therefore male with low or no levels of neophobia, low disgust sensitivity and who have already consumed insects (Verbeke 2015, Hartmann and Siegrist 2016, Schlup and Brunner 2018). In Europe, Northern European consumers are more keen towards entomophagy than Central Europeans (Piha, Pohjanheimo et al. 2018).

Another aspect strongly influencing the acceptability of insects as food is the way they are conveyed to the average consumer. For instance, meat products are less accepted than baked goods and snacks (Ardoin and Prinyawiwatkul 2021). Most importantly, insects are preferred when they are processed,
so that no body parts are recognisable. Making insects invisible, for example by using them in form
of a flour, is the most effective strategy to mitigate negative evaluations (Ardoin and Prinyawiwatkul
2021; Dagevos 2021). Modern and advanced food technologies, like micro-encapsulation, can be also
applied to improve the appearance, the sensory properties and other organoleptic characteristics of
insects, helping them to be better accepted by the society (Sanchez, Gomez et al. 2021). Finally,
attractive naming and images on the packaging, as well as communication of health benefits on the
label are important to the perception of the consumers (de Magistris, Pascucci et al. 2015).

At last, public political statements and stances can play a pivotal role in enabling a shift towards new
and more sustainable food options. According to some authors, the sole assurance of safety already
removes a layer of risk from entomophagy (Baker, Shin et al. 2016), and promotes willingness to try
insect-based foods. As an example, the Food and Agriculture Organization of the United Nations
started to promote edible insects around 10 years ago as a vision for global food security (van Huis,
J. et al. 2013). On the contrary, legislative restraints present the utmost hurdle for insects to enter in
the food chain in Europe (Belluco, Halloran et al. 2017). Insiders know that insects are a sustainable
and nutritious integration into diets, and the message is trying to open its way to the outside as well.

In the EU, the number of consumers willing to eat insects is increasing thanks to current consumption
trends and changes in attitude around food. In 2019, nearly 9 million Europeans consumed insects or
their derived products (IPIFF 2020b). They were reached through marketing channels used by insect
food business operators, namely company’s website, fairs, conferences or related events. The opinion
of the IPIFF is that the rise in consumption is determined by several factors, particularly the
authorisation of insects as a novel food, the rising availability and diversity in products on the market,
and more in general the increased consumers’ awareness and acceptance (IPIFF 2020b).

The consumer acceptance of livestock fed with insects has been also addressed in literature, showing
promising results. A study conducted by Weinrich and Busch showed that willingness to buy meat
produced from broilers with insects in the feeding regime depends on attitudes towards product
introduction and on social norms (Weinrich and Busch 2021). Another study by Llagostera and
collaborators revealed that Spanish consumers were keen to pay a premium price for fish coming from aquaculture production systems based on insect protein compared to current feeding systems; also, fish produced with insect meal appeared the most valued concerning the environmental impact. However, taste expectation for this sort of fish was still low (Ferrer Llagostera, Kallas et al. 2019). In 2021, an online survey showed that many UK consumers were willing to try and pay for eggs from insect-fed hens. The main driver towards consumption was the positive attitude towards the product (Spartano and Grasso 2021). This same finding was outlined by Sogari and collaborators in their publication about willingness to pay for insect-feed ducks, suggesting that a good strategy to increase the appeal of these products would be increasing awareness among consumers by communicating the positive environmental impacts of the use of insects as feed (Sogari, Menozzi et al. 2022).

10. Final remarks

The Farm-to-Fork strategy is a key part of the European Green Deal regarding agri-food chain. The use of insects as food and feed can significantly contribute to the improvement of the sustainability from Farm to Fork by implementing the objectives of the strategy. Insect farming ranks among the most efficient protein production systems, and hence, can be a promising and reliable solution to challenges like population rising, increasing demand for protein and reduced land area available for agriculture. At the same time, insect farming is characterized by a very efficient use of water, energy and land, which means a reduced environmental footprint and contribution to climate neutrality.

Another important aspect of the Green Deal is the promotion of the production and use of new protein sources that can help to relieve pressure on agricultural land. Insect farming can actually reduce the need of importing certain food and feed commodities by diversifying the spectrum of products rich in protein available in the EU, while shortening the agri-food chain. This aspect, together with the use of insects generate by-products as fertilisers, contribute to improving the circularity of agriculture. The well-balanced content of essential amino acid and fatty acids of insects matches the nutritional
needs of both humans and livestock, such as fishes, poultry and swine. Where the application in the
field of animal feed seems to have a promising future, in the food area insects have so far struggled
to overcome the initial reluctance of Western consumers. The adoption of large-scale entomophagy
needs a steady re-positioning of insects in the marketplace, as well as in the minds of the consumers.
The recent approval of three insect species as novel foods by the EC has given new life to the market,
as well as new prospects to the growing number of operators in the sector.

Conflict of interest

The authors declare no conflict of interest in publishing this work.

Funding

Dr. Delgado contributed to this publication within the frame of the EU-FORA program, a European
funded EFSA initiative to promote the training of new risk assessors in the EU

Acknowledgments

Authors want to thank the Bundesinstitut für Risikobewertung (BfR) and the European Food Safety
Authority (EFSA) for their support.
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Meticulous Research (2020) "Edible Insects Market by Product (Whole Insect, Insect Powder, Insect Meal, Insect Oil) Insect Type (Crickets, Black Soldier Fly, Mealworms), Application (Animal Feed, Protein Bar and Shakes, Bakery, Confectionery, Beverages) - Global Forecast to 2027."


### Table 1. EU Regulations applicable to insects intended as food or feed.

<table>
<thead>
<tr>
<th>Regulation Number</th>
<th>Topic</th>
<th>Applicable to</th>
<th>Application to the insect sector</th>
</tr>
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</table>
| 999/2001          | TSE (feed ban)                                 | Feed                | - Insects and derived products must be produced in processing plant dedicated exclusively to the production of products derived from insects  
- Includes limitations on both the target species to which the insect products are intended to, as well as the categories of animal by-products used  
- Authorises the use of processed animal protein derived from insects and compound feed containing such processed animal protein for feeding aquaculture animals  
- Authorises processed animal protein (PAPs) derived from insects to feed poultry and porcine animals |
| 2002/32           | Undesirable substances in animal feed          | Feed                | Contaminants or harmful substances may not exceed the maximum limits                                                                                                                                                                                      |
| 178/2002          | General food law                               | food                | - Applies to all insect producers rearing, processing, handling (e.g., transport, storage) or distributing insects along the food or feed chain  
- Insect producers must register the substrate provider’s name, its address and delivery date |
| 1831/2003         | Additives in animal nutrition                  | Feed                | The list of authorised additives is provided within the EU Register of Feed Additives. Only generic feed additives (i.e. additives for which the approval is not specific to certain animal species) may be used as feed for insects |
| 852/2004          | Hygiene of foodstuffs                          | Food                | - Operators producing insects for human consumption must register with and notify national competent authorities  
- Operators producing insects for human consumption, at ‘other stages than primary production’, i.e. from the killing stage up to further processing stages including distribution, must comply with specific hygiene requirements |
| 853/2004          | Hygiene rules for food of animal origin        | Food                | - Insect food business operators carrying out any stage of production, processing and distribution of food after primary production and associated operations must put in place, implement and maintain procedures based on HACCP principles  
- Insect-based food business operators should emphasise identification mark on end products |
| 183/2005          | Feed hygiene                                   | Feed                | - Operators producing insects for animal feed must be registered before the national competent authorities  
- Operators producing insects for animal feed, at ‘other stages than primary production’, i.e. from the killing stage up to further processing stages, must comply with specific hygiene requirements |
| 2073/2005         | Microbiological criteria for foodstuffs        | Food                | Foresees that *Listeria monocytogenes* must be controlled in ready-to-eat (insect-based) foods                                                                                                                                                            |
| 767/2009          | Market placing of feed                        | Feed                | - Establishes rules on the marketing of feed materials and compound feed  
- Prohibits the feeding of manure/animal faeces to insects                                                                                                                                                |
| 1069/2009         | Health rules for feed                          | Feed                | - As category 3 material, insect-derived products must be treated in accordance with validated processing standards  
- Registration as establishment producing ‘category 3’ animal by-products                                                                                                                                    |
- Insects reared within the EU fall within the category of ‘farmed animals’ and may only be fed with eligible materials.
- Prohibits the feeding of catering waste to insects.

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<tr>
<th>Regulation</th>
<th>Topic</th>
<th>Type</th>
<th>Description</th>
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| 142/2011   | Animal by-products as feed | Feed | - Prohibits the feeding of ‘former foodstuffs’ containing meat and fish to insects.  
- For the killing of insects and the further processing steps required to produce animal feed, insect producers must conform with common processing standards and/or criteria. Operators must choose between methods 1 to 5 or method 7.  
- Authorises the use of 8 insect species for feeding aquaculture animals, poultry and porcine animals. |
| 1169/2011  | Food labelling | Food | - End products shall be labelled with the legislative ‘mandatory labelling particulars’.  
- Insect-based food business operators should emphasise on shelf life, date of minimum durability or use-by date. |
| 68/2013    | Catalogue of feed materials | Feed | Insect species and products thereof shall not be pathogenic or have other adverse effects on plant, animal or human health. |
| 511/2014   | Nagoya protocol | Food & feed | Restricts the use of certain exotic or endemic species. |
| 1143/2014  | Invasive alien species | Food & feed | Insect species and products thereof shall not be protected or defined as an invasive alien species. |
| 2015/2283  | Novel foods | Food | A specific application needs to be submitted to the European Community in case an applicant wants to place an insect-based food on the EU market. |
| 2016/429   | Transmissible animal diseases | Food & feed | Insect producers must comply with animal health and biosecurity measures on transmissible animal diseases. |
| 2017/625   | Official Controls | Food & feed | - Addresses official controls and other official activities performed to ensure the application of food and feed law, rules on animal health and welfare, plant health and plant protection products. |
| 2017/2470  | Union list of novel foods | Food | Contains the insects authorized in EU as novel foods. |
| 2019/625   | Requirements for the entry into EU of animals as food | Food | Contains the definition of insects as food. |
| 2020/2235  | Requirements for the entry into EU of animals | Food & feed | Annex III contains the model official certificate for the entry into the union of insects intended for human consumption. |
| 2021/632   | Rules for the application of 2017/625 | Food & feed | Live insects are included into the list of animals, products of animal origin, germinal products, animal by-products and derived products, composite products, and hay and straw that are subject to official controls at border control posts. |
| 2021/405   | Lists of third countries authorised for the entry of food into EU | Food | Lays down the list of third countries authorised for the entry into the Union of insects intended for human consumption. |

1 Also referring to all the amendments of the original Regulation'
<table>
<thead>
<tr>
<th>Insect species</th>
<th>Common name</th>
<th>Status on EC authorisation</th>
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<tbody>
<tr>
<td></td>
<td>As feed (PAPs)</td>
<td>As food</td>
</tr>
<tr>
<td><strong>Acheta domesticus</strong></td>
<td>House cricket</td>
<td>Authorised in feed for aquaculture, pigs and poultry¹</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Whole and ground grasshoppers authorised in EU as novel food²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Defatted whole cricket powder as a novel food under risk assessment by EFSA</td>
</tr>
<tr>
<td><strong>Alphitobius diaperinus</strong></td>
<td>Lesser mealworm</td>
<td>Authorised in feed for aquaculture, pigs and poultry¹</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Whole and grinded lesser mealworm as a novel food under risk assessment by EFSA</td>
</tr>
<tr>
<td><strong>Apis mellifera</strong></td>
<td>Honey bee</td>
<td>Not authorized</td>
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<tr>
<td></td>
<td></td>
<td>Male pupae as a novel food under risk assessment by EFSA</td>
</tr>
<tr>
<td><strong>Bombyx mori</strong></td>
<td>Domestic silkworm</td>
<td>Authorised in feed for aquaculture, pigs and poultry¹</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No applications</td>
</tr>
<tr>
<td><strong>Gryllodes sigillatus</strong></td>
<td>Banded cricket</td>
<td>Authorised in feed for aquaculture, pigs and poultry¹</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dried crickets as a novel food under risk assessment by EFSA</td>
</tr>
<tr>
<td><strong>Gryllus assimilis</strong></td>
<td>Jamaican cricket, Silent cricket, Field cricket</td>
<td>Authorised in feed for aquaculture, pigs and poultry¹</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No applications</td>
</tr>
<tr>
<td><strong>Hermetia illucens</strong></td>
<td>Black soldier fly</td>
<td>Authorised in feed for aquaculture, pigs and poultry¹</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Hermetia illucens</em> meal as a novel food under risk assessment by EFSA</td>
</tr>
<tr>
<td><strong>Locusta migratoria</strong></td>
<td>Migratory locust</td>
<td>Not authorized</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Whole and ground grasshoppers authorised in EU as novel food²</td>
</tr>
<tr>
<td><strong>Musca domestica</strong></td>
<td>Common housefly</td>
<td>Authorised in feed for aquaculture, pigs and poultry¹</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No applications</td>
</tr>
<tr>
<td><strong>Tenebrio molitor</strong></td>
<td>Yellow mealworm</td>
<td>Authorised in feed for aquaculture, pigs and poultry¹</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dried mealworms authorised in EU as novel food⁴</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Whole and ground mealworms authorised in EU as novel food⁴</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flour as a novel food under risk assessment by EFSA</td>
</tr>
</tbody>
</table>

¹Comm. Reg. 2011/142
²Comm. Impl. Reg. 2022/188
⁵Comm. Impl. Reg. 2022/169
Table 3. Summary of the applications of insects as Novel Foods handled by EFSA (updated to 17.05.2022)

<table>
<thead>
<tr>
<th>Question Number</th>
<th>Subject</th>
<th>Status</th>
<th>Reception Date</th>
<th>Applicant</th>
</tr>
</thead>
<tbody>
<tr>
<td>EFSA-Q-2022-00095</td>
<td>&lt;i&gt;Hermetia illucens&lt;/i&gt; larvae refined fat (Refined Black soldier fly larvae fat)</td>
<td>Intake</td>
<td>14/02/2022</td>
<td>Protix B.V.</td>
</tr>
<tr>
<td>EFSA-Q-2021-00262</td>
<td>Request for a scientific opinion on &lt;i&gt;Acheta domesticus&lt;/i&gt; Flour as a novel food (NF 2020/1860)</td>
<td>Ongoing Risk Assessment</td>
<td>11/05/2021</td>
<td>Italian Cricket Farm S.r.l</td>
</tr>
<tr>
<td>EFSA-Q-2021-00105</td>
<td>Request for a scientific opinion on Protein-rich flour from fresh larvae of mealworm (&lt;i&gt;Tenebrio molitor&lt;/i&gt;) as a novel food (NF 2020/1959)</td>
<td>Ongoing Risk Assessment</td>
<td>24/02/2021</td>
<td>Ynsect</td>
</tr>
<tr>
<td>EFSA-Q-2020-00748</td>
<td>Request for a scientific opinion on Dried &lt;i&gt;Acheta domesticus&lt;/i&gt; as a novel food (NF 2018/0623)</td>
<td>Intake</td>
<td>17/11/2020</td>
<td>National Bureau of Agricultural Commodity and Food Standards, Ministry of Agriculture and Cooperatives, Thailand</td>
</tr>
<tr>
<td>EFSA-Q-2019-00748</td>
<td>Request for a scientific opinion on &lt;i&gt;Tenebrio molitor&lt;/i&gt; (mealworm) flour as a novel food (NF 2019/1142)</td>
<td>Ongoing Risk Assessment</td>
<td>21/11/2019</td>
<td>Nutri'Earth</td>
</tr>
<tr>
<td>EFSA-Q-2019-00690</td>
<td>Request for a scientific opinion on Protein powders from the &lt;i&gt;Alphitobius diaperinus&lt;/i&gt; larva as a novel food (NF 2019/1292)</td>
<td>Ongoing Risk Assessment</td>
<td>30/10/2019</td>
<td>Protifarm Holding N.V.</td>
</tr>
<tr>
<td>EFSA-Q-2019-00589</td>
<td>Request for a scientific opinion on defatted whole cricket (&lt;i&gt;Acheta domesticus&lt;/i&gt;) powder as a novel food (NF 2019/1227)</td>
<td>Opinion published</td>
<td>10/09/2019</td>
<td>CRICKET ONE CO., LTD</td>
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<tr>
<td>EFSA-Q-2019-00201</td>
<td>Request for a scientific opinion on &lt;i&gt;Apis mellifera&lt;/i&gt; male pupae as a novel food (NF 2018/0754)</td>
<td>Ongoing Risk Assessment</td>
<td>22/03/2019</td>
<td>The Finnish Beekeepers’ Association</td>
</tr>
<tr>
<td>EFSA-Q-2019-00121</td>
<td>Request for a scientific opinion on Whole and ground crickets (&lt;i&gt;Acheta domesticus&lt;/i&gt;) as a novel food (NF 2018/0804).</td>
<td>Finished and approved</td>
<td>27/02/2019</td>
<td>Fair Insects BV (A Protix Company)</td>
</tr>
<tr>
<td>EFSA-Q-2019-00115</td>
<td>Request for a scientific opinion on Whole and ground Grasshoppers (&lt;i&gt;Locusta migratoria&lt;/i&gt;) as a novel food (NF 2018/0803).</td>
<td>Finished and approved</td>
<td>22/02/2019</td>
<td>Fair Insects BV (A Protix Company)</td>
</tr>
<tr>
<td>EFSA-Q-2019-00101</td>
<td>Request for a scientific opinion on whole and ground mealworms (&lt;i&gt;Tenebrio molitor&lt;/i&gt;) larvae as a novel food (NF 2018/0802).</td>
<td>Finished and approved</td>
<td>15/02/2019</td>
<td>Fair Insects BV (A Protix Company)</td>
</tr>
<tr>
<td>EFSA-Q-2018-00543</td>
<td>Request for a scientific opinion on <em>Acheta domesticus</em> as a novel food (NF 2018/0128)</td>
<td>Intake</td>
<td>03/07/2018</td>
<td>Belgian Insect Industry Federation (BiiF)</td>
</tr>
<tr>
<td>-------------------</td>
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</tr>
<tr>
<td>EFSA-Q-2018-00513</td>
<td>Request for a scientific opinion on <em>Locusta migratoria</em> as a novel food (NF 2018/0395)</td>
<td>Intake</td>
<td>20/06/2018</td>
<td>Belgian Insect Industry Federation (BiiF)</td>
</tr>
<tr>
<td>EFSA-Q-2018-00282</td>
<td>Request for a scientific opinion on whole and grinded lesser mealworm (<em>Alphitobius diaperinus</em>) larvae products as a novel food (NF 2018/0125)</td>
<td>Opinion under publication</td>
<td>10/04/2018</td>
<td>Proti-Farm Holding NV</td>
</tr>
<tr>
<td>EFSA-Q-2018-00262</td>
<td>Request for a scientific opinion on dried mealworms (<em>Tenebrio molitor</em>) as a novel food (NF 2018/0241)</td>
<td>Finished and approved</td>
<td>21/03/2018</td>
<td>SAS EAP Group - Micronutris</td>
</tr>
</tbody>
</table>