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The future is crawling: Evaluating the potential of insects for food and feed security

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ABSTRACT

Current estimations showed that the number of people affected by hunger doubled in the last two years, reaching 9.8% of the global population. According to FAO, in order to satisfy the demand for food in the next few years, it will be necessary to double food production. Moreover, the call for a change in dietary patterns has been raised, showing how the food sector is responsible of 1/3 of climate change where meat-based diets or overconsumption of meat play an important role in the negative environmental impact. Consequently, there is a growing concern in how to achieve the goal of increasing food productions without exploiting environmental resources and to explore the production and use of alternative resources, such as insects. Insects are gaining interests both as food and feed not only to reduce the environmental costs in feed production for common livestock, but also to reduce farmers' dependence on traditional protein sources.

In this work we aimed to provide an overview of the state-of-the-art upon insect studies, highlighting the most important results obtained from both an industrial and market perspective. The legislative framework concerning edible insects as food and feed is also analyzed, with the final purpose to highlight recent reforms, relevant case-law as well as unsolved regulatory challenges.

From a normative perspective, regulatory efforts are still required to fully take advantage of the potentialities of insects-industry. From a consumer point of view, consumers' willingness to pay a premium is going to be a key issue for economic sustainability of the insect farming chain. To meet the food and feed security challenges, insects will have to be considered all-around, including applications in the food, feed, and other sectors.

We believe that this review is an important contribution to the field of food science and will be of interest to researchers, food industry professionals, and policymakers in order to prioritize research questions and help communicate scientific knowledge to a broader audience.

1. Introduction

The 2030 Agenda for Sustainable Development Goals adopted by the United Nations (UN) in 2015 provides 17 Sustainable Development Goals (SDGs) with 169 targets as a global call for action to ensure a more cooperative, environmentally sustainable, and fair world for future generations. "Zero Hunger" is the second goal of the SDGs aiming to "end hunger, achieve food security, improve nutrition and promote sustainable agriculture"; according to this statement there are 8 targets where the first five are directly linked to food security and sustainability of agriculture whilst the last three targets are related to trade and market issues. As the importance of food security relies upon its deep interconnection with all the other SDGs, it also faces more challenges, both present and future. COVID19 pandemic, conflicts, climate change, and a growing demand for food along with a growing global population are the main drivers for a call to change the current food system (UN Sustainable Development Group, 2020). Future challenges are about finding new sustainable and resilient practices along with more

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incentives and investments for small-scale food producers, in particular women and indigenous people, sustainable production of food, improvement of land and soil quality, and maintenance of the genetic diversity in food production. It appears clear the need to adjust the concept of food security with the multiple aspects of sustainability, which can be far more than tricky (Arora and Mishra, 2022). The concept of food security as recognized by the SDGs and current literature follows the definition 'food security exists when all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life' (Webster et al., 2020). Current estimates by the UN reported that the number of people affected by hunger doubled in the last two years reaching the 9.8% of the global population, whilst people without access to a healthy diet is about 3.1 billion, increased by COVID19 pandemic, climate shocks, and gas and wheat crisis which have deepened inequalities (FAO, IFAD, UNICEF, WFP and WHO, 2022). According to FAO, in order to satisfy the demand for food in the next few years, it will be necessary to double food production (FAO, 2019). As a consequence, there is a growing concern in how to achieve the goal without exploiting environmental resources, dismantling biodiversity and ecosystems or causing depletion of freshwater resources, pollution and land use (van Huis, 2020). The call for a change in dietary patterns has been raised, showing how the food sector is responsible of 1/3 of climate change (Crippa et al., 2021), where meat-based diets or overconsumption of meat play an important role in the negative environmental impact (González et al., 2020). As result it is fundamental to explore the production and use of alternative proteins (van der Weele et al., 2019) such as plant-based (Hadi and Brightwell, 2021), pulses (Fernando, 2022), algae (Becker, 2007), cultured meat (Bryant and Barnett, 2020) or insects (Sogari et al., 2022a).

Insects are gaining interest in the field both as food and feed not only to reduce the environmental costs in feed production for common livestock, but also for the significant reduction in food waste as some insects can be used for biodegradation and biotransformation of organic side streams, achieving the request of the SDGs in contrasting food waste (Moruzzo et al., 2021; van Huis, 2020) and to face malnutrition and protein-deficiency widespread in most undeveloped countries (Meyer--Rochow, 1975). To reduce farmers' dependence on traditional protein sources (e.g. fishmeal and soybean meal), overcome animal feed shortages and potentially reducing costs, alternative feed sources like insects could be a nutritional and sustainable alternative for protein components of feed (Saatkamp et al., 2022; Sogari et al., 2019a). In fact, in the contest of strengthening food security, there is a growing need of finding alternative protein feed sources which are capable of not competing with food. Current feedstocks include cereals that are suitable as food for humans and, according to FAO, only 42.6% of wheat, rice and coarse grains world production are directly used as food for human consumption while the 35.6% is used as animal feed (FAO, 2019); it is expected that, by 2050, up to 50% of global cereal production will be used as feed instead of food (HLPE, 2019). Insects represent a great opportunity to integrate and, therefore, limit fishmeal, soymeal and cereals (Gougbedji et al., 2022; Melenchón et al., 2022; Nieto et al., 2022) as feeds; furthermore, as several carnivore or omnivorous species are fed exclusively with feeds made of plants raw ingredients (Mancini, 2020), insects may potentially provide significant extra advantages to livestock health and wellbeing.

Entomophagy as a solution to food insecurity and sustainable diets has already been present in academic literature for many years, testifying also a European/Western attitude to think of their own diet as "civilized" compared to those where insects are present (Meyer-Rochow, 1975). The publication of studies about knowledge and awareness about alternative proteins like edible insects as food is growing (Onwezen et al., 2021). In the following sections we will provide an overview of the current legislative status on insects; the various applications of insects in food and feed, as well as in another industrial applications, and how the consumers acknowledge and perceive edible insects and evaluate both direct and indirect entomophagy.

2. Insects as food and feed: evolution and open challenges of the EU legal framework

In recent years, the regulatory framework concerning the production and marketing of insect-based food and feed has been extensively reformed by the EU legislators, facing unprecedented and urgent food security and food sustainability challenges (Vauterin et al., 2021). Specifically focusing on insects for human consumption, these products currently fall under the scope of application of Regulation (EU) 2015/2283. This EU Regulation entered into force 1 January 2018 and disciplines the so-called Novel Foods (NFs) (Lähteenmäki-Uutela and Grmelová, 2016; Scaffardi and Formici, 2022). Not being habitually consumed in the EU territory prior to 15 May 1997 (signing the entry into force of the first EU NFs Regulation (EC) 258/97), insects-based products enter into the category indicated in Art. 3, para. 2, lett. a), n. v) "food consisting of, isolated from or produced from animals or their parts"; as a consequence, insects producers interested in marketing their products must obtain a prior marketing authorisation issued by the EU Commission at a centralized level.

In fact, reflecting a 'precautionary' approach, (Scaffardi, 2020) 'new' foods are considered per se unsafe so that producers are required to provide a scientific dossier demonstrating that the NF does not pose a safety risk to human health. While EFSA (European Food Safety Authority) is identified as the sole authority appointed to deliver a risk assessment evaluation, the risk management phase is operated by the Commission; this Institution has to prepare a draft implementing decision authorizing or not the NFs (i.e., insect) products, taking into account the food safety considerations expressed in EFSA's opinion; the draft decision will then need the final approval of the Standing Committee on Plants, Animals, Food and Feed, composed by Member States' representatives (Volpato, 2015).

Differently from the past, the inclusion of a product in the NF Union List has a generic effect: this means that food business operators (FBOs) other than the applicant are allowed to commercialize an already authorized NF without submitting another specific application. These new procedural and substantial rules, positively answering to the shortcomings and applicative doubts emerged by the previous Regulation (Formici, 2020; Jones, 2012; Paganizza, 2019), soon demonstrated their positive impact on insects-as-food industry. While under the 1997 Regulation no authorisation for insect-based foods was obtained or promoted due to both the high costs and timing required, in June 2021 the EU Commission Implementing Regulation (EU) 2021/882 permitted the placing on the market of dried *Tenebrio molitor* (mealworm) larva. Subsequently, other authorisations have followed, concerning: frozen, dried and powder forms of *Locusta migratoria* (migratory locust); frozen and dried formulations of whole *Acheta domesticus* (house crickets) as well as partially defatted powder obtained from whole house crickets; frozen and dried formulations of whole *Tenebrio molitor*; frozen, paste, dried and powder forms of *Alphitobius diaperinus* (lesser mealworm).

These unprecedented evolutions testify the capability of the new regulatory framework to more attentively balance the guarantee of consumers health and the need to boost innovation and investments in NFs production, also to the benefit of sustainability (Sforza, 2022). Notwithstanding these positive aspects, some legal uncertainties, and doubts as to the tangible effects of the 2015 discipline still remain to be solved (Finardi and Derrien, 2016); a perfect example of the abovementioned issues is represented by the interpretation and application of the transitional measure (art. 35). This provision concerns foods that fall within the scope of the more recent Reg. EU 2015/2283 but which were not considered as Novel according to the 1997 Regulation, and were consequently already lawfully marketed in the EU territory. In order to allow a clearer regulatory transition of these products, art. 35 of the current legislation permits these foods to continue to be placed on the market until an authorisation procedure – promoted according to the

new legislation – is concluded. The main risk linked to such a transitional discipline is the re-proposal of the fragmented regulatory landscape derived from the 1997 Regulation with reference the status of whole insects; in particular, in the past these specific products have been at the centre of a complex interpretative debate that brought different solutions amongst Member States (Paganizza, 2016, 2020; Scaffardi and Formici, 2022).

Moreover, the impact of the data protection rule (Art. 26, Reg. EU, 2015/2283) is to be investigated: this provision ensures a five-year period of 'secrecy' of the scientific data presented by the applicant, provided that the data are essential for assessment and are designated as proprietary. The economic benefits of such a guarantee are evident, ensuring to the applicant a sort of market exclusivity for 5 years; this means that during that time period, other operators interested in marketing the same NF are obliged to bear the costs of their own food safety dossiers, without benefitting from the positive effects of a generalized authorisation. On the one hand, this measure undoubtedly represents an incentive for "first-movers" applicants, who can potentially recoup the previous R&D investments and the authorisation procedure costs thanks to the obtained 'secrecy'. On the other hand, this provision could ultimately result in a limitation of the insects' market: the absence of a generalized effect of the "first-mover"'s authorisation multiply the authorisation procedures required for the same product, without considering that the food safety assessment has already been provided for in the first authorisation. The limited efficacy of the market authorisation in that case could severely impact on small and medium-sized enterprises lacking the expertise and economic resources to afford the expensive authorisation procedure (Simpson, 2016).

If the regulatory debate on insects-as-food is not over, the one concerning insects-as-feed seems to open even more questions. In particular, the so-called TSE Regulation (Reg. EC No. 999/2001) has been adopted in 2001 in order to eradicate transmissible spongiform encephalopathies (TSE) and to prohibit the use of Processed Animal Proteins (PAPs) as feed materials for farmed animals; this legislation has represented a significant barrier to the expansion of insect-as-feed in the EU and, consequently, to the potentialities of the insects industry to mitigate -the environmental footprint of traditional livestock.

Only in recent years this vast ban has been modified, relying on scientific studies: Regulation (EU) 2017/893 authorized the use of certain insects' PAPs in feed in aquaculture, while Regulation (EU) 2021/1372 allowed insect, pig and poultry PAPs as swine and poultry feed. At the seven species authorised in 2017, namely *Hermetia illucens* (black soldier fly), *Musca domestica* (common housefly), *Tenebrio molitor* (yellow mealworm), *Alphitobius diaperinus* (lesser mealworm), *Acheta domesticus* (house cricket), Gryllodes sigillatus (banded cricket), and *Gryllus assimilis* (field cricket) an eight specie, *Bombyx mori* (silkworm), was added in 2021 (Regulation EU, 2021/1925).

Notwithstanding the enormous potentialities of such regulatory innovations, other legislative reforms seem to be necessary in order to facilitate a scale-up of the insects-industry: scientific studies should be at the basis of future evaluations on the opportunity to further relax the current ban on the use of insects-as-feed for ruminants; the possibility to reform laws impeding to use substrates of waste (derived from urban or domestic waste, catering, restaurant waste, or other former foodstuffs or unsold products from supermarkets or industries containing meat and/or fish) as feeding materials for insects should also be evaluated. These regulatory modifications could positively impact on the promotion of circular economy, on productions costs as well as on the economic and environmental sustainability of insects farming.

Moreover, insects' producers are now obliged to comply with all the legal rules applying to other FBOs (e.g. the General Food Law, Regulation 178/2002/EC) as well as the Hygiene Package, Regulation 852/2004/EC and 183/2005/EC and the Regulation (EU) 2016/429 on transmissible animal diseases: the EU legislators seem to be required to rethink and carefully evaluate the necessity to tackle regulatory issues deriving from laws that were not originally intended to discipline also insects-based products (for example the current EU legislation concerning animal welfare, namely Directive 98/58/EC, does not apply to insects producers since invertebrate animals are excluded from the scope of application of such provisions). As a consequence, while regulating this evolving sector, EU Institutions should take into proper consideration the peculiarities of insects-production processes (e.g. the need to promote specific rules on insects welfare or hygiene conditions, see IPIFF, 2022).

The evolution of the EU legislative framework on insects for food and feed, here described, will be of crucial importance to enhance investments in this sector, while ensuring a high standard of food safety and reinforcing consumers' trust. Different legislative solutions are established in Countries outside the EU: even if some legal systems share several similarities with the European regulatory approach, for example by imposing a prior authorisation based on a risk assessment phase (Canada), the existence of different disciplines are seen as a potential obstacle to the promotion of a normalized insects-based products industry. Some legal scholars and stakeholders thus suggest that private and public actors seriously discuss the adoption of a "global regulatory framework for insects as a part of sustainable food systems" (Lähteenmäki-Uutela et al., 2021).

3. Applications of edible insects

3.1. Insects as food industrial applications

Edible insects could be used as whole-body (insect processed to be ready-to-eat), or as ingredients in both well-known food or in novel products. Indeed, following the NF applications presented in EU and the products already sold worldwide, insects can be presented after different processing steps as roasting, frying, baking, defatting, and drying or as insects' powder/oil (Mancini et al., 2022). Mealworm, superworms, and lesser mealworm larvae, as well as adult crickets, locusts, and grasshoppers are proposed to the consumers as processed whole-body insects that conserve the actual body structure of the insects. Local, cultural, or exotic culinary uses of spices, processing and way of serving are normally employed in the presentation of the whole insect products to make them more affordable for the consumers (Boukid et al., 2022). Despite being still a niche, insects' powder or oil-fats are also sold to be used by consumers in their home recipes as well as already employed in final products as ingredients. Bakery products, pasta, pizza, bread are the more well-known products (products that consumers recognize as part of their diet) in which insect powders could be added as partial substitution of other ingredients, also affecting the nutritional values of the food (in some case could lead to an increasing of the protein intake). Fats or oils could be also employed as substitution of animal-vegetable fats in the formulation of the food as they can also be sold as alternative to the conventional butter, margarins and table oils (Delicato et al., 2020; Smetana et al., 2020; Tzompa-Sosa et al., 2021).

Other uses in the food industry could arise in the future, mostly in relation to the consumers' willingness to try, buy and add into their diet insect-based products. The "exoticist" of including insects in well-known food may be a driver to attract curiousness of the buyers. Indeed, insects as garnishing or the presence of the labelling reporting the use of them (even if in low percentages) could be a way to attract consumers and add an originality feature to the products. These intentions are already showed by the producers as reported in the NF requests in the EU. For instance, applicants proposed uses of migratory locusts, mealworms, and crickets in the food category "unsweetened spirits and liqueurs" and "mixed alcoholic drinks" at low percentages of inclusion (Mancini et al., 2022). Notably, the insects NF applications that reach the positive opinion by EFSA are intended (proposed target population by the applicant) for a wide consumer audience (general population) on their use as food ingredients. One only exception was set for the request about lesser mealworm that was proposed by the applicant for the general population as ingredients and as food supplements only for the adult

population (notably, food supplements are concentrated sources of nutrients or other substances with a nutritional or physiological effect that are marketed in "dose" form). Boukid et al. (2022) reported that from a market perspective, 236 products (220 foods and 16 drinks) containing edible insects have been launched in the global market since 1996. It is expected that in the future more insect-based food will be launched into the market, following the implementation of the legal framework and the boost consumer awareness about the health benefits.

3.2. Insects as feed industrial applications

Insects are part of the natural diet of several animals, also of the farmed ones. Although insects are part of the naturally occurring diet of farm animals, they were not largely employed as administered feed, mostly because they were not reared with this purpose and were nearer to a supplement preyed by the animals farmed in open range facilities (van Huis et al., 2015). Their use as ingredients in commercial feed are nowadays considered, both as protein and energy (fat) parts. In the last decades several research studies tested the substitution of vegetable (mostly soya derivates as the soya meal, oil, or cake) or animal (mostly fishmeal and fish oil) ingredients in the diet of farmed fish, avian species, and pigs (Sogari et al., 2022b). Insects' meal and oil could be used as raw ingredient in different stages of the production animals rearing, also in relation to the nutritional requirements of the animals. Noteworthy, the feed sector still need time to standardize the use of insects' products as several benefits and disadvantages could emerge. For instance, a high percentage of substitution of soy meal with insect meal could negatively affect the live performances of the animals as other nutrients, such as the chitin, are added into the feed. Fatty acids of the insects could as well affect the nutritional values of the final products, such as meat and eggs, in relation to their level into the feed and type of ingredient replaced (i.e., content of n-3 fatty acids in fishmeal). Another use of insects as feed could be the employment of live larvae. If on one hand it led to boost the animals' benefit, increasing foraging behaviour and activity, thus improving the innate behaviour (Colombino et al., 2021); on the other hand, it may represent an insurmountable technical issue as the addition of live insects do not permit the monitoring of the animals' nutritive ingested as not mixed with the other ingredients of the diet. Indeed, another point to be added to the list is the farmed animals' selection. During the last decades, in order to reach high performances in livestock productions, a co-selection was placed leading to animals that express such good performances (high production yields with low feed conversion level) only with selected feeds. Insects therefore could be part of the diets of less selected breeds or, in the future, could be part of selected animals that could show hight performances in relation to the insects-based feeds.

3.3. Insects in non-food and non-feed industrial applications

Given the great variety of species and their composition, insects are also used for applications that go beyond food and feed. As we previously said, insects are a source of proteins and lipids. The composition and quantity of these depend on several factors such as species, sex, development stage, and growth substrate (Hawkey et al., 2021). The main component of insect lipids is triacylglycerol, with the most commonly occurring fatty acids, in various species, being oleic, linoleic, palmitic, lauric, and stearic acids (Dos Santos Aguilar, 2021). Lipids can be used for different purposes such as cosmetics and biofuels. In the cosmetic industry, lipids are used in the formulation of skin care products and creams. Depending on the nature of the fats, they are added to increase the protective properties of creams or the viscosity of the formulation (Franco et al., 2021). One of the current challenges of this market is the transition to using natural ingredients, more sustainable and environmentally friendly than synthetic chemicals, hence the name 'green cosmetics' (Amberg and Fogarassy, 2019). Since insects have a low environmental impact, they can be reared using food waste and have a large reserve of fats (Almeida et al., 2020), the use of their lipids could be part of green cosmetics. Although studies on their application in cosmetic products are still few, the yield data of the extraction of fats from insects are promising (Dos Santos Aguilar, 2021; Almeida et al., 2022). As the fossil fuel depletion crisis advances, the search for an alternative energy source is becoming increasingly necessary (Pandey et al., 2011). Among the alternatives, such as vegetable oils, animal fats, cooking oils, and oleaginous microorganisms, some insect oils could be used for the production of biodiesel (Manzano-Agugliaro et al., 2012). Indeed, biodiesel made from black soldier fly (*Hermetia illucens*) larvae and prepupae was reported to have characteristics and properties that fall within international biodiesel standards. One of the constituents of the insect is chitin, a polysaccharide that covers the exoskeleton and is one of the most abundant biopolymers after cellulose. This compound and its derivative chitosan have been studied a lot in recent years because they lend themselves to a great variety of uses, as it possesses antimicrobial activity, biodegradability, and non-toxicity (Hahn et al., 2020).

Chitin and chitosan are often used in biomedical applications such as wound-dressing material, hydrogel, and fibers (Rinaudo, 2006). They are also studied for the treatment of wastewater as they show great physical and mechanical properties for the removal of contaminants from aqueous solutions (Sarode et al., 2019). Moreover, in agriculture, it was demonstrated that insect frass, which is also composed of chitin, exert a beneficial effect in different ways such as in plant growth, resistance, and reproduction or in stimulation of soil microbial community (Barragán-Fonseca et al., 2022). For these reasons, they could be a valuable alternative to conventional fertilizers and pesticides. At the moment, chitin and chitosan derive mainly from crustacean exoskeletons but it is reasonable to assume that crustacean yields are likely to decline with ongoing climate change, ocean acidification and reef damage, so farmed insects could represent a valuable alternative source of these two molecules.

The antimicrobial activity of insects has triggered the curiosity of the scientific community. Indeed, they have tried to deepen the subject to understand how and from what it derives. The reason they manage to survive and evolve in hostile environments is their immune systems (Sheehan et al., 2020). This activity is due to the composition of insects such as chitin, and fatty acid profile that exert an antimicrobial activity, but also to the production of molecules called AMP (antimicrobial peptides), small peptides that inhibit a large spectrum of bacteria and fungi. These molecules are of great value as they bypass common resistance mechanisms (Hadj Saadoun et al., 2022) and therefore could be used in various sectors besides feed, such as agriculture, disease vector control, and medicine. Although the production costs of these molecules are still too high at the moment, the field of the applications looks promising as they are present in large number, in different form and, for the characteristic mentioned above, they represent a novel source of molecules of medical importance. Insects are also a valuable aid in the field of biological control as they can be used as antagonists of pests in agriculture. For example, the case of the *Halyomorpha halys* stink bug which in Italy has become the largest pest of fruit plants and has caused damage for millions of euros. A recent study has shown that biocontrol using a parasitoid *Trissolcus japonicus* and *Trissolcus mitsukurii* is effective in the fight against *H. halys* (Costi et al., 2022). Moreover, many efforts have been made on the biological control within fruit flies (*Tephritidae*) management programs in different parts of the world from America to Africa using parasitoids or predators. Another example of biological control is the use of ladybirds (*Coccinellidae*) against aphids (*Aphidae*) in greenhouse, which has proved to be promising. These are some examples to demonstrate and shed light on the potential that insects have, which could cover multiple markets from food to feed to the medical, pharmaceutical and agricultural fields.

4. Insects & consumer perception

4.1. Are consumers ready for insects as feed?

Even though, as shown in the previous section, it is technically feasible to use insects as a sustainable protein-rich feed ingredient with minimal impact on the sensorial and quality characteristics of the animal food products (Gasco et al., 2019), consumers' acceptance on using insects as a feed or "indirect entomophagy" (La Barbera et al., 2020) has only recently started to be investigated (Mancini et al., 2022). First, most consumers are unaware of how animals are generally fed and therefore they do not have an opinion, or they do not care about the feeding system (Popoff et al., 2017; Ankamah-Yeboah et al., 2018; Spartano and Grasso, 2021a). This is true also for insect as feed considering that only recently this opportunity has been taken into consideration by private sector and policy makers (Sogari et al., 2019a). The studies conducted so far shown that consumers have slightly positive opinion about insect feed especially with animals that already consume insects in the nature like fish and poultry (Menozzi et al., 2021; Sogari et al., 2022b; Verbeke et al., 2015). However, so far, the introduction of farmed animals fed with insects into mainstream markets is limited due to several reasons. Among those we have perhaps the high price as shown by several studies which suggest low or no price premium for such products (Ankamah-Yeboah et al., 2018; Bazoche and Poret, 2021; Menozzi et al., 2021; Saatkamp et al., 2022). So far, only a few studies showed positive willingness to pay. For example, a study by Ferrer Llagostera et al. (2019) conducted among Spanish consumers, showed a higher premium price for gilthead sea bream fed with insect meal than fish fed only with fish meal. However, their findings indicated also low taste expectations for fish fed with insect meal; thus, suggesting that the quality of the final product remains of great importance. Also, Giotis and Drichoutis (2021), found that 55.55% of their respondents (Greek consumers) would be willing to pay a premium to purchase the gilt-head bream fed with insect-based feed. Besides many studies on fish consumers, which is probably the most studied animal species in terms of consumer acceptance of insects as feed, other works focused on poultry and pigs. Spartano and Grasso (2021b) focused on willingness to try (WTT) and to pay (WTP) for eggs produced from insect-fed hens in the United Kingdom. They found that consumers have little knowledge about the benefits of insects as hen feed, but they have positive attitudes towards the product and its benefits. They also suggested that future studies could focus on whether using different insect species could influence consumers' responses. Following this line of research, Sogari et al. (2022a) investigated how the processed stage of the insect feed (i.e., the use of "insect-based meal" vs "live insects") influence consumers' purchase intention and willingness to pay for duck meat among Italian consumers. Their results showed the main drivers (i.e., previous entomophagy experience, positive attitude, interest in environmental issues) are the same regardless the type of insects.

Taking into consideration the consumers' limited knowledge about this topic and the beliefs that foods obtained from insect-fed animals could have some off-flavour (Verbeke et al., 2015), it has been found that communicate that the final taste will not change compared to a traditional feedstuff are important determinants to decrease disgust and increase acceptance (Menozzi et al., 2021). The study by Verbeke et al. (2015) remains one of the few to have conducted a comprehensive analysis of the acceptance of insect as animal feed between different animal species and among different stakeholder groups. They found that farmers' attitude towards the use of insects in animal feed in livestock farmers with ruminants is less favourable compared to livestock farmers without cattle (e.g., pigs or poultry). Thus, the idea of consuming beef or milk obtained from cattle raised on insect-based feed was the most disliked (Verbeke et al., 2015). This was also confirmed by another study which showed that the acceptance to use insects feed for cattle was the lowest compared to other animals (Domingues et al., 2020). The main rejection barriers toward this new feeding practice are related to food neophobia and the disgust of the idea of consuming animals fed with insects (Bazoche and Poret, 2021; Sogari et al., 2022b; Spartano and Grasso, 2021b). Such psychological barriers could be reduced by providing them information on the several benefits of using insects as a promising, sustainable, protein rich (partial) alternative compared to traditional feed (Bazoche and Poret, 2021; Sogari et al., 2022b). For example, Menozzi et al. (2021) reported that information about the naturalness of feeding poultry with insects contributed to reduce the disgust among the respondents who received the information treatment compared to the control group.

So far, it is not still clear whether and how much socio-demographic variables influence consumers' acceptance of the use of insects as feed or not. Most of the studies used convenience samples and results are ambiguous; thus it is difficult to determine which individual traits (e.g., age, gender) will help to predict the readiness to consume and purchase farmed animals fed with insects. More studies with representative samples of the countries are needed. Understanding which individual factors and marketing/communication strategies could affect consumers' perceptions of insects as feed plays an important role in the development of the emerging sector of insects as feed. For example, Bazoche and Poret (2021) showed that the term "insect-based feed" was linked to higher acceptability than the term "insect meal", probably due to a close connection of this latter with the term 'animal meal' and to the mad cow crisis. Moreover, considering that the components of feed meals could affect the sensory quality of animal products, i.e. meat and eggs (Gasco et al., 2019; Shaviklo, 2022; Sogari et al., 2022b) it is necessary to investigate deeper the sensory evaluation using both trained panels and untrained panels (i.e., consumers). These studies for example could focus also on the different level of inclusion of insect-derived feeds and understand which is the optimal level of inclusion that do not negatively affect consumer sensory preferences.

4.2. Are consumers ready for insects as food?

Eating insects is a very common and culturally ingrained practice of many populations, especially in certain geographical areas of Southeast Asia or Tropical countries, where insects have long served as traditional foods (DeFoliart, 1999). Food preferences are the results of cultural conditioning (Harris and Ross, 1987) therefore, if the attention is shifted towards Western societies, where entomophagy is not embedded in culinary traditions, the study of acceptance and psychological drivers that influence the introduction of insects into westerners' diet turns out to be a major challenge and a very active topic for many scholars (Ghosh et al., 2018). Understanding and shifting consumers' preferences towards "unknown" foods that does not belong to the current traditional diet is no easy task (Dagevos, 2021). Insofar, several consumer studies have been carried in Europe (Mancini et al., 2022; Tan et al., 2016; Verneau et al., 2016, 2020), North America (Looy and Wood, 2006; Ruby et al., 2015) and Australia (Lensvelt and Steenbekkers, 2014; Sogari et al., 2019b), which differ in terms of both cultural traditions as well as lifestyles and eating habits, highlighting the overall low willingness to consume insects among western consumers. If psychological traits are considered, it has been widely acknowledged that food neophobia and disgust play an utterly important role in determining Westerners' acceptance of edible insects (Fischer and Steenbekkers, 2018; La Barbera et al., 2018; Mancini et al., 2019; Sogari et al., 2019b; Tan et al., 2016). Food neophobia is the propensity to eschew unknown and novel foodstuffs (Pliner and Hobden, 1992), while disgust is an emotional defence reaction designed to prevent the intake of potentially harmful substances through the mouth (Oaten et al., 2009). Both traits have been found to be positively correlated (Björklund and Hursti, 2004) and might be affected and, in turn, may be influential, by other impediments to the consumption of edible insects, such as food safety and health concerns. According to Dagevos (2021), edible insects are often associated with negative attitudes, expectations, and appropriateness because of Westerners' lack of familiarity with product itself.

Furthermore, if edible insects are suggested as an alternative source of protein, competing against central position of meat in the ubiquitous omnivores' regime, consumers' expectations, perception of appropriateness or perceived benefits also play a key role (Onwezen et al., 2021). In a study attempting to determine people's attitudes towards novel foods using a sample testing of burgers made with different and unusual ingredients (insects, lamb brain and frog meat), participants expected those with novel ingredients to be less tasty than the conventional product containing only beef (Tan et al., 2016), although, according to Sogari and colleagues, the perception of insect food products is more favourable after tasting than what was expected (Sogari et al., 2018). Another key element that may influence consumers' willingness to try new foods is the appropriateness of the ingredients in comparison to conventional product ingredients, e.g., Lombardi and colleagues highlighted that enriching a pasta with insect flour was found to be more acceptable than a chocolate bar containing insects (Lombardi et al., 2019). Given the positive impact that edible insects rearing, and possible human consumption have upon the three pillars of sustainability (see Guiné et al., 2021, for a review), many scholars highlighted the prominent role of communication to convey edible insects' benefits, both from a marketing or policy perspectives. Precisely, it has been shown that information provision does have significant and positive effect upon consumers' intention, behaviour, and willingness to pay, with social benefit messages being more salient than health- or environmental-benefits messages (Fasanelli et al., 2020; La Barbera et al., 2016; Lombardi et al., 2019). Many studies showed that Western consumers are more prone to eat processed insects instead of raw insects (Hartmann and Siegrist, 2016; Ruby et al., 2015; Schösler et al., 2012), ascertained that they are satisfactory from a sensory point of view (Schouteten et al., 2016). However, food products containing processed insects cannot be considered "meat-replacers" (e.g., insect chips or chocolate bars enriched with insect proteins), but they could act as a driving force towards the consumption of raw insects. Overcoming the barrier that Western consumers have raised against edible insects remains a major challenge and insect marketing should focus heavily on generating positive associations towards edible insects, perhaps placing social benefits alongside the subject of a more sustainable diet. Nevertheless, if the consumption of insects is going to increase worldwide, several nutritional challenges may arise. Given that insects contain antinutrients like phytic acid and protease inhibitors, or chitin, a complex polysaccharide that can be difficult to digest, developing methods to minimize antinutrient content and increase digestibility of insects before consumption will be important to ensure optimal nutrient absorption. In summary, while the nutritional benefits of consuming insects are clear, there are still several challenges that must be addressed in order to increase their consumption on a global scale.

5. Future perspectives of the insect farming industry: concluding remarks

A new production sector of insects as food and feed, as well as for other industrial applications, is emerging and is fast developing. The above analyzed legislative, economic, and scientific aspects related to insects' consumption allow to propose some final remarks on future evolutions. From a normative perspective, regulatory efforts are still required in order to fully take advantage of the potentialities of insects-industry; future regulatory interventions will thus reveal crucial to ensure a more effective balance-point between food safety, food security, promotion of investments in innovative insects-based products for animal and human consumption and a more sustainable food sector. From a consumer point of view, several studies agree that consumers will have higher acceptance of "indirect entomophagy" than using insect as food. However, as insect meal is currently more expensive to procure than soybean meal price premiums for alternatively insect-fed animal and insect-based food products will be needed to compensate for higher feed input costs. Thus, consumers' willingness to pay a premium is going to be a key issue for economic sustainability of the insect farming chain. This could lead retailers (including wholesale and purchase organisations) to switch from conventional to insect-fed animal products. We believe that this review could pave the way for further studies on the topic. For instance, future research regarding insects as an alternative feed for domesticated species and insect-based food should include sensory evaluation along with consumer experiments to better investigate the potential consumer acceptance of current commercial and available products. As a result, more real behavioural studies will allow to understand whether consumers are interested in repeated purchase behaviour which will allow the market to grow. To meet the food and feed security challenges, insects will have to be considered all-around, including applications in the food, feed, and other sectors. In particular, their potentiality will be used to increase the protein content of food, to integrate protein content in animal feed and/or to extract other bioactive compounds, such as chitin, that might be used for other industrial applications. Thus, the development of insects and insect-products might lead the way towards a more sustainable food supply chain.

CRediT authorship contribution statement

Giovanni Sogari: Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing. **Mario Amato:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing. **Rossella Palmieri:** Writing – original draft, Writing – review & editing. **Jasmine Hadj Saadoun:** Investigation, Writing – original draft, Writing – review & editing, Visualization. **Giulia Formici:** Investigation, Writing – original draft, Writing – review & editing. **Fabio Verneau:** Writing – original draft, Writing – review & editing, Supervision. **Simone Mancini:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

References

Almeida, C., Murta, D., Nunes, R., Baby, A.R., Fernandes, Â., Barros, L., Rijo, P., Rosado, C., 2022. Characterization of lipid extracts from the Hermetia illucens larvae and their bioactivities for potential use as pharmaceutical and cosmetic ingredients. Heliyon 8 (5), e09455. https://doi.org/10.1016/j.heliyon.2022.e09455.

Almeida, C., Rijo, P., Rosado, C., 2020. Bioactive compounds from Hermetia illucens larvae as natural ingredients for cosmetic application. Biomolecules 10, 976. https://doi.org/10.3390/biom10070976.

Amberg, N., Fogarassy, C., 2019. Green consumer behavior in the cosmetics market. Resources 8, 137. https://doi.org/10.3390/resources8030137.

Ankamah-Yeboah, I., Jacobsen, J.B., Olsen, S.B., 2018. Innovating out of the fishmeal trap: the role of insect-based fish feed in consumers' preferences for fish attributes. Br. Food J. 120, 2395–2410. https://doi.org/10.1108/BFJ-11-2017-0604.

Arora, N.K., Mishra, I., 2022. Current scenario and future directions for sustainable development goal 2: a roadmap to zero hunger. Environ. Sustain. 1–5. https://doi.org/10.1007/s42398-022-00235-8.

Barragán-Fonseca, K.Y., Nurfikari, A., van de Zande, E.M., Wantulla, M., van Loon, J.J. A., de Boer, W., Dicke, M., 2022. Insect frass and exuviae to promote plant growth and health. Trends Plant Sci. 27, 646–654. https://doi.org/10.1016/j.tplants.2022.01.007.

Bazoche, P., Poret, S., 2021. Acceptability of insects in animal feed: a survey of French consumers. J. Consum. Behav. 20, 251–270. https://doi.org/10.1002/cb.1845.

Becker, E.W., 2007. Micro-algae as a source of protein. Biotechnol. Adv. 25 (2), 207–210.

Björklund, F., Hursti, T.J., 2004. A Swedish translation and validation of the Disgust Scale: a measure of disgust sensitivity. Scand. J. Psychol. 45, 279–284. https://doi.org/10.1111/j.1467-9450.2004.00406.x.

Boukid, F., Sogari, G., Rosell, C.M., 2022. Edible insects as foods: mapping scientific publications and product launches in the global market (1996-2021). J. Insects Food and Feed. https://doi.org/10.3920/JIFF2022.0060, 1–16.
Bryant, C., Barnett, J., 2020. Consumer acceptance of cultured meat: an updated review (2018–2020). Appl. Sci. 10 (15), 5201.
Colombino, E., Biasato, I., Ferrocino, I., Bellezza Oddon, S., Caimi, C., Gariglio, M., Dabbou, S., Caramori, M., Battisti, E., Zanet, S., Ferroglio, E., Cocolin, L., Gasco, L., Schiavone, A., Capucchio, M.T., 2021. Effect of insect live larvae as environmental enrichment on poultry gut health: gut mucin composition, microbiota and local immune response evaluation. Animals 11, 2819. https://doi.org/10.3390/ani11102819.
Costi, E., Di Bella, E., Iotti, D., Maistrello, L., 2022. Biocontrol implications of multiparasitism by Trissolcus mitsukurii and Trissolcus japonicus on the invasive brown marmorated stink bug. Entomol. Exp. Appl. 170, 772–781. https://doi.org/10.1111/eea.13185.
Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F.N., Leip, A.J.N.F., 2021. Food systems are responsible for a third of global anthropogenic GHG emissions. Nat. Food 2 (3), 198–209.
Dagevos, H., 2021. A literature review of consumer research on edible insects: recent evidence and new vistas from 2019 studies. J. Insects Food and Feed 7, 249–259. https://doi.org/10.3920/JIFF2020.0052.
DeFoliart, G.R., 1999. Insects as food: why the western attitude is important. Annu. Rev. Entomol. 44, 21–50. https://doi.org/10.1146/annurev.ento.44.1.21.
Delicato, C., Schouteten, J.J., Dewettinck, K., Gellynck, X., Tzompa-Sosa, D.A., 2020. Consumers' perception of bakery products with insect fat as partial butter replacement. Food Qual. Prefer. 79, 103755 https://doi.org/10.1016/j.foodqual.2019.103755.
Domingues, C.H.D.F., Borges, J.A.R., Ruviaro, C.F., Gomes Freire Guidolin, D., Rosa Mauad Carrijo, J., 2020. Understanding the factors influencing consumer willingness to accept the use of insects to feed poultry, cattle, pigs and fish in Brazil. PLoS One 15, e0224059. https://doi.org/10.1371/journal.pone.0224059.
Dos Santos Aguilar, J.G., 2021. An overview of lipids from insects. Biocatal. Agric. Biotechnol. 33, 101967 https://doi.org/10.1016/j.bcab.2021.101967.
FAO, 2019. Food Outlook—Biannual Report on Global Food Markets. FAO, Rome, Italy.
Fao, I.F.A.D., Unicef, W.F.P., Who, 2022. The State of Food Security and Nutrition in the World 2022. Repurposing Food and Agricultural Policies to Make Healthy Diets More Affordable. FAO, Rome.
Fasanelli, R., Galli, I., Riverso, R., Piscitelli, A., 2020. Social representations of insects as food: an explorative-comparative study among millennials and X-generation consumers. Insects 11, 656. https://doi.org/10.3390/insects11100656.
Fernando, S., 2022. Pulse protein ingredient modification. J. Sci. Food Agric. 102 (3), 892–897.
Ferrer Llagostera, P., Kallas, Z., Reig, L., Amores de Gea, D., 2019. The use of insect meal as a sustainable feeding alternative in aquaculture: current situation, Spanish consumers' perceptions and willingness to pay. J. Clean. Prod. 229, 10–21. https://doi.org/10.1016/j.jclepro.2019.05.012.
Finardi, C., Derrien, C., 2016. Novel food: where are insects (and feed...) in regulation 2015/2283? Eur. Food and Feed Law Rev. 11, 119–129.
Fischer, A.R.H., Steenbekkers, L.P.A., Bea), 2018. All insects are equal, but some insects are more equal than others. Br. Food J. 120, 852–863. https://doi.org/10.1108/BFJ-05-2017-0267.
Formici, G., 2020. Novel Food e insetti per il consumo umano tra interventi legislativi e Corte di giustizia: alla ricerca di un difficile equilibrio. Rivista di Diritto Alimentare 14 (4), 48–68.
Franco, A., Salvia, R., Scieuzo, C., Schmitt, E., Russo, A., Falabella, P., 2021. Lipids from insects in cosmetics and for personal care products. Insects 13, 41. https://doi.org/10.3390/insects13010041.
Gasco, L., Biasato, I., Dabbou, S., Schiavone, A., Gai, F., 2019. Quality and consumer acceptance of products from insect-fed animals. In: Sogari, G., Mora, C., Menozzi, D. (Eds.), Edible Insects in the Food Sector. Springer International Publishing, Cham, pp. 73–86. https://doi.org/10.1007/978-3-030-22522-3_6.
Ghosh, S., Jung, C., Meyer-Rochow, V.B., 2018. What governs selection and acceptance of edible insect species? In: Halloran, A., Flore, R., Vantomme, P., Roos, N. (Eds.), Edible Insects in Sustainable Food Systems. Springer International Publishing, Cham, pp. 331–351. https://doi.org/10.1007/978-3-319-74011-9_20.
Giotis, T., Drichoutis, A.C., 2021. Consumer acceptance and willingness to pay for direct and indirect entomophagy. Q Open 1 (2). https://doi.org/10.1093/qopen/qoab015 qoab015.
González, N., Marquès, M., Nadal, M., Domingo, J.L., 2020. Meat consumption: which are the current global risks? A review of recent (2010–2020) evidences. Food Res. Int. 137, 109341.
Gougbedji, A., Detilleux, J., Lalèyè, P.A., Francis, F., Caparros Megido, R., 2022. Can insect meal replace fishmeal? A meta-analysis of the effects of black soldier fly on fish growth performances and nutritional values. Animals 12 (13), 1700. https://doi.org/10.3390/ani12131700.
Guiné, R.P.F., Correia, P., Coelho, C., Costa, C.A., 2021. The role of edible insects to mitigate challenges for sustainability. Open Agriculture 6, 24–36. https://doi.org/10.1515/opag-2020-0206.
Hadi, J., Brightwell, G., 2021. Safety of Alternative Proteins: technological, environmental and regulatory aspects of cultured meat, plant-based meat, insect protein and single-cell protein. Foods 10 (6), 1226.
Hadj Saadoun, J., Sogari, G., Bernini, V., Camorali, C., Rossi, F., Neviani, E., Lazzi, C., 2022. A critical review of intrinsic and extrinsic antimicrobial properties of insects. Trends Food Sci. Technol. 122, 40–48. https://doi.org/10.1016/j.tifs.2022.02.018.
Hahn, T., Tafi, E., Paul, A., Salvia, R., Falabella, P., Zibek, S., 2020. Current state of chitin purification and chitosan production from insects. J. Appl. Chem. Biotechnol. 95, 2775–2795. https://doi.org/10.1002/jctb.6533.
Harris, M., Ross, E.B., 1987. Food and Evolution: toward a Theory of Human Food Habits. Temple University Press.
Hartmann, C., Siegrist, M., 2016. Becoming an insectivore: results of an experiment. Food Qual. Prefer. 51, 118–122. https://doi.org/10.1016/j.foodqual.2016.03.003.
Hawkey, K.J., Lopez-Viso, C., Brameld, J.M., Parr, T., Salter, A.M., 2021. Insects: a potential source of protein and other nutrients for feed and food. Ann. Rev. Anim. Biosci. 9, 333–354. https://doi.org/10.1146/annurev-animal-021419-083930.
HLPE, 2019. Agroecological and Other Innovative Approaches for Sustainable Agriculture and Food Systems that Enhance Food Security and Nutrition. A Report by the High Level Panel of Experts on Food Security and Nutrition of the Committee. World Food Security, Rome.
IPIFF, 2022. Guide on good hygiene practices for European union (EU) producers of insects as food and feed. Available online at: https://ipiff.org/good-hygiene-practices/, 9.13.22.
Jones, C., 2012. The novel food regulation: revision required? A view from a regulator. Eur. Food and Feed Law Rev. 7, 81–83.
La Barbera, F., Riverso, R., Verneau, F., 2016. Understanding beliefs underpinning food waste in the framework of the theory of planned behaviour. Calitatea 17, 130.
La Barbera, F., Verneau, F., Amato, M., Grunert, K., 2018. Understanding Westerners' disgust for the eating of insects: the role of food neophobia and implicit associations. Food Qual. Prefer. 64, 120–125. https://doi.org/10.1016/j.foodqual.2017.10.002.
La Barbera, F., Verneau, F., Videbæk, P.N., Amato, M., Grunert, K.G., 2020. A self-report measure of attitudes toward the eating of insects: construction and validation of the Entomophagy Attitude Questionnaire. Food Qual. Prefer. 79, 103757 https://doi.org/10.1016/j.foodqual.2019.103757.
Lähteenmäki-Uutela, A., Grmelová, N., 2016. European law on insects in food and feed. Eur. Food and Feed Law Rev. 11, 2–8.
Lähteenmäki-Uutela, A., Marimuthu, S.B., Meijer, N., 2021. Regulations on insects as food and feed: a global comparison. J. Insects Food and Feed 7 (5), 849–856. https://doi.org/10.3920/JIFF2020.0066.
Lensvelt, E.J.S., Steenbekkers, L.P.A., 2014. Exploring consumer acceptance of entomophagy: a survey and experiment in Australia and The Netherlands. Ecol. Food Nutr. 53 (5), 543–561. https://doi.org/10.1080/03670244.2013.879865.
Lombardi, A., Vecchio, R., Borrello, M., Caracciolo, F., Cembalo, L., 2019. Willingness to pay for insect-based food: the role of information and carrier. Food Qual. Prefer. 72, 177–187. https://doi.org/10.1016/j.foodqual.2018.10.001.
Looy, H., Wood, J.R., 2006. Attitudes toward invertebrates: are educational "bug banquets" effective? J. Environ. Educ. 37, 37–48. https://doi.org/10.3200/JOEE.37.2.37-48.
Mancini, S., 2020. Insects as sustainable feed and food. Acta Fytotech. Zootech. 23, 214–216.
Mancini, S., Sogari, G., Espinosa Diaz, S., Menozzi, D., Paci, G., Moruzzo, R., 2022. Exploring the future of edible insects in Europe. Foods 11, 455. https://doi.org/10.3390/foods11030455.
Mancini, S., Sogari, G., Menozzi, D., Nuvoloni, R., Torracca, B., Moruzzo, R., Paci, G., 2019. Factors predicting the intention of eating an insect-based product. Foods 8, 270. https://doi.org/10.3390/foods8070270.
Manzano-Agugliaro, F., Sanchez-Muros, M.J., Barroso, F.G., Martínez-Sánchez, A., Rojo, S., Pérez-Bañón, C., 2012. Insects for bio-diesel production. Renew. Sustain. Energy Rev. 16, 3744–3753. https://doi.org/10.1016/j.rser.2012.03.017.
Melenchón, F., de Mercado, E., Pula, H.J., Cardenete, G., Barroso, F.G., Fabrikov, D., Lourenço, H.M., Pessoa, M.-F., Lagos, L., Weththasinghe, P., Cortés, M., Tomás-Almenar, C., 2022. Fishmeal dietary replacement up to 50%: a comparative study of two insect meals for rainbow trout (Oncorhynchus mykiss). Animals 12, 179. https://doi.org/10.3390/ani12020179.
Menozzi, D., Sogari, G., Mora, C., Gariglio, M., Gasco, L., Schiavone, A., 2021. Insects as feed for farmed poultry: are Italian consumers ready to embrace this innovation? Insects 12, 435. https://doi.org/10.3390/insects12050435.
Meyer-Rochow, V.B., 1975. Can insects help to ease the problem of world food shortage? Search 6 (7), 261–262.
Moruzzo, R., Mancini, S., Guidi, A., 2021. Edible insects and sustainable development goals. Insects 12 (6), 557.
Nieto, J., Plaza, J., Lara, J., Abecia, J.-A., Revilla, I., Palacios, C., 2022. Performance of slow-growing chickens fed with Tenebrio molitor larval meal as a full replacement for soybean meal. Vet. Sci. 9, 131. https://doi.org/10.3390/vetsci9030131.
Oaten, M., Stevenson, R.J., Case, T.I., 2009. Disgust as a disease-avoidance mechanism. Psychol. Bull. 135, 303–321. https://doi.org/10.1037/a0014823.
Onwezen, M.C., Bouwman, E.P., Reinders, M.J., Dagevos, H., 2021. A systematic review on consumer acceptance of alternative proteins: pulses, algae, insects, plant-based meat alternatives, and cultured meat. Appetite 159, 105058. https://doi.org/10.1016/j.appet.2020.105058.
Paganizza, V., 2016. Eating insects: crunching legal clues on entomophagy. Rivista di Diritto Alimentare 10 (1), 16–41.
Paganizza, V., 2019. Bugs in law: insetti e regole dai campi alla tavola. CEDAM.
Paganizza, V., 2020. Are insects novel foods? Eur. Food and Feed Law Rev. 15, 579–587.
Pandey, A., Larroche, C., Ricke, S.C., Dussap, C.G., Gnansounou, E. (Eds.), 2011. Biofuels: Alternative Feedstocks and Conversion Processes. Academic Press.
Pliner, P., Hobden, K., 1992. Development of a scale to measure the trait of food neophobia in humans. Appetite 19, 105–120. https://doi.org/10.1016/0195-6663(92)90014-W.
Popoff, M., MacLeod, M., Leschen, W., 2017. Attitudes towards the use of insect-derived materials in Scottish salmon feeds. J. Insects Food and Feed 3, 131–138. https://doi.org/10.3920/JIFF2016.0032.

Rinaudo, M., 2006. Chitin and chitosan: properties and applications. Prog. Polym. Sci. 31, 603–632. https://doi.org/10.1016/j.progpolymsci.2006.06.001.
Ruby, M.B., Rozin, P., Chan, C., 2015. Determinants of willingness to eat insects in the USA and India. J. Insects Food and Feed 1, 215–225. https://doi.org/10.3920/JIFF2015.0029.
Saatkamp, H.W., Aartsma, Y., Hogeveen, H., Augustijn, M., Baumann, A., Beukeboom, L. W., Borghuis, A., Bovenkerk, B., van der Bruggen, M., Companjen, M.H., Dörper, A., Salles, J.F., van der Fels-Klerx, H.J., Fischer, A.R.H., Haenen, O., Hosseini, A., van den Hurk, J., Jacobs, P., Jansen, W.L., de Jong, M., Kortsmit, Y., Leipertz, M., Lommers, H., van Loon, J.J.A., van Loon, M.S., Maistrou, S., Niermans, K., Schmitt, E., Shah, P.N., Spaans, A., Veldkamp, T., Verweij, M.F., Vogel, M., Kokota, A.V., Wertheim, B., Dicke, M., 2022. Development of sustainable business models for insect-fed poultry production: opportunities and risks. J. Insects Food and Feed. https://doi.org/10.3920/JIFF2021.0216, 1–16.
Sarode, S., Upadhyay, P., Khosa, M.A., Mak, T., Shakir, A., Song, S., Ullah, A., 2019. Overview of wastewater treatment methods with special focus on biopolymer chitin-chitosan. Int. J. Biol. Macromol. 121, 1086–1100. https://doi.org/10.1016/j.ijbiomac.2018.10.089.
Scaffardi, L., 2020. I novel food, un futuro ancora da definire. BioLaw J. Rivista di BioDiritto 43–66. https://doi.org/10.15168/2284-4503-649.
Scaffardi, L., Formici, G. (Eds.), 2022. Novel Foods and Edible Insects in the European Union. An Interdisciplinary Analysis. Springer Nature.
Schösler, H., de Boer, J., Boersema, J.J., 2012. Can we cut out the meat of the dish? Constructing consumer-oriented pathways towards meat substitution. Appetite 58, 39–47. https://doi.org/10.1016/j.appet.2011.09.009.
Schouteten, J.J., De Steur, H., De Pelsmaeker, S., Lagast, S., Juvinal, J.G., De Bourdeaudhuij, I., Verbeke, W., Gellynck, X., 2016. Emotional and sensory profiling of insect-, plant- and meat-based burgers under blind, expected and informed conditions. Food Qual. Prefer. 52, 27–31. https://doi.org/10.1016/j.foodqual.2016.03.011.
Sforza, S., 2022. Food (In)Security: the role of novel foods on sustainability. In: Scaffardi, L., Formici, G. (Eds.), Novel Foods and Edible Insects in the European Union. An Interdisciplinary Analysis. Springer, Cham, pp. 59–79. https://doi.org/10.1007/978-3-031-13494-4_4 Nature.
Shaviklo, A.R., 2022. The influence of insect-derived and marine-based diets on sensory quality of poultry meat and egg: a systematic review. J. Food Sci. Technol. https://doi.org/10.1007/s13197-022-05484-3.
Sheehan, G., Farrell, G., Kavanagh, K., 2020. Immune priming: the secret weapon of the insect world. Virulence 11, 238–246. https://doi.org/10.1080/21505594.2020.1731137.
Simpson, C., 2016. Data protection under food law post: in the aftermath of the novel foods regulation. Eur. Food and Feed Law Rev. 11, 309–314.
Smetana, S., Leonhardt, L., Kauppi, S.M., Pajic, A., Heinz, V., 2020. Insect margarine: processing, sustainability and design. J. Clean. Prod. 264, 121670 https://doi.org/10.1016/J.JCLEPRO.2020.121670.
Sogari, G., Amato, M., Biasato, I., Chiesa, S., Gasco, L., 2019a. The potential role of insects as feed: a multi-perspective review. Animals 9, 119. https://doi.org/10.3390/ani9040119.
Sogari, G., Bogueva, D., Marinova, D., 2019b. Australian consumers' response to insects as food. Agriculture 9, 108. https://doi.org/10.3390/agriculture9050108.
Sogari, G., Dagevos, H., Amato, M., Taufik, D., 2022a. Consumer perceptions and acceptance of insects as feed and food: current findings and future outlook. In: Scaffardi, L., Formici, G. (Eds.), Novel Foods and Edible Insects in the European Union. An Interdisciplinary Analysis. Springer, Cham. https://doi.org/10.1007/978-3-031-13494-4_8.
Sogari, G., Menozzi, D., Mora, C., 2018. Sensory-liking expectations and perceptions of processed and unprocessed insect products. Int. J. Food Syst. Dynam. 9, 314–320. https://doi.org/10.18461/ijfsd.v9i4.942.
Sogari, G., Menozzi, D., Mora, C., Gariglio, M., Gasco, L., Schiavone, A., 2022b. How information affects consumers' purchase intention and willingness to pay for poultry farmed with insect-based meal and live insects. J. Insects Food and Feed 8, 197–206. https://doi.org/10.3920/JIFF2021.0034.
Spartano, S., Grasso, S., 2021a. Consumers' perspectives on eggs from insect-fed hens: a UK focus group study. Foods 10, 420. https://doi.org/10.3390/foods10020420.
Spartano, S., Grasso, S., 2021b. UK consumers' willingness to try and pay for eggs from insect-fed hens. Fut. Foods 3, 100026. https://doi.org/10.1016/j.fufo.2021.100026.
Tan, H.S.G., Fischer, A.R.H., van Trijp, H.C.M., Stieger, M., 2016. Tasty but nasty? Exploring the role of sensory-liking and food appropriateness in the willingness to eat unusual novel foods like insects. Food Qual. Prefer. 48, 293–302. https://doi.org/10.1016/j.foodqual.2015.11.001.
Tzompa-Sosa, D.A., Dewettinck, K., Gellynck, X., Schouteten, J.J., 2021. Replacing vegetable oil by insect oil in food products: effect of deodorization on the sensory evaluation. Food Res. Int. 141, 110140 https://doi.org/10.1016/J.FOODRES.2021.110140.
UN Sustainable Development Group, 2020. The Impact of COVID-19 on Food Security and Nutrition (Policy Brief 1-23). Retrieved from. https://unsdg.un.org/resources/policy-brief-impact-covid-19-food-security-and-nutrition, 9.13.22.
Van der Weele, C., Feindt, P., van der Goot, A.J., van Mierlo, B., van Boekel, M., 2019. Meat alternatives: an integrative comparison. Trends Food Sci. Technol. 88, 505–512.
Van Huis, A., 2020. Insects as food and feed, a new emerging agricultural sector: a review. J. Insects Food and Feed 6 (1), 27–44.
van Huis, A., Dicke, M., van Loon, J.J.A., 2015. Insects to feed the world. J. Insects Food and Feed 1, 3–5. https://doi.org/10.3920/JIFF2015.x002.
Vauterin, A., Steiner, B., Sillman, J., Kahiluoto, H., 2021. The potential of insect protein to reduce food-based carbon footprints in Europe: the case of broiler meat production. J. Clean. Prod. 320, 128799 https://doi.org/10.1016/j.jclepro.2021.128799.
Verbeke, W., Spranghers, T., De Clercq, P., De Smet, S., Sas, B., Eeckhout, M., 2015. Insects in animal feed: acceptance and its determinants among farmers, agriculture sector stakeholders and citizens. Anim. Feed Sci. Technol. 204, 72–87. https://doi.org/10.1016/j.anifeedsci.2015.04.001.
Verneau, F., La Barbera, F., Amato, M., Riverso, R., Grunert, K.G., 2020. Assessing the role of food related lifestyle in predicting intention towards edible insects. Insects 11, E660. https://doi.org/10.3390/insects11100660.
Verneau, F., La Barbera, F., Kolle, S., Amato, M., Del Giudice, T., Grunert, K., 2016. The effect of communication and implicit associations on consuming insects: an experiment in Denmark and Italy. Appetite 106, 30–36. https://doi.org/10.1016/j.appet.2016.02.006.
Volpato, A., 2015. La riforma del regolamento sui Novel Food: alla ricerca di un impossibile equilibrio? Rivista di Diritto Alimentare 9 (4), 26–43.
Webster, E., Gupta, A., Ambros, R. (Eds.), 2020. Transnational Food Security. Routledge.