The International Platform of Insects for Food and Feed

Building bridges between the insect production chain, research and policymakers

v2 May 2022

ipiff

THREE RESEARCH PRIORITIES

1

EXPLORING THE USE OF ‘NEW SUBSTRATES’ AS FEED FOR INSECTS

2

THE REUSE OF INSECT BY-PRODUCTS - A FOCUS ON THE PROMISING CONTRIBUTION OF INSECT FRASS TO AGRICULTURE

3

EXPLORING THE NUTRITIONAL AND HEALTH BENEFITS OF USING INSECTS FOR FOOD AND FEED

PREFACE

The European insect sector is a new agricultural industry that continues to expand rapidly across the four corners of the continent. Driven by the challenge to feed a growing population within planetary boundaries, entrepreneurs, startups, and established agri-food actors alike joined forces with academia to address knowledge gaps that would contribute to unlocking opportunities under the EU legislative framework.

This collaboration bore fruit: after several years of intensive efforts, major regulatory milestones were achieved in the European Union in 2021, with the **first novel food authorisations**, the **approval of insect processed animal proteins in poultry and pig feed** and the **first standards for processing insect frass** entering into force in the same year. The efficient dialogue between industry, led by the International Platform of Insects for Food and Feed (IPIFF), policymakers (e.g. European Commission, Member States authorities), academia (Universities, research centres) - and several other actors - was instrumental in unlocking such legislative opportunities.

The successful story of insect farming continues. In addition to the imminent threat of climate change and the need to provide sustainably produced food for both developed and developing countries, new challenges arise ahead of us. With insect farming, we have an opportunity to make our food systems more resilient in the face of future disruptions caused by pandemics or military conflicts - while also opening new horizons for biobased innovation or even self-sustaining future human settlements in outer space.

Initiatives such as this brochure are of crucial importance for the future success of the sector. Through a comprehensive multistakeholder dialogue, this publication identified and prioritised knowledge gaps which - if addressed - will provide a beneficial contribution to the expansion of insect farming. ***Diversifying the spectrum of authorised substrates***, strengthening agri-food circularity by ***improving the knowledge around the multiple advantages of insect frass as fertiliser***, while also ***filling gaps around the health benefits of insects in food and feed*** - these are topics that academia focused on through EU funded projects (*e.g. such as the Horizon 2020 project SUSINCHAIN*) and matters that will remain of high relevance in the future. In the longer run, targeted research that will demonstrate the nutritional, environmental and economic advantages of insect farming will be key to maximising the contribution of the insect sector to the EU Green Deal ambitions and overarching UN Agenda 2030.

Therefore, in my capacity as the President of the Study Commission Insects of the European Federation of Animal Science (EAAP), I encourage stakeholders active in this field to rely on this document and other IPIFF publications - and I warmly invite everyone to continue to engage in this fruitful dialogue with the industry and policymakers.

Dr Teun Veldkamp
President of the Study Commission Insects of the European Federation of Animal Science (EAAP) – Senior researcher insects as feed and food at Wageningen University & Research, Wageningen Livestock Research

1. UNLEASHING THE CIRCULARITY POTENTIAL OF THE INSECT SECTOR

1.1. Exploring the use of 'new substrates' as feed for insects

OBJECTIVE A: Expanding the knowledge around the safe use of new substrates as feed for insects

OBJECTIVE B: Broadening the use of insects in bio-based applications

1.1.1. The relevance of the topic

New figures indicate that up to 130 million tonnes of food is wasted every year in the EU

Between one third and 40% of the food produced is not consumed – with figures indicating that between 90 and 130 million tonnes of food are being wasted every year in the European Union[1], creating a financial burden 'estimated at more than 143 billion euros'[2]. As natural decomposers, insects can successfully transform such organic inputs (including former foodstuffs[3] containing meat and fish or catering waste) – that would otherwise be discarded or downcycled. While such materials are not necessarily suitable for other food-producing animals, insect larvae have the unique ability to upcycle these inputs into a wide range of valuable products – protein, lipids, as well as insect frass, which has been shown to be a potent soil amendment. In our view, this will increase the circularity potential of the European insect sector, by closing the loop on unvalued edible resources. In the long run, regulatory reforms on this matter are expected to play a key role in upscaling the production capacity of the European insect sector, as highlighted in a recent paper published by the Joint Research Centre of the European Commission[4].

Insects are highly efficient in converting a wide range of inputs into high-quality protein

As recognised by the Food and Agriculture Organisation (FAO), one of the key advantages of insect farming is their high feed conversion efficiency[5]. Notably, throughout their larval life stages, insects have a comparative advantage in converting inputs into high-quality products (such as protein, fat and fertiliser) – especially due to their ability to adapt to the ambient temperature[6]. Diversifying the spectrum of substrates allowed in insect farming, by including former foodstuffs containing meat and fish and subsequently catering waste to the list of authorised substrates, will further reduce the footprint of the insect sector, while efficiently converting such inputs into valuable and sustainable products – paving the way for the safe reintroduction of valuable nutrients in the feed chain following bioconversion underwent by insects.

Today's legislative framework - what do insects feed on?

Naturally, insects feed on a wide range of inputs. In line with the principles of circular economy and EU's new circular action plan[7], European insect producers do their share by reusing resources in a more sustainable way and by relying on locally produced substrates. According to an internal consultation, most IPIFF members rely on fruit, vegetables, cereal raw materials or other co-products from the agri-food industry, co-products which would otherwise be discarded or underexploited.

As defined by EU standards, former foodstuffs, as well as certain animal by-products (also known as 'category 3' materials) could be used as animal feed. However, presently it is not possible to include former foodstuffs with meat and fish in animals' diets. Yet, the circularity potential of insects could be further enhanced by allowing the wider reuse of animal origin materials - if authorised by the EU legislator.

New categories of insect substrates can positively contribute to unleashing the circularity potential of the European insect sector

Widening the possibilities of using new substrates will play a key role in enhancing the circularity of insect production, helping European insect farms to reach their full potential. The inclusion of former foodstuffs containing meat and fish, followed by catering waste, will be an essential pillar – such materials, not suitable for other farmed animals are better upcycled by insect bioconversion. To complement the increasing demand for protein in both human food and animal feed, these 'yet unauthorised' substrates would enable the European insect sector to reach the expected level of production.

Therefore, aligning the current legislative framework with the on-site realities of insect farms and the unique ability of insects to upcycle such materials remains a priority for the European insect sector. New substrates authorised in insect farming will prove to be beneficial for insect farming, but also in addressing key societal challenges relevant for the EU Member States[8].

IPIFF advocates for the proper science-based evaluation of potential new substrates that could be used in insect farming. In the past years, our association worked on collecting the available evidence on the possible authorisation of former foodstuffs containing meat and fish as insect substrate. Another matter that may restrict the wider use of former foodstuffs in animal feed is the presence of adventitious plastic packaging residues that hinder the possibility of reusing certain products (due to the 'zero tolerance' standards). In the past years, research also looked into the potential of insects to safely transform such materials – with promising results[9]. Ongoing research projects (under national, Horizon 2020 or Horizon Europe projects) will play a key role in providing a suitable context, prior to 'mandating the European Food Safety Authority (EFSA) to deliver fully documented conclusions on the potential risks'[10] on former foodstuffs containing meat and fish in the feed of insects.

The use of new substrates in technical applications

In addition to their positive contribution throughout the food and feed chains, insects can also play a key role in facilitating the implementation of EU Bioeconomy Strategy's goals[11]. To this end, new innovative materials may also be used in distinct insect farming facilities in order to produce a wide range of bio-based materials (such as biofuels, bioplastics and others – later referred to as 'technical applications'). Therefore, numerous inputs – which are not necessarily suitable for insects farmed for food and feed - may be integrated into such closed production cycles, ensuring that materials which could otherwise be considered waste are upcycled into sustainable sources of energy or alternatives to linear systems of production. Ensuring that animal safety and welfare standards are met, these new substrates will play an essential role in the production of biobased products - without competing for limited natural resources.

By authorising new substrates suitable for technical applications, the bioconversion underwent by insects will unleash bio-based innovation, defining new business models that will strengthen the ties between agriculture (in this case, by-products from farms), energy (by producing biogas, biofuel and others), and research and innovation (investigating the immense potential of insect by-products in bioplastics, bio-lubricants, etc.). In line with the updated EU Bioeconomy Strategy[12] and the EU Green Deal objectives, scaling up the circularity potential of insect farming will reduce the pressure on the environment, while improving its competitive advantage in the EU. In the long run, closing the loop through a multistakeholder approach (that considers farmers essential players in bio-based innovation) will play a key role in reducing the greenhouse gases emissions, facilitating climate change mitigation and adaptation.

1.1.2. The state of research

According to the Scientific Opinion published by the European Food Safety Authority (EFSA) in 2015, 'the environmental risk of insect farming is expected to be comparable to other animal production system'. Yet, the same EFSA report specifies that factors such as the 'production methods, the substrate used, the stage of harvest, the insect species and developmental stage, as well as the methods for further processing will all have an impact on the occurrence and levels of biological and chemical contaminants in food and feed products derived from insects'. To some extent, this conclusion sieves the research priorities on the topic of new potential substrates.

Hermetia illucens larvae - credits to Shutterstock

Since the publication of the first version of this brochure, several research groups looked into the suitability of substrates not presently authorised for insect farming activities, as well as the safety implications related to their use. In this updated version, a couple of such studies are included – yet, the objective of this chapter is not to include a complete literature overview of these publications.

Chemical contaminants

The inclusion of former foodstuffs containing meat and fish and catering waste in the feed of insects is expected to have low chemical risks for insect production activities, particularly because such products were intended to be used for human consumption[13]. A recent study evaluating the potential of unauthorised former foodstuffs hypothesized that differences concerning possible chemical risks could depend taking into account the presence of meat or possible packaging residues. However, the same study concluded that 'none of the concentrations of the analysed contaminants in the substrate and the larvae exceeded the respective legal limits in the EU'[14].

The adventitious presence of inedible elements that are used to facilitate the placing on the market of foodstuffs (such as labels, packaging and other food contact materials[15]) or that come in contact with catering products (such as paper tissues, plastic cutlery, etc.) is also a subject somewhat covered in the context of studies on unauthorised materials. Research confirms that certain insect species are likely to have different responses to synthetic products, such as plastics. Some have shown the ability to degrade plastics (e.g. yellow mealworm)[16], while others (e.g. black soldier fly) would avoid these physical impurities[17]. Yet, further evidence on the impact of such items on the development and health of farmed insect species is needed, in order to provide farmed insects with nutritious and safe feed – while also guaranteeing the suitability of the end products.

Furthermore, according to EFSA's Risk profile from 2015, considering the specific life cycle (i.e. short life span from egg to adult) and limited repeated feeding, insects have a lower risk of bioaccumulation than other farmed animals[18]. Presently, studies indicate that insect species process heavy metals differently[19]. The same research group concluded that black soldier fly larvae did not accumulate mycotoxins[20] and pesticides, and that these substances had no negative influence on their development. Furthermore, recent investigations show that different insect species have distinct responses in contact with substrates contaminated with mycotoxins, with certain species degrading such substances, while others are excreting them.

Microbiological contaminants

Similarly to the chemical contaminants, microbiological risks are also expected to be low in catering waste and former foodstuffs containing meat and fish. However, it is essential to ensure that such possible inputs do not undergo significant deterioration prior to their use as insect substrate[21]. Limiting the time frame between collection and bioconversion of insects will play a key role in guaranteeing the safety of the products. In case biological contaminants are present in the 'substrates used to grow insects, active replication of the pathogens in the intestinal tract does not seem to happen in insects'[22]. Moreover, in 2015, EFSA concluded that 'mammalian prions cannot replicate in insects, and therefore insects are not considered to be possible biological vectors and amplifiers of prions'[23].

Technical applications

With regard to technical applications, studies confirm the added value of insects in converting low-value materials into a wide range of outputs, such as bioplastics[24], biogas[25] and biodiesel[26], for instance. Upcycling unauthorised agricultural by-products by using insects has the potential to reduce certain environmental challenges (due to the inappropriate disposal of such materials).

Taking advantage of the fat content of insect larvae, biodiesel of similar qualities to rapeseed oil-derived fuel can be produced[27]. While generally biorefineries would rely on products that could also be suitable for food and feed, bioconversion underwent by insects could effectively use resources that would otherwise be considered 'waste'[28]. In addition, the inclusion of insect frass in the production of biogas has also shown promising results[29]. To ensure the safety of the production chain for technical applications, it is preferred to include the frass in the biorefinery[30]. Subsequently, the digestate can be disposed of taking into account the best available technology[31]. Moreover, chemical substances – such as polymers – may be extracted following the bioconversion of substrates unauthorised for food and feed (examples are pheomelanin, insect gelatin, or chitin). However, while the presently available scientific evidence confirms the immense potential of insect bioconversion, research on technical applications in an EU context is not as evolved due to legislative constraints[32].

1.1.3. The research needs of the

European insect sector

Implementing a life cycle approach, while ensuring the health and safety of insects

In the long run, identifying the **species-specific types of feed with the aim to achieve a lower feed conversion ratio**, while taking into account a life cycle perspective, could play a role in reducing the environmental footprint of animal farming[33]. More precisely, the authorisation of new substrates will not only diversify the options insect farmers have, but they will also help in **the development of personalised feeding strategies** – depending on the nutrition of the substrates that are available. The further investigation of such **optimised feed formulations** for non-ruminant livestock should also rely on the promising inclusion of insect-based ingredients in combination with novel ingredients (e.g. algae, yeast, fermentation products, etc.).

Guaranteeing the safety of insect-based products

Specific research needs shall be prioritised by companies, academia or consortia applying for research funding, taking into account the categories of potential new substrates that are available, feasible and compatible with their business targets[34]. Yet, the EFSA scientific opinion from 2015 provides interesting directions on this matter[35]. To this end, future research can contribute to expanding the current knowledge around the possible risks of insect-derived products reared on former foodstuffs containing meat and fish and catering waste.

Chemical contaminants

With some exceptions that deserve further attention, insect larvae are generally less prone to the bioaccumulation of heavy metals, pesticides or persistent organic pollutants[36]. Yet, further research on the potential response of insect species to heavy metals[37] and mycotoxins is likely to answer numerous questions on species-specific mechanisms.

Microbiological contaminants

While microbiological parameters are closely monitored by food business operators, the occurrence of certain pathogens depends on the processing methods applied once inputs such as catering products and foodstuffs are not considered to be suitable for human consumption. It is necessary to investigate **the suitability of the different categories of former foodstuffs containing meat and fish[38]**, taking into account **species-specific biological needs[39]**. While it is likely that different species will have peculiar pathways for processing certain microbiological contaminants, more remains to be investigated on the role of the intestinal microbiota and its development in contact with such inputs. Potentially, modulating the abilities of insect larvae to better respond to such possible pathogens will facilitate the elimination of potential hazards in the feed chain.
Moreover, much remains to be investigated on the topic of ‘ **trans-generational immune priming**’ (TGIP) – a mechanism which allows insects to improve the immunity of their offspring following an interaction with a particular pathogen[40]. To this end, building on the developing experience of the insect sector in the field of genetics (for example, through the selection of particular insect strains taking into consideration their digestion, production, reproduction and resistance), TGIP can serve as a complementary mechanism for **optimising the fitness of farmed insects[41]** - and implicitly the efficiency of insect farming.

The case of ‘packaging materials’

While certain foodstuffs are already authorised in animal feed (e.g. containing products of vegetal origin), the ‘zero tolerance’ for plastic materials (and other items used for packaging) may imply an additional processing step prior to the inclusion of such items in animal feed. However, insects – having the capacity to biotransform certain plastic-derived materials - could be the solution to

Credits to Innovafeed

transforming former foodstuffs into animal feed (as long as the 'zero tolerance' for the insect-based animal feed is ensured), reducing the gap between 'disposal'[42] and 'reuse'[43]. To this end, it is necessary to evaluate the techniques that would ensure the compliance of insect-based[44] ingredients and the safe transformation of by-products[45]. The same approach should be considered for former foodstuffs containing meat and fish.

Including insects in the bio-based industry

The ability of insects to degrade organic matter is widely recognised. Yet, to develop the knowledge around the use of insects in bio-based applications future studies are expected to address matters related to the optimisation of such production chains and improve predictability with regards to the properties of the end-product. Taking into account the wide diversity of potential inputs that are not authorised for insect farming, but which can be directly used for technical applications (such as manure, sludges, etc.), it is necessary to consider the ability of insects to improve the efficiency of such chains (for instance, insects would have a positive contribution by reducing the mass of the inputs used in technical applications, such as biogas production – while concentrating the necessary elements needed in technical applications). Thus, it is necessary to investigate the influence of abiotic factors on the bioconversion of such materials (temperature, humidity, the chemical composition of the substrate, etc.) on an industrial scale.

Up to date, several species that are authorised at EU level (e.g. for food or feed production) have been tested for technical applications – other species, including those that are not authorised in food and feed could also show promising results in converting by-products into versatile inputs[46].

According to recent scientific evidence, the academic community sees a lot of potential in the **bioconversion of products that are not suitable for the food and feed chains**. For example, in the context of the transition towards more sustainable fuels (in response to need to replace currently-used fossil fuels), the development of efficient production chains for biogas and biodiesel should be a priority. Moreover, for other biobased materials (such as bioplastics, biolubricants, etc.), it is necessary to broaden the knowledge around the insect substrates that are suitable in order to produce goods of predictable quality, in line with market requirements.

Credits to Shutterstock

1. UNLEASHING THE CIRCULARITY POTENTIAL OF THE INSECT SECTOR

OBJECTIVE A: Better characterise the benefits of frass application on soils properties

OBJECTIVE B: Develop better knowledge around the nutritional benefits of frass on relevant crops

1.2.1. The relevance of the topic

Insect species are essential for most terrestrial food webs, contributing to numerous interactions between producers, consumers and decomposers. In natural environments, insects consume organic matter and decompose it into excrements that provide valuable nutrients and microorganisms for plants. Similarly to 'mainstream' animal farming, there is a multitude of by-products that insect farms could valorise. However, given the novelty of the sector, most of these goods are not used at their full potential. In addition to the main outputs of insect farms (i.e. whole insects, proteins or fats[47]), the excrements originating from larvae (also known as 'insect frass' or 'frass') have a great potential to be reused as a high-quality soil amendment.

On 29 November 2021, the European Commission adopted a piece of legislation (Regulation (EU) 2021/1925[48]) which regulates the production and placing on the EU market of insect frass. This legal text also includes a definition:

'61. 'frass' means a mixture of excrements derived from farmed insects, the feeding substrate, parts of farmed insects, dead eggs and with a content of dead farmed insects of not more than 5% in volume and not more than 3% in weight.

Since autumn 2021, when European Member States voted on the first baseline standards for insect frass processing, farmers from all across the continent have the possibility to incorporate frass in their crop fertilisation strategies.

Global Context

It is expected that the global market of mineral fertilisers will remain an unpredictable terrain[49]- and crises, such as the COVID-19 pandemic and the unlawful military aggression of Russia in Ukraine will further affect the global supply and demand for such products. Thus, diversifying the spectrum of locally produced soil amendments will reduce the dependency on imported minerals. In the search for more sustainable alternatives, organic fertilising materials - such as insect frass - are presently considered a complementary solution to the increasing demand for high-quality organic[50] soil amendments[51]. The reuse of insect frass in agriculture will improve the circularity of the insect-producing industry. Moreover, building on the recent studies in the past years, a complete research-based characterisation of this by-product would contribute to certifying its excellent fertilising potential – while also generating a complementary revenue for insect producers.

Similar to compost or other types of animal manure, frass contains relevant nutrients and micronutrients, as well as chitin, which could stimulate the growth of beneficial bacteria in soil. These properties make frass a valuable solution for farmers active in crop production (e.g. vineyard producers) or by gardeners across the EU, who can incorporate insect frass as part of their fertilisation strategies (more information was recently published in an IPIFF factsheet on this matter[52]). As described in the chapter below the reuse of frass in agriculture has also been shown to be beneficial for plant growth, health and development. The excrements of insects 'can contain large amounts of nutrients in forms that are easily assimilated by plants'[53]. Furthermore, incorporating insect frass in fertilisation strategies could not only provide plants with essential nutrients and micronutrients, but also with microorganisms inhibiting the growth of pathogens[54] that will, in turn, reduce the necessity to apply additional inputs, such as mineral fertilisers or plant protection products.

1.2.2. The state of research

Several studies were published in recent years on the benefits of frass for soil and plant health. In parallel, research on new applications for farmed insects and their frass is developing rapidly[55]. While changes in the content of animal manure have already been reported in numerous animals[56], it is foreseen that the properties of the insect frass, as well as other insect by-products, could be diet and species-specific.

Chemical properties – the nutrient content of insect frass and its potential in farming

New evidence indicates that the NPK ratio of the frass is similar to the one of animal manure or compost[57]. In addition, the use of such soil amendments is known to improve the weight of seeds[58], as well as seed germination[59]. Frass contributes to higher chlorophyll content, plant fresh weight, as well as length and width – with interesting positive effects on improving the resistance of the plants on abiotic stress factors (such as drought or salinity)[60]. These positive consequences of frass application are also the result of the presence of numerous micronutrients that are essential for plants, as well as other constituents that make frass a valuable soil amendment – some aspects being the subject of ongoing research[61].

Proportional correlations between the diet of insects and their frass have also been made, reflecting the role of the substrate on the nutrient content of frass[62]. Additionally, a recent study evaluating the application of *Tenebrio molitor* frass on plants indicated that 'best results were obtained when the insects were fed a diet low in fat and starch content'[63]. However, the same publication underlines the importance of the insect's diet - which could lead to different outcomes on plant development. For example, one study indicated that eucalypt-feeding beetles suppressed germination and growth of several herbs, due to the chemicals present in the substrate of the insects[64]. This example reflects the need to further investigate the correlations between the diet of the insects and the characteristics of their frass – which could further have different applications due to its possible feed-specific properties.

Microbial properties – the role of frass in improving plant health, growth and development

While the chemical characteristics of a fertiliser are of utmost importance for farmers, their microbial properties are equally relevant. To this end, certain microbes present in insect frass act as plant growth-promoting microorganisms (PGPMs) - improving the health of plants and facilitating the absorption of nutrients[65]. These microbes present in the intestinal microbiota of insects improve the availability of nutrients for plants[66], positively contributing to parameters relevant for plant growth and development (such as root length, seedling vigour and dry biomass)[67]. Additionally, certain bacteria isolated from larval guts – also present in insect frass - have already shown positive results in inhibiting the growth of pathogenic fungi on plants[68]. Implicitly, taking advantage of all these properties insect frass has, would reduce the need to apply supplementary agrochemicals, facilitating the use of such materials in Integrated Pest Management (IPM) strategies.

The physical structure of insect frass may likewise have a positive influence on soil structure enabling better aeration of agricultural fields and thus promoting the activity of beneficial soil invertebrates (e.g. earthworms). However, the actual implications of frass on this aspect is still relatively unexplored.

Lastly, the impact of thermal treatment methods on the characteristics of insect frass, such as the above-mentioned inhibition of pathogenic fungi, is still presently subject to research. According to trials, applying thermal stress is believed to have detrimental consequences on the quality of the product, by killing the PGPMs.

1.2.3. The research needs of the European insect sector

In relation to the research priority **1.2.**, scientific investigations on the **chemical and microbiological properties of frass** are needed in order to improve our overall knowledge regarding the different ways to process and apply insect frass, as well as to better understand the compatibility of insect frass with the sector-specific needs of plants[69].

Generally, the research priorities shall be formulated considering the characteristics of soil amendments, their potential environmental impact, as well as the possible presence of relevant contaminants[70]. As it has been underlined by the above-mentioned studies, the properties of frass vary depending on the insect's diet, as well as their intestinal microbiota. Therefore, building on the existing scientific evidence would contribute to cementing the science-based description of insects frass and the factors influencing its chemical, physicochemical and biological characteristics (depending on the various substrates used, including presently unauthorised inputs such as catering waste and former foodstuffs containing meat and fish) will implicitly improve the predictability of the end-product, allowing farmers to integrate it in their fertilisation strategy depending on the crops that are cultivated and their specific needs[71].

Notwithstanding the chemical and microbiological properties of insect frass, the **interactions between its use in agriculture and the impact on abiotic stress factors** definitely require more attention. In the context of the already frequent drought events, facilitating the role of frass in facilitating the adaptation of plants to saline conditions or water scarcity shall be further investigated.

Lastly, in light of the recent regulatory reforms at EU level (such as the EU baseline standards for insect frass[72] and the approval of insect frass in EU organic crop production[73]), monitoring the longer-term impact of frass on soil properties could offer valuable insights into its benefit on soil carbon sequestration, among others. This aspect - while insufficiently addressed in this paper - may become of high relevance in the future, particularly in the context around the need to identify longer-term solutions in the fight against climate change.

Chemical properties – exploring the nutrients present in insect frass

Studies have already provided results on the correlations between substrates used in insect farming and their manure. Yet, the topic deserves more attention in order to determine the influence of the insect substrate on the specific mechanisms altering the properties of frass[74]. Of particular importance is the NPK content, but also the presence of essential micronutrients. The carbon content and its potential to enhance carbon sequestration in soil represents a very relevant topic, too. Conversely, physical properties relevant for fertilising products are of equal importance[75].

Moreover, the nutritional homeostasis of insects - allowing them to maintain similar elemental composition in their body (such as carbon, nitrogen and phosphorus), when fed with changing diets - shall be further investigated[76]. Analysing such mechanisms that make insects highly efficient in their feeding strategy could play a key role in improving the optimisation of their nutritional needs in insect farms.

Microbial properties – the potential of insect frass in IPM strategies

Complementarily, building on the conclusions of the studies identifying links between insect's diet and the impact of frass on plant health[77], research shall equally evaluate the **general interactions between the substrate used** in insect farming and the consequences on **plant health and plant development**. Such studies shall prioritise taking into account the general guidelines and technical elements for the evaluation of fertilisers and biostimulants[78].

The role of the plant growth-promoting microorganisms (PGPMs) present in the intestinal microbiota and insect frass shall be further investigated. In particular, their **ability to facilitate the absorption of nutrients**[79] and to improve the resistance of plants to pests remain elements that will implicitly bring benefits to farmers: less agricultural inputs (such as mineral fertilisers and pesticides) will be needed without negative impacts on the harvest.

Ensuring that beneficial bacteria for plant health are not lost shall be a priority, too. While the presently used thermal treatment follows the standards for animal manure, **it is necessary to identify the least-harmful sequence of treatment procedures that will keep the beneficial properties of frass**, facilitating its use on farmland.

Tenebrio molitor – credits to Shutterstock

2. EXPLORING THE NUTRITIONAL AND HEALTH BENEFITS OF USING INSECTS FOR FOOD AND FEED

OBJECTIVE A: Demonstrating new health benefits of insects in food and feed

OBJECTIVE B: Backing claims around the nutritional and health advantages of insects in food and feed

2.1.1. The relevance of the topic

Edible insects are presently consumed by more than a quarter of the world population[80]. While in tropical countries most species are harvested from the wild, in the rest of the world indoor farming is becoming more efficient in converting lower value agri-food products into high- quality products for food and feed. The growing demand for alternatives to 'mainstream' sources of animal protein, coupled with the increasing interest in food products that are designed for particular diets or that have a lower environmental footprint[81], reflect the **need to further evaluate the nutritional, chemical and implicitly health related properties of insect based products.**

Insects as food in the EU

New regulatory developments in the European Union opened the market for various products derived from yellow mealworm, migratory locust and the house cricket (note: this document was updated in April 2022)[82]. There is growing evidence that highlights how the consumption of edible insects is developing from an occasional snack[83] to a potent complement in sports nutrition or an alternative to meat consumption[84]. The change in consumers' attitude, driven by health issues, personal or collective beliefs, or simply because of curiosity, creates new opportunities for the insect sector[85]. The diverse ingredients found in insect-based food make such products versatile and compatible with the dietary preferences of semimeatatarian[86] or meatgan[87], flexitarians[88], or athletes[89]. Including insect-based ingredients into staple foods is also a promising sector, since it can improve the nutritional value without affecting technological features[90]. Going beyond the possible substitution of basic ingredients in food, the proteins (particularly the essential amino acids), fatty acids, minerals (e.g. zinc, iron and vitamins (e.g. D, B12) found in insects could be a viable tool in tackling deficiencies – very common also in developed countries.

Insects and their contribution to health throughout the agri-food nexus

The multiple interactions between humans' diets and their health have been and will be an interesting subject for research. While today's challenges impacting food production, such as climate change, are likely to lead to a change in consumers' preference and dietary habits, animal meat will remain a nutritious source of proteins for many Europeans. Therefore, further investigating the health of animals – while taking into account its impacts on human health – should remain a priority. A better understanding of the digestive system, metabolism and immune system of animals might also help us in prioritising the research needs relevant for human health, since some animals (such as pigs, for instance) have been used as model (mainly due to their similarities in terms of anatomy, genetics and physiology).

Similarly to the developments related to the use of insects in human nutrition, **the recent authorisation of insect-derived processed animal proteins (PAPs)** in poultry and pig nutrition opened the market for insect feed products - which, since September 2021, can be legally used across the European Union. Added to animal feed, insects can play a key role in improving the sustainability of animal farming. For example, their potential to modulate animal microbiota has already been recognised as very likely to improve animal health and implicitly contribute to a reduction in pharmaceuticals[91].

Last but not least, the above-mentioned authorisation of insects in poultry and pig feed is also likely to open new avenues for insect producers. In particular, in addition to EU's high dependency on imported animal feed, new scientific evidence on the digestibility and the immunostimulatory and antioxidant properties of insect-derived feed ingredients[92] will facilitate the inclusion of insect-based feed in the diet of animals (such as poultry and porcine species), while also reducing the use of certain supplements (vitamins, antibiotics, etc.), making animal farming more cost efficient and sustainable.

2.1.2. The state of research

The nutritious elements found in insects (e.g. high levels of proteins, diverse fibres and fatty acids etc), including several vitamins and minerals, are known to have numerous health benefits for both humans and animals. As noted by Wageningen University, ‘the composition of unsaturated omega-3 and six fatty acids in mealworms is comparable with that in fish (and higher than in cattle and pigs), and the protein, vitamin and mineral content of mealworms is similar to that in fish and meat’[93]. Yet, it is worth underlining that the nutritive value of insects depends on species, substrate, growth stage as well as the processing methods used.

In the context of functional food, supplements and tailored animal feed[94], further evidence correlating the inclusion of insects in the (human or animal) diet with concrete benefits is needed.

Informing consumers regarding the scientifically proven advantages of the combined ingredients found in insects is likely to be a boost for the industry itself. This will reflect the **added value of insects as whole**[95], but also as a **beneficial ingredient**[96].

Characteristics relevant to human nutrition

A number of publications have addressed the health effects of insects in human food[97].

The **fat** content of edible insects is mainly interesting because of their polyunsaturated fatty acids[98] - the presence of the essential linoleic (omega-6) and a-linolenic acids (omega-3) is important particularly for their role in the development of children and infants[99]. While fish species also contain such fatty acids, in countries with reduced consumption of fish, insects could complement the absence of such nutrients. Preliminary studies indicate that the fatty acid composition of insects depends on the substrate used in insect farms.

According to the FAO, **micronutrient deficiencies** - common not only in developing countries - are likely to have serious health consequences[100]. Numerous micronutrients are found in edible insects - iron, magnesium, manganese, phosphorus, selenium or zinc are just some examples. To this end, the concentration of iron found in insects[101], for example, could be a solution to preventing or tackling anaemia - one of the most frequent non-communicable diseases[102]. Zinc deficiency, another important topic for child and maternal health, could also be tackled by including insect-based products in the human diet. Complementary, **vitamins** relevant for metabolic processes and immunity are found in a wide range of edible insects. Riboflavin (vitamin B2), thiamine (vitamin B1), but also cobalamin (vitamin B12) - only found in food of animal origin - all are present in *Tenebrio molitor*[103], *Acheta domesticus*[104] or other species.

Chitin, an insoluble fibre from insects’ exoskeleton, may range from 2.7 mg to 49.8 mg per kg (fresh weight). The presence of this modified polysaccharide might cause different immune responses with evidence suggesting that chitin may have a prebiotic effect boosting the gut microbiome[105]; however, a too high intake of chitin in the diet may not be beneficial as it can lead to constipation. Lastly, it should be noted that certain people have shown allergic reactions to insects, most likely due to similar mechanisms such as the intolerance to tropomyosin or arginine kinase from crustaceans or mites.

Animal feed

A wide range of insects is used as animal feed across the world[106]. Studies on silkworm pupae reflect its potential to replace fishmeal in chickens used for egg productions, supplementing up to half of their diets. In the light of increasing feed prices - amplified by market disturbances (e.g. such as the COVID pandemic or the ongoing unlawful military intervention of Russia in Ukraine) numerous insect species could play a key role in complementing or partially substituting vegetable meal in animal feed. Among those, several have proven such a potential and are already being produced at industrial level in the European Union, notably *Hermetia illucens* and *Tenebrio molitor*.

Credits to Essento Food

Many trials with insect-based products produced from the above-mentioned species have shown promising results in terms of animal growth performance[107]. In addition to the proteins, vitamins, minerals, or fats listed above, bioactive components such as lauric acid, antimicrobial peptides and chitin have immune-boosting properties[108].

The role of chitin has been presented in depth by L.Gasco et al. 2018[109]. Additionally, *Tenebrio molitor* and *Zophobas morio* fermented meal have been shown to reduce cecal *E.coli* and *Salmonella* spp in broiler chicks - this combined effect confirms the high potential to substitute antibiotics[110].

In aquaculture, **chitin** enhanced the development of beneficial intestinal microbiota and implicitly the performance and health of fish[111]. *Hermetia illucens* larvae meal fed to rainbow trout has also been evaluated by Bruni et al. 2018[112] - confirming the increased incidence of probiotic bacteria[113] in the intestinal microbiota. No allergy caused by insect-derived feed has been reported in pet and farmed animals[114]. The prebiotic effect of insects is also likely to occur due to the presence of oligosaccharides – in particular, immunosaccharides are known to stimulate the innate immune system directly[115].

The presence of lauric acid[116] in insect larvae is known for its antiviral and antibacterial properties[117]. In vitro trials with *Hermetia illucens* on pigs showed antibacterial effects against Dstreptococci infections[118]. 'The greatest diversity of antimicrobial peptides is found in insects'[119]. These peptides promote digestibility, gut health and enhance immunity while promoting growth performance[120]. Ji et al. 2016 concluded that the inclusion of yellow mealworm, giant mealworm and housefly meal in the diet of weaning pigs contributed to a decrease in diarrhoea.

Credits to Roy Buri from Pixabay

2.2.3. The research needs of the European insect sector

Insects and their potential to improve the health of Europeans

The present state of research supports the use of insects as complementary source material in human food and feed formula for aquaculture and livestock animals. Notwithstanding the wide range of scientific publications on nutritious and healthier diets (for both humans and animals), topics such as the **digestibility of insects** (in particular in animal feed), or the **immune- boosting properties** of insect-based food and feed deserve more attention from the scientific community. Concurrently, species-specific causalities between the growth stage and processing methods and the previously mentioned properties will contribute to a more complete science-based characterisation of insect farming and insect-based ingredients.

Future studies shall improve our current understanding regarding the **correlations between the growing conditions** (both biotic and abiotic) in insect farms and the content of amino acids, vitamins[122], minerals[123], fats, as well as substances having antibacterial, antiviral or immuneboosting properties – including **their impact on nutrition and health**. For example, it has been noted that the addition of linseed to the diet of insects has the potential to increase their nutritional quality for human consumption[124]. Also, certain peptides derived from the lesser mealworm larvae were shown to influence the metabolism of glucose and potentially serve as a complementary ingredient in functional food for glycemic regulation[125].

Moreover, the allergenicity of insects – a reaction that is common among people that are allergic to crustaceans – is a subject that should be addressed in detail. To this end, the potential to decrease allergenicity in insect-based ingredients[126] deserves more attention from the scientific community.

Last but not least, future projects (e.g. such as those funded under the Horizon Europe Programme) could play a key role in cementing the science-based evidence on matters related to **personalised nutrition** (relevant for pre- and neonatal, maternal, paternal, infant and child health, as well as healthy ageing), **also in the context of athletes and vulnerable groups.**

The role of insects in aquaculture and animal farming

IPIFF believes that, as part of the food-health nexus[127], the potential of insects in supporting European livestock producers' constant efforts towards optimised animal health in their farms cannot be omitted. For example, building on the experience of the aquaculture sector – where insect-derived feed products were used in the diet of several fish species since 2017 - further analyses should aim at **identifying optimum feed formulations focusing on the species-specific needs**. The final aim is primarily to improve the performance of the animal, while taking into consideration its health, development, as well as a life cycle perspective. The presently used diet should not be completely replaced - yet, it is necessary to evaluate the potential of insects to complement and fortify feed formulations, as part of the efforts to reach optimised feeding strategies. Furthermore, the role of insects on the intestinal microbiota of animals deserves further attention. Improving digestibility, gut health and immunity will, gradually, reduce the necessity to use agro pharmaceutical products in animal farming. As indicated in the state of research, the presence of immunosaccharides might offer more answers regarding their immune-boosting potential[128]. Thus, taking into consideration the entry into force of the ban of the prophylactic use of antibiotics in farming in 2022[129], this topic becomes ever more relevant for insect producers and farmers alike. More research shall investigate in depth the possibilities of incorporating insect-based feed in the diet of poultry and pigs, necessary to evaluate the potential of insects to complement and fortify feed formulations as part of the efforts to reach optimised feeding strategies.

Tenebrio molitor – credits to Ynsect

Afterword

In the past months, the European insect sector achieved key regulatory milestones that will play a crucial role in the advancement of this new industry. Through this updated document (*building on the original version launched in 2019*), our objective is to contextualise the messages conveyed in the first version of the document – including references to the recent novel food authorisations, the approval of insect processed animal proteins (PAPs) in poultry and pig feed, or the EU baseline standards for insect frass, among others. The objective of this document is therefore not to aggregate all scientific evidence on the subjects covered – as 'more than 80% of the publications dealing with edible insects appeared during the five years' (*van Huis, 2022).*

Through this brochure, we aim at providing support to stakeholders working on project development (*e.g. facilitating their applications for EU funding*), while also shedding light on matters that will contribute to growing the production capacity of the insect sector (*e.g. diversifying the spectrum of authorised substrates*) and its market penetration (*e.g. strengthening the evidence around the benefits of insect-derived products in food, feed or as fertilisers).* If the reader was involved on matters covered by this brochure, we kindly invite you to get in touch with the IPIFF Secretariat. In the future, we will continue working on updating this and other IPIFF documents – therefore do not hesitate to contact us in case you have relevant materials to share. We thank you for reading this document!

IPIFF Secretariat, May 2022

Bibliography

1.1. Exploring the use of 'new substrates' as feed for insects

[1] Quantification of food waste per product group along the food supply chain in the European Union: a mass flow analysis - Caldeira *et al.* (2019).

[2] In per capita terms, more than 170 kg/year is wasted -source: Food waste in the EU. One year after the launch of this brochure, the European Commission 'committed to halving per capita food waste at retail and consumer levels by 2030 (SDG Target 12.3)' through the 'Farm to Fork' strategy, launched in May 2020.

[3] Regulation (EC) No 178/2002 - For the purposes of this Regulation, 'food' (or 'foodstuff') means any substance or product, whether processed, partially processed or unprocessed, intended to be, or reasonably expected to be ingested by humans – Chapter I, Scope and Definitions. In February 2020, the Office for Risk Assessment & Research (BuRo) of the Dutch Minister of Agriculture, Nature and Food Quality published a document providing 'Advice on animal and public health risks of insects reared on former foodstuffs as raw material for animal feed'.

[4] Insects Reared on Food Waste: A Game Changer for Global Agricultural Feed Markets? Elleby *et al.* (2021).

[5] An animal's capacity to convert feed mass into increased body mass, represented as kg of feed per kg of weight gain. For further details, see 'Edible insects: Future prospects for food and feed security' - Food and Agriculture Organization of the United Nations - Rome, 2013.

[6] While other animals spend energy for thermoregulation, insects are poikilothermic - animals in which body temperature is variable and dependent on the ambient temperature.

[7] Circular economy action plan – European Commission, 2022

[8] Such as the dependency on imported proteins and the increasing food waste burden, among others.

[9] Enhanced Bioavailability and Microbial Biodegradation of Polystyrene in an Enrichment Derived from the Gut Microbiome of *Tenebrio molitor* (Mealworm Larvae) - Brandon *et al.* (2021). Ongoing research projects, such as the 'Recover' project (project funded through the Bio-based Industries Joint Undertaking (JU) under the European Union's Horizon 2020 - looking into the ability of insects to degrade conventional plastic packaging and agricultural film waste streams) are continuing the work on this matter.

[10] Earlier in 2017, IPIFF mentioned the relevance of diversifying the substrates authorised in insect production – source: 'The use insect proteins as animal feed' IPIFF Position Paper, 2017 (note: some content included in this paper may be obsolete, as it was published before the authorisation of insect processed animal proteins in poultry and pig feed from September 2021).

[11] The Bioeconomy Strategy – European Commission, 2022

[12] 'A sustainable Bioeconomy for Europe: strengthening the connection between economy, society and the environment' ; complemented by the reflection paper towards a Sustainable Europe by 2030, the Clean planet for all.

[13] For example, according to EFSA's report on the presence of plant protection product residues in food, 98.9% of the animal-based food contained a concentration of pesticides below the Maximum Residue Levels (MRLs) – with 87.5% of the samples below the Limit of Quantification (LoQ).

[14] Chemical food safety of using former foodstuffs for rearing black soldier fly larvae (*Hermetia illucens*) for feed and food use - Van der Fels-Klerx *et al.* (2020).

[15] As defined by the Article 2 of Regulation (EC) No 1935/2004 of the European Parliament and of the Council of 27 October 2004 on materials and articles intended to come into contact with food.

[16] 'Biodegradation of polystyrene wastes in yellow mealworms (larvae of *Tenebrio molitor* Linnaeus): Factors affecting biodegradation rates and the ability of polystyrene-fed larvae to complete their life cycle' - Yang *et al.*, 2018, Chemosphere.

[17] According to a publication of the Danish Environmental Protection Agency, the response of black soldier flies to plastic was investigated by the Danish Technological Institute – source: WICE - Waste, Insects and Circular Economy, Fischer *et al.*, 2018. Report on environmental project no. 2011 (in Danish). Danish Environmental Protection Agency, 51 pp.

[18] For insects with a short life cycle and, thus limited repeated feeding, bioaccumulation is less likely to occur than in insects that are reared over a longer time period' – source: Risk profile related to production and consumption of insects as food and feed, EFSA 2015.

[19] 'Impact of substrate contamination with mycotoxins, heavy metals and pesticides on the growth performance and composition of black soldier fly larvae (*Hermetia illucens*) for use in the feed and food value chain' - Purschke *et al.*, 2017, Food Additives & Contaminants: Part A.

[20] 'Impact of Naturally Contaminated Substrates on *Alphitobius diaperinus* and *Hermetia illucens*: Uptake and Excretion of Mycotoxins' - G. Leni *et al.*, 2019, Toxins. Tolerance and Excretion of the Mycotoxins Aflatoxin B1, Zearalenone, Deoxynivalenol, and Ochratoxin A by *Alphitobius diaperinus* and *Hermetia illucens* from Contaminated Substrates, Camenzuli *et al.* (2018)

[21] In the sense of natural biological and chemical degradation, ensuring the suitability of the former foodstuffs with the requirements applicable for insect substrates.

[22] Risk profile related to production and consumption of insects as food and feed - EFSA 2015.

[23] However, in certain instances, insects could serve as 'mechanical vectors of infectious prions' - source: Risk profile related to production and consumption of insects as food and feed - EFSA 2015.

[24] From Food Processing Leftovers to Bioplastic: A Design of Experiments Approach in a Circular Economy Perspective - Barbi *et al.* (2021).

[25] Insect gut bacteria: a promising tool for enhanced biogas production. Show *et al.* (2022)

[26] Biodiesel production from the black soldier fly larvae grown on food waste and its fuel property characterization as a potential transportation fuel - Park *et al.* (2022).

[27] 'Biodiesel production from various feedstocks and their effects on the fuel properties' - Canakci *et al.* (2008).

[28] Fly larvae may be used for organic waste treatment

[29] WICE - Waste, Insects and Circular Economy, Fischer et al., 2018. Report on environmental project no. 2011 (in Danish). Danish Environmental Protection Agency, 51 pp. More recent studies also looked into the production of methane from insect frass, worm or mushroom waste streams and combinations Elissen *et al.* (2019) or biogas generation from insects frass Bulak *et at.* (2020), among others.

[30] In this case, the frass derived from insects farmed on substrates unsuitable for the food and the feed chain.

[31] For example, it can often be used as fertilising material.

[32] While for experimental purposes unauthorised substrates could be used, in practice, in the absence of a suitable legislative context, the findings of such investigations cannot be implemented.

[33] For instance, while cattle can biologically absorb certain materials that may not be used for food directly (materials which have high fibre content such as sugar beet, brewers' grains), poultry or aquaculture species have distinct nutritional needs. Insects can upcycle what we refer in this paper as 'unauthorised substrates' – providing added value by using organic side-stream products (not used in livestock nutrition).

[34] In terms of availability, costs, life-cycle analysis and other relevant factors for each individual producer.

[35] Risk profile related to production and consumption of insects as food and feed, EFSA 2015.

[36] Chemical safety of black soldier fly larvae (*Hermetia illucens*), knowledge gaps and recommendations for future research: a critical review. Lievens *et al.* (2021)

[37] Cadmium (Cd) and lead (Pb) in particular

[38] Taking into consideration the primary ingredient found in such products (fish or meat) or the processing methods used (frozen, pre-cooked, etc.).

[39] Certain species are able to degrade meat-based products, while others show a vegetarian behaviour.

[40] TGIP allows immune-challenged parents to produce more resistant offspring' - source: Vigneron *et al.* (2019). This mechanism has been found in *Tenebrio molitor* and it is likely to be common in other species, too.

[41] Without using GM techniques.

[42] The step when foodstuffs 'become' former foodstuffs.

[43] The phase when insect-based feed is consumed by animals.

[44] Such as the duration of the 'starving period', in line with animal welfare standards.

[45] In this case, insect frass should be processed using appropriate techniques, ensuring its compatibility with market standards. Frass that would not meet such requirements shall be used for technical applications

[46] 'Conversion of organic wastes into fly larval biomass: bottlenecks and challenges' – Pastor *et al.* (2015).

1.2. The reuse of insect by-products - a focus on the promising contribution of insect frass to agriculture

[47] While these products are the main outputs of insect farming activities, quantitatively speaking, insect frass represents the highest share of the total outputs.

[48] Commission Regulation (EU) 2021/1925 of 5 November 2021

[49] While most of the phosphorus-containing minerals are found in Morocco and Russia (source: Fertilisers in the EU), the financial volatility of such products indirectly facilitated the development of alternatives to mineral fertilisers.

[50] Organic in the sense that such products are not mineral fertilisers

[51] The subject of alternatives to mineral fertilisers has been researched in depth in the past decades (Dawson and Hilton, 2011, Neset *et al.* 2016). However, even if the benefits of organic fertilising products on soil and plant health have been somewhat proven (Nardi *et al.* 2004, Kakar *et al.* (2020)), more remains to be investigated in the context of good agricultural practices that rely on possible synergies between organic and mineral fertilising products.

[52] IPIFF fact sheet on insect frass

[53] 'Mealworm frass as a potential biofertilizer and abiotic stress tolerance-inductor in plants' - Poveda *et al.* (2019).

[54] Investigating alternatives to pest control methods, in the context of the current climatic events that facilitate the migration of such pathogens, is of extreme relevance for EU's agriculture – source: Sustainable use of pesticides.

[55] In the first version of this brochure, several studies were shared as examples on the use of insect excrement from grasshoppers (Fielding *et al.*, 2013), bees (Mishra *et al.*, 2013), ants (Pinkalski *et al.*, 2017), cabbage moths (Kagata and Ohgushi, 2012), etc. Since the publication of the first version (in December 2019), several new studies were published on this matter, among them Schmitt and de Vries, 2020, Houben *et al.*, 2020, etc.

[56] Pigs (Jarret *et al.*, 2011, 2012), ruminants (Codron *et al.*, 2012), laying hens (Zhang and Kim, 2013), broiler chicks (Donsbough *et al.*, 2010 Namroud *et al.*, 2008) and hamsters (Villanueva *et al.*, 2011)

[57] In *Tenebrio molitor* frass, the NPK balance has been estimated by Liu *et al.* (2003). More recently, Poveda *et al.* (2019) and Houben *et al.* (2020) looked into the characteristics and benefits of mealworm derived frass. Studies on *Hermetia illucens* frass were published by Schmitt and de Vries, 2020 and Tanga *et al.* (2021), among others.

[58] For the bean species *Phaseolus vulgaris* the mass of seeds was increased by 18% (Liu *et al.*, 2003)

[59] For the wheat species *Triticum aestivum* germination was increased by 4% (Li *et al.*, 2013)

[60] Insect frass in the development of sustainable agriculture. A review – Poveda (2021).

[61] Various projects are presently working on this subject (e.g. The Horizon 2020 project SUSINCHAIN; the TETRA funded project VaLoReSect, supported by the Flemish Agency for Innovation and Entrepreneurship, etc)

[62] 'Diet influences rates of carbon and nitrogen mineralization from decomposing grasshopper frass and cadavers' – Fielding *et al.* (2013).

[63] 'Mealworm frass as a potential biofertilizer and abiotic stress tolerance-inductor in plants' – Poveda et al. (2019).

[64] 'Chemical interference among plants mediated by grazing insects' - Silander *et al.* (1983).

[65] Also referred to as plant growth-promoting rhizobacteria (PGPR) in a recent paper 'Insect frass and exuviae to promote plant growth and health' – Barragán-Fonseca *et al.* (2022).

[66] Many of these PGPMs can fix atmospheric nitrogen, produce indole acetic acid (IAA) and salicylic acid (SA), solubilize phosphates, promote zinc absorption, and produce glucanases, chitinases and ACC deaminase (Indiragandhi *et al.*, 2008).

[67] Acinetobacter sp. PSGB04 significantly increased root length (41%), seedling vigor, and dry biomass (30%) of the canola test plants, whereas *Pseudomonas* sp. PRGB06 inhibited the mycelial growth of *Botrytis cinerea, Colletotrichum coccodes, C. gleospoiroides, Rhizoctonia solani*, and *Sclerotia sclerotiorum* under in vitro conditions (Indiragandhi *et al.*, 2008).

[68] *Rhizoctonia solani* or *Sclerotinia sclerotiorum* (Indiragandhi *et al.*, 2008).

[69] Such as for instance arable crops, horticulture, viticulture, plant nurseries etc

[70] Regulation (EU) 2019/1009, Regulation (EC) 2003/2003 etc.

[71] While the positive characteristics of frass have been to a wider extent proven, much remains to be done in order to develop specific good agricultural practices for frass application in the context of longer term fertilisation strategies. Concretely, such investigations shall focus on the application time, optimum application rates, or good agricultural practices strategies to reduce potential emissions of greenhouse gasses and run-off. To this end, IPIFF members have joined forces in the *'Knowledge Platform on Frass'*, with a view to facilitating collaboration on such matters.

[72] Commission Regulation (EU) 2021/1925 of 5 November 2021

[73] Commission implementing regulation (EU) 2021/1165 of 15 July 2021

[74] 'Diet influences rates of carbon and nitrogen mineralization from decomposing grasshopper frass and cadavers' – Fielding *et al.* (2013).

[75] pH, electrical conductivity (EC), bulk density, water holding capacity, etc.

[76] Fagan *et al.* (2002) ; Clissold *et al.* (2010).

[77] Fielding *et al.* (2013); Indiragandhi *et al.* (2008); Kagata and Ohgushi (2012); Mishra *et al.* (2013); Pinkalski *et al.* (2017).

[78] 'The potential to improve nutrient use efficiency, tolerance to abiotic stress, crop quality trains or availability of confined nutrients in the soil and rhizosphere' – source : Ricci *et al.* (2019).

[79] Considering a focus on phosphorus, a nutrient which is likely to become scarce in the near future.

2.Exploring the nutritional and health benefits of using insects for food and feed

[80] Nearly 2.5 billion people in the world currently supplement their diet with insects (Van Huis, 2016).

[81] Including goods that are produced locally, using inputs sourced from nearby providers.

[82] For more information regarding the placing on the market of edible insects in the EU see the 'Briefing Paper – The provisions relevant to the commercialization of insect-based products intended for human consumption in the EU').

[83] 'Modes of Eating and Phased Routinisation: Insect-Based Food Practices in the Netherlands' – House (2019).

[84] In the context of diets that aim at reducing the consumption of red meat

[85] Such as environmental matters, animal welfare-related concepts, etc. More information in IPIFF's Vision Paper (see IPIFF's publications – 'IPIFF vision paper on the future of the insect sector towards 2030' (*note: as of spring 2022, this document is presently in the process of being updated*).

[86] Person avoiding green veggies, mostly eating meat.

[87] Person eating only eat red meat, avoiding white meat and all kinds of plant products

[88] Person eating plant-based products, with the occasional inclusion of meat.

[89] Who would be interested in products fortified with insect protein.

[90] Circa 5 and 10% substitution of wheat by *Tenebrio molitor* in bread did not affect its technological features (Roncolini *et al.*, 2019).

[91] Insect-based products have been showing promising immunostimulatory properties in animal farming.

[92] Beyond the protein concept: health aspects of using edible insects on animals - Gasco *et al.* (2020).

[93] 'Edible insects: Future prospects for food and feed security' - Food and Agriculture Organization of the United Nations - Rome, 2013.

[94] Taking into account the different dietary needs of animal species.

[95] For instance, fried larvae in human food and raw insects in the diet of farmed animals

[96] For example, insect pasta for human consumption, insect-based animal feed for aquaculture, or insects combined with other potential complementary ingredients, such as algae or yeast, in both human and animal diet.

[97] A comprehensive list can be found in the paper – 'Consuming insects: are there health benefits?' – Roos and van Huis (2017).

[98] 'Oils of insects and larvae consumed in Africa: potential sources of polyunsaturated fatty acid'- Womeni *et al.* (2009).

[99] 'Choice of foods and ingredients for moderately malnourished children 6 months to 5 years of age' - Michaelsen *et al.* (2009).

[100] 'Combating Micronutrient Deficiencies: Food-based Approaches' - Food and Agriculture Organization of the United Nations - Rome, 2011.

[101] 'Most edible insects boast equal or higher iron contents than beef' – source: 'Insects in the Human Diet: Nutritional Aspects' - Bukkens, M.G. Paoletti (Ed.), Ecological Implications of Minilivestock; Role of Rodents, Frogs, Snails, and Insects for Sustainable Development, Science Publishers.

[102] WHO has flagged iron deficiency as the world's most common and widespread nutritional disorder.

[103] 0.47 µg per 100 g – source: 'Edible insects: Future prospects for food and feed security' - Food and Agriculture Organization of the United Nations - Rome, 2013. **Note**: the recently published EFSA opinions on yellow mealworm (January 2021 and August 2022), migratory locust (July 2021) and house cricket (August 2021) include detailed information regarding the nutritional characteristics of edible insects.

[104] 5.4 µg per 100 g in adults and 8.7 µg per 100 g in nymphs – source: 'Edible insects: Future prospects for food and feed security' - Food and Agriculture Organization of the United Nations - Rome, 2013. **Note**: the recently published EFSA opinions on yellow mealworm (January 2021 and August 2022), migratory locust (July 2021) and house cricket (August 2021) include detailed information regarding the nutritional characteristics of edible insects.

[105] The Effects of Dietary Insect Meal from *Hermetia illucens* Prepupae on Autochthonous Gut Microbiota of Rainbow Trout (*Oncorhynchus mykiss*) – Rimoldi *et al.* (2019).

[106] Grasshoppers, crickets, cockroaches, termites, lice, stink bugs, cicadas, aphids, scale insects, psyllids, beetles, caterpillars, flies, fleas, bees, wasps and ants

[107] Experiments that are publicly available, as well as commercial trials initiated by insect producing companies

[108] 'Edible insects: Future prospects for food and feed security' - Food and Agriculture Organization of the United Nations,Rome,2013.

[109] 'Can diets containing insects promote animal health?' – Gasco *et al.* (2018).

[110] 'Efficacy of mealworm and super mealworm larvae probiotics as an alternative to antibiotics challenged orally with Salmonella and E. coli infection in broiler chicks - Islam and Yang (2017).

[111] Atlantic cod, Atlantic salmon and Atlantic halibut – source: Karlsen *et al.* (2017).

[112] 'Characterisation of the intestinal microbial communities of rainbow trout (Oncorhynchus mykiss) fed with *Hermetia illucens* (black soldier fly) partially defatted larva meal as partial dietary protein source' – Bruni *et al.* (2018).

[113] *Carnobacterium* genus.

[114] 'Edible insects: Future prospects for food and feed security'.

[115] 'Prebiotics as immunostimulants in aquaculture: A review' – Song *et al.* (2014).

[116] Naturally found in coconut oil.

[117] 'A review of monolaurin and lauric acid. Natural virucidal and bactericidal agents' - Lieberman *et al.* (2006).

[118] 'Gut antimicrobial effects and nutritional value of black soldier fly (*Hermetia illucens* L.) prepupae for weaned piglet' - Spranghers *et al.* (2018).

[119] 'The medical potential of antimicrobial peptides from insects' - Tonk and Vilcinskas (2017).

[120] 'Review of Black Soldier Fly (*Hermetia illucens*) as Animal Feed and Human Food' - Wang *et al.* (2017).

[121] 'Use of insect powder as a source of dietary protein in early-weaned piglets' – Ji *et al.* (2016).

[122] **Note**: the recently published EFSA opinions on yellow mealworm (January 2021 and August 2022), migratory locust (July 2021) and house cricket (August 2021) include detailed information regarding the nutritional characteristics of edible insects. The scientific literature also includes information around the characteristics of other species used in food and feed.

[123] The iron content of locusts (*Locusta migratoria*) varies between 8 and 20 mg per 100 g of dry weight, depending on their diet source - Oonincx *et al.* (2010).

[124] 'Dietary enrichment of edible insects with omega 3 fatty acids' – (Oonincx *et al.* 2019).

[125] 'Investigation into the potential of commercially available lesser mealworm (*A. diaperinus*) protein to serve as sources of peptides with DPP-IV inhibitory activity' – Lacroix *et al.* (2018).

[126] For example, by using hydrolysates instead of intact protein preparations.

[127] In line with the approach described by the IPES-Food report 'Unravelling the Food-Health Nexus: Addressing practices, political economy, and power relations to build healthier food systems'.

[128] Through the carbohydrate characterisation of insects

[129] Regulation (EU) 2019/6 of the European Parliament and of the Council of 11 December 2018 on veterinary medicinal products and repealing Directive 2001/82/EC entered into force in 2022.

ipiff