The International Platform of Insects for Food and Feed – building bridges between the insect production chain, research and policymakers

The Research Priorities of the European Insect Sector in the context of the future framework of the Horizon Europe Programme

The ***European insect sector*** - a new agricultural industry that is gradually growing into a reputable actor in terms of products' quality and sustainability - has the potential to become an important player, but also ***a strategic link of the EU's food and feed chains***. Notably, insects have been recognised for their role in complementing both humans' and animals' diets - with an enormous potential to improve the circularity of the agri-food nexus.

With its goals to produce '*world-class science, remove barriers to innovation and make it easier for the public and private sectors to work together in delivering innovation*', the ***future framework of the Horizon Europe Programme*** encompasses research objectives that we consider to be key common denominators between some European and global pressing challenges and the development of the European insect sector. IPIFF believes that ***science-based evidence*** is of the utmost importance for the ***sustainable advancement of the insect production sector***. Therefore, through our association, European insect producers, processors and research institutes aim at bridging the gap between research, innovation and the future-oriented evolution of the legislative framework.

Following internal debates on the key Pillars and Clusters of the future Horizon Europe Programme, IPIFF members have identified two key research priorities:

1. Unleashing the circularity potential of the insect sector (in the context of the Cluster 6.);

2. Exploring the nutritional and health benefits of using insects for food and feed (in the context of the Cluster 1).

As a contribution to the public consultation on the **Co-design of the Horizon Europe** (2021-2024), our association has also developed a Contribution Paper (sent via email to Clement.Evroux@ec.europa.eu) - which offers contextual elements for our research priorities, each divided into three key sections: the relevance of the topic, the state of research and the research needs of the European insect sector. While this overview is a comprehensive summary, it does not necessarily include all the scientific evidence relevant to these two main research priorities. In addition, the research needs have been formulated considering the progress that has already been done by the European insect sector, but also to focus primarily on close-to-market solutions which could deliver cost-effective and environmentally sound answers to numerous challenges. Complementarily, we have underlined the above-mentioned priorities also taking into account some of the most ***pressing global issues*** (as extracted from the comprehensive list of UN Sustainable Development Goals, including but not limited to health, economic growth, innovation, sustainable communities, etc.), as well as ***EU related challenges*** (the high dependency on imported vegetal proteins, the increasing volume of organic waste, diet-related issues of Europeans in general).

We hope that this Contribution Paper will serve as a useful reference in the development of the Strategic Plan of the Horizon Europe Programme. Our association is willing to continue dialogue with national and European policymakers in the near future. Concretely, we look forward to continuing this multistakeholder dialogue at the ***European Research and Innovation Days***, taking place in Brussels.

1.Unleashing the circularity potential of the insect sector
1.1. Exploring the use of 'new substrates' as feed for insects

1.1.1. The relevance of the topic

Up to 90 million tonnes of food is wasted every year in the EU

Between one third and 40% of the food produced is not consumed – with close to 90 million tonnes of food being wasted every year in the European Union, creating a financial burden '*estimated at 143 billion euros*'[1]. As natural decomposers, insects can successfully transform such organic inputs (including unprocessed former foodstuffs[2] 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.

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

As recognised by the **Food and Agriculture Organisation** (FAO[3]), one of the key advantages of insect farming is their high feed conversion efficiency[4]. Notably, throughout their larval life stages, insects have a comparative advantage in converting inputs into high-quality quality products (such as protein, fat and fertiliser) – especially due to their ability to adapt to the ambient temperature[5]. Diversifying the spectrum of substrates allowed in insect farming, by including former foodstuffs containing meat and fish and subsequently catering waste, will further reduce the footprint of the insect sector, while efficiently converting such inputs into valuable and sustainable products – allowing 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[1]. In line with EU's Circular Economy Package[1], 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[1], co-products which would otherwise be discarded or underexploited[1].

As defined by EU standards[1], former foodstuffs, as well as certain animal by-products (also known as 'category 3' materials) could be used as animal feed. However, 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[6].

IPIFF advocates for the proper science-based evaluation of potential new substrates that could be used in insect farming. Presently, our association is collecting the available evidence on the possible authorisation of former foodstuffs containing meat and fish as insect feed[7]. Plastic packaging residues hinder the possibility of reusing materials such as former foodstuffs (due to the 'zero tolerance' standards), yet the proven potential of insects to safely transform such materials cannot be underestimated. Ongoing research projects (under national, Horizon 2020 projects)[8] 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*'[9] 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[10]. 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[11], 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.

The new substrates (former foodstuffs and catering waste) for animal feed

Chemical contaminants

The inclusion of former foodstuffs and catering waste containing meat and fish in the feed of insects is expected to have minimum chemical risks for insect production activities, particularly because such products were intended to be used for human consumption[12]. However, inedible elements that are used to facilitate the placing on the market of foodstuffs (such as labels, packaging and other food contact materials[13]) or that come in contact with catering products (such as paper tissues, plastic cutlery, etc.) might also be present in such 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[14]), while others (e.g. black soldier fly) would avoid these physical impurities[15]. 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.

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[16]. Presently, studies indicate that insect species process heavy metals differently[17]. The same research group concluded that black soldier fly larvae did not accumulate mycotoxins 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[18], 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[19] prior to their inclusion in insect feed[20]. 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[21]'*. 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[22]'*.

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 biogas and biodiesel, 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[23]. 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'[24]. In addition, the inclusion of insect frass in the production of biogas has also shown promising results[25]. To ensure the safety of the production chain for technical applications, it is preferred to include the frass[26] in the biorefinery. Subsequently, the digestate can be disposed taking into account the best available technology[27].

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[28].

1.1.3. The research needs of the European insect sector

The case of 'packaging materials'

While certain foodstuffs are already authorised in animal feed, the 'zero tolerance' for plastic materials (and other items used for packaging) implies an additional processing step prior to the inclusion of such items in animal feed. However, insects – having the capacity to biotransform such materials - could be the solution to 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'[29] and 'reuse'[30]. To this end, it is necessary to evaluate the techniques that would ensure the compliance of insect-based ingredients[31] and the safe transformation of by-products[32]. The same approach should be considered for former foodstuffs containing meat and fish.

Implementing a life-cycle approach, while ensuring the health and welfare 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 lifecycle 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** should also rely on the promising inclusion of insect-based ingredients in combination with novel ingredients (e.g. algae, fermentation products, etc.).

Guaranteeing the safety of insect-based products

Specific research needs shall be prioritised by individual applicants, taking into account the categories of potential new substrates that are feasible[34] and compatible with their business targets.

Yet, the EFSA scientific opinion provides interesting directions on this matter[35]. To this end, particular attention should be given to the response of insects to potential risks derived from former foodstuffs containing meat and fish and catering waste[36].

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. 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. 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[38]. 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**[39] - and implicitly the efficiency of insect farming.

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**[40], taking into account **species-specific biological needs**[41]. 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.

Including insects in the bio-based industry

The ability of insects to degrade organic matter is widely recognised. Yet, more remains to be researched in order to optimise 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, only a couple of species have been tested for technical applications (such as *Hermetia illucens*, *Musca domestica)* – other species, including those that are not authorised in food and feed could also show promising results in converting by-products into versatile inputs[42].

The **bioconversion of products that are not suitable for the food and feed chains by insects shall be considered from a life-cycle perspective**. For example, in the context of the transition towards more sustainable fuels (in response to 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 evaluate the categories of inputs that are suitable in order to produce goods of predictable quality, in line with market requirements.

1.Unleashing the circularity potential of the insect sector

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

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. 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[43]), 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.

It is expected that the global market of mineral fertilisers will remain an unpredictable terrain[44]. 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[45] soil amendments[46]. The reuse of insect frass in agriculture will improve the circularity of the insect-producing industry. Moreover, a complete research-based characterisation of this by-product would contribute to certifying its excellent fertilising potential[47] - generating a complementary revenue for insect producers.

Nonetheless, in numerous EU Member States, insect frass has to be thermally treated prior to its application[48] and sometimes the competent authorities require different treatment standards. In the absence of harmonised practices at EU level, one of the most common procedures is the 'heat treatment'[49]. The goal of this step is to eliminate potential unwanted pathogens present in insect frass.

Building on the experience and observations of on-farm trials, IPIFF believes that in the case of the procedures prior to the application of insect frass in agriculture, a tiered approach shall be considered. The objective of this methodology is to ensure that potential biological[50] and microbial risks[51] of the frass are addressed[52]. The first step shall consist of a mechanical process, setting sieving criteria for the safe use of thermally untreated frass[53] - which is notably key in case of direct land application[54]. Subsequently, for frass that is intended to be commercialised, it is necessary to ensure compatibility with market requests relevant to the category of organic fertilising products[55].

Last but not least, 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*[56]'. 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[57] that will, in turn, reduce the necessity to apply additional inputs, such as mineral fertilisers and pesticides[58].

1.2.2. The state of research

The research on farmed insects and their frass is presently developing[59]. While changes in the content of animal manure have already been reported in numerous animals[60], 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

For some insect species, the NPK ratio of the frass has been already estimated[61]. In addition, the use of such soil amendments is known to improve the weight of seeds[62], as well as seed germination[63]. 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)[64]. 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 – not yet completely understood.

Proportional correlations between the grasshoppers' diet and their frass have also been made, reflecting the role of the substrate on the nutrient content of frass[65]. Additionally, a recent study evaluating the application of mealworm[66] frass on plants indicated that '*best results were obtained* *when the insects were fed a diet low in fat and starch content[67]'*. 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 beetle suppressed germination and growth of several herbs, due to the chemicals present in the substrate of the insects[68]. 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)[69] - improving the health of plants and facilitating the absorption of nutrients. These microbes present in the intestinal microbiota of insects improve the availability of nutrients for plants[70], positively contributing to parameters relevant for plant growth and development (such as root length, seedling vigour and dry biomass)[71]. Also, 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[72]. 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 impacts of certain treatment methods on the characteristics of insect frass, such as the above-mentioned inhibition of pathogenic fungi, are not entirely known[73]. According to trials, applying high thermal and pressure 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[74].

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[75]. 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, a science-based description of insects frass and the factors influencing its chemical, physicochemical and biological characteristics (depending on the various substrates used, including unauthorised inputs such as catering waste and former foodstuffs[76]) 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[77].

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 adaption to saline conditions or water scarcity shall be further investigated.

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**[78]. 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[79].

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[80]. 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[81], 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[82], recently listed in a publication[83].

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**[84] 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.

2.Exploring the nutritional and health benefits of using insects for 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[85]. 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 insect feed 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[86], reflect the ***need to further evaluate the nutritional, chemical and implicitly health-related properties of insect-based products***.

Insects as food in the EU[87]

In the European Union, the consumption of edible insects is developing from an occasional snack[88] to a potent complement in sports nutrition or an alternative to meat consumption[89]. The change in consumers' attitude, driven by health issues, personal or collective beliefs[90], or simply because of curiosity, creates new opportunities for the insect sector. The diverse ingredients found in insect-based food make such products versatile and compatible with the dietary preferences of semimeatatarian[91] or meatgan[92][93], flexitarians[94], or athletes[95]. Including insect-based ingredients into staple foods is also a promising sector, since it can improve the nutritional value without affecting technological features[96]. 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 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).

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[97].

Last but not least, the possible future authorisation of insects in poultry feed is also likely to open new avenues for insect producers. In particular, given the high dependency on imported animal feed, new scientific evidence on the digestibility and the immune-boosting properties 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[98], 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[99]'. 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[100], 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***[101], but also as a ***beneficial ingredient***[102].

Characteristics relevant to human nutrition

A number of publications have addressed the health effects of insects in human food[103].

The **fat** content of edible insects is mainly interesting because of their polyunsaturated fatty acids[104] - the presence of the essential linoleic (omega-6) and α-linolenic acids (omega-3) is important particularly for their role in the development of children and infants[105]. While fish species also contain such fatty acids, in countries with reduced consumption of fish[106], 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[107]. 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[108], for example, could be a solution to preventing or tackling anaemia - one of the most frequent non-communicable diseases[109]. Zinc deficiency, another important topic for child and maternal health, could also be tackled by including insect-based products in the human diet[110]. 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*[111], *Acheta domesticus*[112] or other species.

Chitin, an insoluble fibre from insects' exoskeleton, may range from 2.7 mg to 49.8 mg per kg[113]. 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; however, a too high intake of chitin in the diet may not 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 crustacean or mites.

Animal feed

A wide range of insects[114] is used as animal feed across the world. 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, 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[115], notably *Hermetia illucens, Tenebrio molitor* and *Musca domestica*.

Many trials with insect-based products produced from the above-mentioned species have shown promising results in terms of animal growth performance[116]. 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[117].

The role of **chitin**[118] has been presented in depth by L.Gasco et al. 2018[119] - *Tenebrio molitor* and *Zophobas morio* fermented meal have been shown to reduce cecal *E.coli* and *Salmonella spp.*[120] in broiler chicks - this combined effect confirms the high potential to substitute antibiotics. In aquaculture, chitin enhanced the development of beneficial intestinal microbiota and implicitly the performance and health of fish[121]. *Hermetia illucens* larvae meal fed to rainbow trout has also been evaluated by Bruni et al. 2018[122] - confirming the increased incidence of probiotic bacteria[123] in the intestinal microbiota. No allergy caused by insect-derived feed has been reported in pet and farmed animals[124]. 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[125].

The presence of **lauric acid**[126] in insect larvae is known for its antiviral and antibacterial properties[127]. In vitro trials with *Hermetia illucens* on pigs showed antibacterial effects against D-streptococci infections[128]. 'The greatest diversity of **antimicrobial peptides** is found in insects'[129]. These peptides promote digestibility, gut health and enhance immunity while promoting growth performance[130]. 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[131].

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 **concentrations** of relevant proteins, vitamins[132], minerals[133], fats, as well as substances having antibacterial, antiviral or immune-boosting 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[134]. 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[135].

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[136] deserves more attention from the scientific community.

Last but not least, in line with the priorities of cluster **1.Health**, the framework of 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

While the topic 'animal health' is not explicitly included in the cluster **1.Health** of the new Horizon Europe Programme, IPIFF believes that, as part of the food-health nexus[137], 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 fish species can feed on numerous insect-derived products[138] - 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[139]. Thus, taking into consideration the entry into force of the ban of the prophylactic use of antibiotics in farming[140][141], more research shall investigate in depth the possibilities of **incorporating insect-based feed in the diet of poultry and pigs.**

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

[1] In per capita terms, more than 170 kg/year is wasted -source: Food waste in the EU.

[2]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.

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

[4] An animal's capacity to convert feed mass into increased body mass, represented as kg of feed per kg of weight gain. See 'Edible insects: Future prospects for food and feed security'.

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

[6]Such as the dependency on imported proteins, growing demand from aquaculture, the expected authorisation of insect meal in poultry feed, downcycling of highly nutritious organic matter - primarily from former foodstuffs, etc.

[7] For insects that will be used as animal feed.

[8] For example, as presented in the EAAP 2019 event, there are ongoing evaluations on the presence of up to 3.5% packaging material in the substrate of black soldier flies, showing no negative effects on growth/survival. The complete results are expected to be published soon by Wageningen University.

[9] 'The use insect proteins as animal feed' IPIFF Position Paper, 2017.

[10] The Bioeconomy Strategy – European Commission

[11] '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 and the Clean planet for all.

[12] 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).

[13] 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.

[14] '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.

[15]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.

[16] '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.

[17]'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' – B.Purschke et al., 2017, Food Additives & Contaminants: Part A.

[18]'Impact of Naturally Contaminated Substrates on *Alphitobius diaperinus* and *Hermetia illucens*: Uptake and Excretion of Mycotoxins' – G. Leni et al., 2019, Toxins.

[19] In the sense of natural biological and chemical degradation.

[20] The compatibility of the former foodstuff has to be ensured.

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

[22] 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.

[23] 'Biodiesel production from various feedstocks and their effects on the fuel properties' - M. Canakci et al., 2008, Journal of Industrial Microbiology & Biotechnology.

[24] The use of fly larvae for organic waste treatment

[25]WICE - Waste, Insects and Circular Economy, Fischer et al., 2018. Report on environmental project no. 2011 (in Danish). Danish Environmental Protection Agency, 51 pp.

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

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

[28] 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.

[29] The step when foodstuffs become former foodstuffs.

[30] The phase when insect-based ingredients become part of animal feed or when live insects are consumed by animals.

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

[32] 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.

[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.

[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] Likely to be found in former foodstuffs or catering waste containing fish and meat.

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

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

[39] Without using GM techniques.

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

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

[42] 'Conversion of organic wastes into fly larval biomass: bottlenecks and challenges' – B.Pastor et al., 2015, Journal of Insects as Food and Feed.

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

[43] While these products are the main outputs of insect farming activities, quantitatively speaking, insect frass represents the highest share of the total outputs.
[44] 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.
[45] Organic in the sense that such products are not mineral fertilisers.
[46] 'Mealworm frass as a potential biofertilizer and abiotic stress tolerance-inductor in plants' - J. Poveda et al., 2019, Applied Soil Ecology.
[47] While different studies and trials reflect the high potential of insect frass as a fertilising product, much remains to be investigated – as indicated in the section **1.2.3. The research needs of the European insect sector**.
[48] Commission Regulation (EU) 142/2011 of 25 February 2011 implementing Regulation (EC) No 1069/2009 of the European Parliament and of the Council laying down health rules as regards animal by-products and derived products not intended for human consumption and implementing Council Directive 97/78/EC as regards certain samples and items exempt from veterinary checks at the border under that Directive.
[49] Heat treatment process of at least 70 °C for at least 60 minutes.
[50] From the possible presence of eggs, live or dead insects.
[51] Salmonella spp, E. coli and others – as mentioned by Regulation (EU) 2019/1009
[52] Insect corpses.
[53] For example, free from live larvae.
[54] This step would also ensure the uniformity of the product - any existing solid residues - above the standard particle size of the frass - shall be mechanically processed, so as to have a more homogenous finite product.
[55] In line with the standards defined by the EU legislation on fertilising products, mainly Regulation (EU) 2019/1009.
[56] 'Mealworm frass as a potential biofertilizer and abiotic stress tolerance-inductor in plants' - J. Poveda et al., 2019, Applied Soil Ecology.
[57] 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.
[58] This topic is described in the next section: the state of research.
[59] There are already publications 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.
[60] 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)
[61]In *Tenebrio molitor* frass, the NPK balance has been estimated by Liu et al., 2003 at 3.5-1.5-1.5 – however, these figures are likely to vary taking into account the substrates used.
[62] For the bean species *Phaseolus vulgaris* the mass of seeds was increased by 18% (Liu et al., 2003)
[63] For the wheat species *Triticum aestivum* germination was increased by 4% (Li et al., 2013)
[64] 'Mealworm frass as a potential biofertilizer and abiotic stress tolerance-inductor in plants' - J. Poveda et al., 2019, Applied Soil Ecology.
[65]'Diet influences rates of carbon and nitrogen mineralization from decomposing grasshopper frass and cadavers' – D.J. Fielding et al., 2013, Biology and Fertility of Soils.
[66] *Tenebrio molitor*.
[67] 'Mealworm frass as a potential biofertilizer and abiotic stress tolerance-inductor in plants' - J. Poveda et al., 2019, Applied Soil Ecology.
[68] 'Chemical interference among plants mediated by grazing insects' -J.A. Silander et al., 1983, Oecologia.
[69] 'Mealworm frass as a potential biofertilizer and abiotic stress tolerance-inductor in plants' - J. Poveda et al., 2019, Applied Soil Ecology.
[70] 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).
[71]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).
[72] *Rhizoctonia solani* or *Sclerotinia sclerotiorum* (Indiragandhi et al., 2008).
[73] Thermal or high-pressure treatment.
[74] Such as for instance arable crops, horticulture, viticulture, plant nurseries etc.
[75] Regulation (EU) 2019/1009, Regulation (EC) 2003/2003 etc.
[76] Containing meat and fish.
[77] While the positive characteristics of frass have been partially proven, much remains to be done in order to develop specific good agricultural practices for frass application. Concretely, such investigations shall focus on the application time, the necessary dose, as well as strategies to reduce potential emissions of greenhouse gasses and run-off. To this end, IPIFF members have joined forces in the '*Working Group on Frass*', with a view to facilitating the development of such guidelines.
[78]'Diet influences rates of carbon and nitrogen mineralization from decomposing grasshopper frass and cadavers' – D.J. Fielding et al., 2013, Biology and Fertility of Soils.
[79] pH, electrical conductivity (EC), bulk density, water holding capacity, etc.
[80] Fagan et al., 2002 ; Clissold et al., 2010
[81] Fielding et al., 2013; Indiragandhi et al. 2008; Kagata and Ohgushi, 2012; Mishra et al., 2013; Pinkalski et al., 2017.
[82]'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.
[83] 'General Principles to Justify Plant Biostimulant Claims' - Ricci et al., 2019, Front. Plant Sci. 10:494.
[84] With 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

[85]Nearly 2.5 billion people in the world currently supplement their diet with insects (Van Huis, 2016).
[86] Including goods that are produced locally, using inputs sourced from nearby providers.
[87] In terms of edible insects, the placing on the market of insects for human consumption within the EU requires a novel food authorisation, in accordance with the provisions of the Regulation (EU) No 2015/2283. Yet, certain EU Member States (Belgium, France, Finland, the Netherlands, etc.) granted a provisional approval for species such as the yellow mealworm, the lesser mealworm and crickets (see IPIFF's publications – 'Briefing Paper – The provisions relevant to the commercialization of insect-based products intended for human consumption in the EU').
[88] 'Modes of Eating and Phased Routinisation: Insect-Based Food Practices in the Netherlands' – J.House, 2019, Sociology.
[89] In the context of diets that aim at reducing the consumption of red meat.
[90] 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'.
[91] Person avoiding green veggies, mostly eating meat.
[92] Person eating only eat red meat, avoiding white meat and all kinds of plant products.
[93] Who would prefer insect-based meat substitutes.
[94] Person eating plant-based products, with the occasional inclusion of meat.
[95] Who would be interested in products fortified with insect protein.
[96] Circa 5 and 10% substitution of wheat by *Tenebrio molitor* in bread did not affect its technological features (Roncolini et al., 2019).
[97] Insect-based products have been showing promising immune-boosting properties in animal farming.
[98] High levels of proteins, diverse fibres and fatty acids etc.
[99] 'Edible insects: Future prospects for food and feed security' - Food and Agriculture Organization of the United Nations - Rome, 2013.
[100] Taking into account the different dietary needs of animal species.
[101] For instance, fried larvae in human food and raw insects in the diet of farmed animals.
[102] Insect pasta for human consumption, insect-based animal feed for aquaculture, or insects combined with other potential complementary ingredients, such as algae, in both human and animal diet.
[103] A comprehensive list can be found in the paper – 'Consuming insects: are there health benefits?' – N.Roos and A. van Huis, 2017, Journal of Insects as Food and Feed.
[104] 'Oils of insects and larvae consumed in Africa: potential sources of polyunsaturated fatty acid'- H.M. Womeni et al., 2009, Lipides tropicaux (Actes des Journées Chevreul de l'AFECG 2009).
[105] 'Choice of foods and ingredients for moderately malnourished children 6 months to 5 years of age' - Michaelsen et al., 2009, Food and Nutrition Bulletin.
[106] Such as landlocked countries.
[107] 'Combating Micronutrient Deficiencies: Food-based Approaches' - Food and Agriculture Organization of the United Nations - Rome, 2011.
[108] '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.
[109] WHO has flagged iron deficiency as the world's most common and widespread nutritional disorder.
[110] Beef averages 12.5 mg per 100 g of dry weight, while the palm weevil larvae (*Rhynchophorus phoenicis*), for example, contains 26.5 mg per 100 g (Bukkens, 2005).
[111] 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.
[112] 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.
[113] Fresh weight.
[114] Grasshoppers, crickets, cockroaches, termites, lice, stink bugs, cicadas, aphids, scale insects, psyllids, beetles, caterpillars, flies, fleas, bees, wasps and ants.
[115] For industrial/mass-scale production in Europe
[116] Experiments, as well as commercial trials initiated by insect producing companies.
[117] 'Edible insects: Future prospects for food and feed security' - Food and Agriculture Organization of the United Nations,Rome,2013.
[118] Investigation into the potential of commercially available lesser mealworm (*A. diaperinus*) protein to serve as sources of peptides with DPP-IV inhibitory activity.

[119]'Can diets containing insects promote animal health?' – L.Gasco et al., 2018, Journal of Insects as Food and Feed.
[120] '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, Poultry Science.
[121] Atlantic cod, Atlantic salmon and Atlantic halibut – source: Karlsen et al., 2017
[122] '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, Aquaculture.
[123] *Carnobacterium* genus.
[124] 'Edible insects: Future prospects for food and feed security'.
[125] 'Prebiotics as immunostimulants in aquaculture: A review' – Song et al., 2014, Fish & Shellfish Immunology.
[126]Naturally found in coconut oil.
[127] 'A review of monolaurin and lauric acid. Natural virucidal and bactericidal agents' - Lieberman et al., 2006, Alternative Complementary Therapies.
[128] 'Gut antimicrobial effects and nutritional value of black soldier fly (Hermetia illucens L.) prepupae for weaned piglet' - Spranghers et al., 2018, Animal Feed Science and Technology.
[129] 'The medical potential of antimicrobial peptides from insects' - Tonk and Vilcinskas 2017, Current Topics in Medicinal Chemistry.
[130] 'Review of Black Soldier Fly (Hermetia illucens) as Animal Feed and Human Food' -Wang et al., 2017, Foods.
[131] 'Use of insect powder as a source of dietary protein in early-weaned piglets' – Ji et al., 2016, Journal of Animal Science.
[132] Many species have very low levels of vitamin B12, which is why more research is needed to identify edible insects are rich in B vitamins (Bukkens, 2005; Finke, 2002).

[133] 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.
[134] 'Dietary enrichment of edible insects with omega 3 fatty acids' – Oonincx et al., 2019, Insect Science.
[135] Investigation into the potential of commercially available lesser mealworm (*A. diaperinus*) protein to serve as sources of peptides with DPP-IV inhibitory activity.
[136] For example, by using hydrolysates instead of intact protein preparations.
[137] 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'.
[138] Including insect protein, following the authorisation from 2017.
[139] Through the carbohydrate characterisation of insects.
[140] Which will come into force in 2022.
[141] 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.