ipiff

International Platform
of Insects for Food and Feed

The International Platform of Insects for Food and Feed

Building bridges between the insect production chain, research and policymakers

MAIN RESEARCH PRIORITIES

01 EXPLORING THE USE OF 'NEW SUBSTRATES' AS FEED FOR INSECTS

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

03 EXPLORING THE NUTRITIONAL AND HEALTH BENEFITS OF USING INSECTS FOR FOOD AND FEED AND BETTER CHARACTERISATION OF THE ALLERGIC PROPERTIES OF INSECT FOOD PRODUCTS

04 IPIFF COMMITMENTS TOWARDS ENSURING HIGH-LEVEL STANDARDS IN ANIMAL WELFARE AND IN THE PREVENTION AND MANAGEMENT OF INFECTIOUS DISEASES IN INSECT PRODUCTION

05 EXPLORING THE SYNERGIES AND COMPLEMENTARITIES BETWEEN INSECT, ALGAE, AND FERMENTATION PRODUCTS

INSIGHT

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 came to fruition.: After 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, as well as the first standards for processing insect frass** entering into force in the same year. The efficient dialogue between industry representatives, led by the International Platform of Insects for Food and Feed (IPIFF), policymakers (e.g. European Commission, Member States authorities), academia (Universities, research centers) - and several other actors - was instrumental in unlocking such legislative opportunities.

The successstory of insect farming continues. In addition to the imminent threats posed byof 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.

Various 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 fertilizer***, while also f***illing 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

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PREFACE

Insects offer a unique and sustainable solution to some of today's most pressing societal and environmental challenges. As our planet's population continues to rise, food security, waste management, and environmental sustainability have become critical concerns. Insects, with their ability to convert organic waste and food losses into high-quality nutrients—particularly proteins, but not only—present a viable alternative for sustainable food and feed production. Insect farming has the potential to enhance circular economy practices by repurposing agri-food by-products as feed, while also contributing to agriculture through frass, which improves soil health and crop yields. Recognizing their relevance, researchers and policymakers are working towards integrating insects into mainstream food, feed, and agricultural systems to support sustainable development goals.

Europe has been at the forefront of advancing insect-related regulations, fostering their integration into food and agricultural industries. A major regulatory milestone has been the European Union (EU) authorisation of certain insect species and products as novel food products. These approvals allow insects including the yellow mealworm, lesser yellow mealworm, house cricket, and migratory locust to be used for human consumption, unlocking new market opportunities. Similarly, insect-derived proteins from eight species have been authorised for the production of feed for fish, poultry, and pigs, further strengthening their role in sustainable protein supply chains.

Beyond food and feed, ongoing regulatory discussions focus on expanding the use of former foodstuffs containing meat and fish as feed for farmed insects. This measure aims to minimise food waste while reinforcing insects as an intermediary between surplus food and sustainable animal nutrition. Another crucial regulatory area under reform is the recognition of frass as a fertilizing product, with efforts underway to authorise its use for biogas transformation at the EU level. These advancements reflect the increasing acknowledgment of insects' contributions to sustainable food systems and align with the EU's Green Deal objectives.

Despite progress, several bottleneckshinder the full potential of insect farming. Regulatory constraints, particularly the limited list of authorised substrates for insect farming, restrict industry expansion and its contribution to circular economy goals. Expanding the list of permitted substrates could enhance resource efficiency and further reduce food waste. Additionally, developing tailored standards for frass usein agriculture is essential to maximise its effectiveness as a biofertiliser.

Further research is crucial to addressing knowledge gaps related to food safety, nutritional profiling, and production scalability. Investment in innovation and science-driven policymaking can unlock new opportunities and enhance the credibility of the sector among stakeholders. Establishing clear standards and safety guidelines will be key to fostering consumer trust and industry growth.
A robust science-policy interface is essential for ensuring informed decision-making and regulatory coherence. Strengthening collaboration among researchers, policymakers, and industry stakeholders can facilitate evidence-based policies that reflect the latest scientific advancements. Dedicated working groups that integrate diverse expertise can drive forward regulatory adaptations that balance sustainability, safety, and economic feasibility.

To align with the concerns of agri-food partners, consumers, and society, the insect sector must address various knowledge gaps. A critical area is measuring the environmental footprint of insect farming through comprehensive life cycle assessments and aggregating sectoral values which would adequately reflect data form companies already active at industrial scale. Quantifying benefits such as reduced greenhouse gas emissions, lower water consumption, and decreased land use will indeed reinforce the sector's sustainability claims. Additionally, further research is needed to evaluate allergic risks associated with insect consumption and improve labelling standards for consumers. The topic of insect welfare also requires a scientific framework to ensure ethical farming practices while maintaining production efficiency. European insect farming companies continue to lead global animal welfare practices with a plethora of precautionary measures taken into account. Another key challenge is consumer acceptance, as cultural perceptions, lack of familiarity, and psychological barriers still limit market penetration. Research into consumer attitudes, targeted education campaigns, and transparent communication about safety and benefits will be essential in overcoming these barriers.

Insects are not the only alternative protein source gaining traction. Other innovative sectors, such as algae and yeast-based proteins, offer complementary benefits that could enhance sustainable food production. Exploring synergies between these industries can lead to hybrid products with improved nutritional profiles, lower environmental footprint greater consumer acceptance, and diversified market opportunities. Combining different protein sources can create products with balanced amino acid profiles, enhanced digestibility, and additional micronutrients, catering to diverse dietary needs. Joint research initiatives can further explore the potential for integrating multiple alternative proteins into a cohesive, sustainable food system.
The full integration of insects into food, feed, and agricultural systems requires sustained efforts from all stakeholders. Ongoing research, regulatory adaptations, and industry engagement are essential for bridging knowledge gaps and fostering consumer confidence. Policymakers must ensure that regulations evolve in tandem with scientific discoveries, enabling the insect sector to thrive while maintaining high food safety and environmental standards.
By supporting evidence-based policymaking and fostering cross-sector collaboration, the potential of insects can be fully harnessed to contribute to a more sustainable and resilient global food system.

Dr Laura Gasco

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INTRODUCTION

Aligned with the latest policy developments and scientific progress, the revised brochure (3rd version) delivers a strategic update designed to tackle critical issues and opportunities within the European insect industry. This document has been craftedto engage key stakeholders, including policymakers, national competent authorities and regional bodies, industry leaders, academic researchers, and potential investors.

Important EU Policy Developments

This update is significantly influenced by recent and forthcoming EU policy initiatives. The anticipated EU Protein Diversification Strategy , expected for release over the year 2026 and the Joint Research Centre's report, "Towards Sustainable Food Consumption" (June 2023), emphasises the essential role of alternative protein sources, including insects, in fostering sustainable food systems. These documents highlight the EU's commitment to food and agri-food production innovation and underscore the importance of aligning with these evolving policy directions.

Advancements in Scientific Research

This revised brochure incorporates key scientific advancements that are pivotal to the success of the insect sector. Current research initiatives, along with insights from the IPIFF Knowledge Platform on 'Research Activities', offer valuable information on the benefits and potential risks associated with insect production and/or insect products for food, feed or plant nutrition. Recent studies on 'frass' and "new feeding substrates" for farmed insects (i.e. currently non-EU authorised feed for farmed insects) showcase significant progress in sustainable practices and reinforce the sector's contribution to both environmental and economic sustainability.

Data Aggregation for Enhanced Environmental Performance

A critical aspect of this document is its focus on data aggregation to improve the assessment of environmental performance of insect production activities. By synthesising literature and life cycle assessments (LCAs) conducted by individual insect production companies , the brochure aims to provides basis in view generating sectorial average values for essential environmental indicators related to insect production for food and for feed. Such data would offer a clearer understanding of the sector's sustainability credentials, thereby supporting informed policymaking and shaping EU and national funding instruments that are tailored to the needs of the industry.

This revised brochure provides a comprehensive and updated perspective on the European insect industry, reflecting on the latest policy developments and scientific advancements. It aims to serve as a vital resource for stakeholders, facilitating informed decision-making, shaping appropriate funding mechanisms and fostering engagement with the sector's innovative solutions. By aligning with current EU priorities and integrating recent research findings, the document reaffirms the commitment of our organisation and actors from our sector to contributing to overcoming the major challenges currently faced by our current food systems. By doing so, we also aim to bolster the industry efforts in advancing sustainable practices while supporting its strategic growth.

1. UNLEASHING THE CIRCULARITY POTENTIAL OF THE INSECT SECTOR

OBJECTIVE:

Expand the knowledge around the safe use of new substrates as feed for insects

1.1.1. Why is this important?

New figures indicate that up to 130 million tons 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 tons of food end up as waste 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 significantly enhance the circularity potential of the European insect sector by effectively closing the loop on currently underused edible resources. Looking ahead, regulatory reforms are anticipated to be pivotal in scaling up production capacity within this sector. (see IPIFF Policy Roadmap from November 2024) . The European Parliament has actively addressed the need for a robust regulatory framework to support insect farming, stressing the importance of clear guidelines and strategic support to bolster sector growth (European Parliamentary Questions, July 2023). Furthermore, the Renew Europe Policy document from July 2023 underscores the strategic value of the insect sector in advancing the European Union's circular economy objectives and advocates for targeted policy interventions to facilitate its development and integration. These insights are corroborated by a recent paper from the Joint Research Centre of the European Commission, which highlights the crucial role of regulatory support in scaling up the insect industry within Europe (JRC Paper, 2024). For more detailed insights, the discussions surrounding these, particularly the negotiations in the European Parliament, have continued throughout 2023 and into 2024. The broader objectives of these debates reflect the EU's focus on fostering sustainable environmental practices, with a keeneye on preserving insect species vital to agriculture and biodiversity.

Recent developments in European policy have greatly enhanced the growth and integration of the insect sector. The EU's updated Circular Economy Action Plan and Biodiversity Strategy for 2030 emphasise the role of insect farming in reducing waste and supporting ecosystem health. Additionally, the Horizon Europe funding program continues to fund research into innovative insect farming technologies. The Renew Europe policy document from July 2023 further advances this agenda by calling for streamlined regulations, increased research and investment, and enhanced market development. It highlights the sector's potential for upcycling underused biomasses, reducing environmental impacts, and contributing to sustainability goals. These measures collectively drive significant growth and sustainability in the sector.

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

As recognised by the Food and Agriculture Organization (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. This would pave 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 authorized by the EU legislator.

New categories of insect substrates can 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 onsite 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 a 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 years past, research also looked into the potential of insects to safely transform such materials – with promising results[9]. A significant challenge in using former foodstuffs is the inadvertent presence of plastic packaging residues, which current 'zero tolerance' standards prohibit. However, recent studies have shown that certain insect species can degrade plastics. For instance, studies have demonstrated that larvae of Tenebrio molitor can biodegrade plastics, offering a potential solution to this issue. °

Ongoing research projects under national initiatives, Horizon 2020, and Horizon Europe are crucial in providing the necessary evidence t in view of backing the future EU authorisation for using former foodstuffs containing meat and fish in insect feed. These studies aim to ensure that such practices are safe and sustainable, paving the way for regulatory approvals.

In summary, the combination of IPIFF's advocacy, emerging research on insect mediated plastic degradation, and ongoing scientific projects is progressively addressing the challenges associated with using former foodstuffs containing meat and fish in insect farming. These efforts are essential for developing a science based regulatory framework that supports the sustainable growth of the insect farming industry.

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 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 systems.*" The report emphasises that various factors—such as *production methods, the substrate used, the stage of harvest, the insect species and developmental stage, as well as methods for further processing*—can influence the occurrence and levels of biological and chemical contaminants in food and feed products derived from insects. This insight helps guide ongoing research into the exploration of new and sustainable substrates for insect rearing.

The **Safe Insects** project is a significant step in advancing this area of research, identifying opportunities to use four residual streams - former food from supermarkets for insect farming. These residual streams, when processed and managed correctly, have the potential to be upgraded into valuable food and feed, contributing to a more sustainable food production system. The project underscores the promising potential of insects like black soldier flies (BSF) and yellow mealworms (YMW), which efficiently convert these residual materials into high-quality protein and fat-rich biomass suitable for animal feed.

The Dutch Food and Consumer Product Safety Authority has noted that the best way to manage risks associated with prion diseases is by ensuring the absence of prions in substrates. Fortunately, naturally occurring prion diseases have not yet been detected in non-ruminant farmed animals, including fish, crustaceans, and shellfish, highlighting the safety of using these substrates for insect rearing.

The **Safe Insects** project supports this view, demonstrating that substrates like Category 2 meat meal are microbiologically and chemically safe for insect farming without the need for additional pre-treatment.

With the proper precautions in place—such as adherence to Regulation (EU) No 142/2011 for the processing of substrates and insect products, and the implementation of HACCP practices—food and feed safety can be assured. This, in turn, supports the development of a sustainable and circular economy, where residual streams are transformed into high-value insect proteins that contribute to reducing food waste and supporting the growing demand for alternative protein sources.

In conclusion, research in this area holds great promise, as the insect farming sector can play a crucial role in ensuring safe, sustainable, and efficient food and feed production systems for the future (Safe Insects Policy Roadmap, 2025).

Since the publication of the second 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.

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 hypothesised 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 unauthorized 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 animals18. 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 studies 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.

Evaluating the chemical risks associated with the use of BSF larvae in animal feed is essential to ensuring food safety and regulatory compliance. The findings indicate that even the highest measured concentrations of heavy metals remained below the EU regulatory limits for animal feed with 12% moisture content, as outlined in Directive (EC) 2002/32. No clear biotransformation pattern was identified, and no secondary oxidative biotransformation products were detected in the larvae, suggesting that microorganism-mediated biotransformation of plasticisers may have occurred. While these results provide valuable insights, further research is essential to assess the potential implications of incorporating BSF larvae containing microplastics into compound feed, particularly concerning chemical safety risks that may depend on the number of particles present, the types of plastics, and their associated additives (Safe Insects Policy Roadmap, Entobiota, WiceSoil).

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].

Moreover, the Dutch Food and Consumer Product Safety Authority (BuRO) (16 October 2019) concluded that no conclusions can be drawn about the degree of transmission of (pathogenic) bacteria and microbiological agents from the substrate to the larvae and also ultimately about the extent to which these can be transmitted to farmed animals fed with these insects'.

Therefore, research was developed to explore the transmission of microbiological agents from former foodstuffs (FF) containing meat and/or fish products to the targeted insect feed, focusing on critical bacteria such as *Listeria monocytogenes, Salmonella, Bacillus cereus, Staphylococcus aureus, Campylobacter, Escherichia coli, and Clostridium perfringens*. These studies notably **assessed** and **recorded** the effectiveness of heat treatment in eliminating these bacteria, demonstrating that adequate germicidal treatment significantly reduces microorganism levels to acceptable standards. A study conducted by Brule et al. 2024 systematically reviewed the microbiological quality of black soldier fly (BSF) larvae reared on four different substrates authorised by EU regulations (cereals, fruits, vegetables) and those not allowed in vegetable agri-food (by-products, food at shelf life, and meat). It found that microbial contamination is common across all types of rearing substrates, including meat, vegetables, fruits, and cereals. This study found that meat-based substrates for rearing black soldier fly (BSF) larvae exhibited lower levels of microbial contamination compared to vegetable substrates, particularly with regard to *Bacillus cereus* and *Clostridium perfringens*. While microbial contamination is common across all substrate types, meat-based substrates showed relatively fewer instances of these pathogenic bacteria. Furthermore, the study found no presence of *Listeria monocytogenes* or C*ampylobacter spp.* in meat substrates, suggesting a relatively lower microbial risk in comparison to vegetable-based rearing options.

In conclusion, for risks associated with the transmission of '**typical bacteria**' from meat and fish containing former foodstuffs (FF) were summarized as follows; heat treatment during processing of insects will have the purpose of effectively inactivating vegetative pathogenic bacteria and viruses. HACCP-based procedures (CCP) recommended to verify absence of pathogens in final insect products. The growth of spores needs to be prevented by low pH, low temperature or low water activity (Safe Insects, Entobiota and joint projects between Mutatec and ONIRIS).

In the scenario of risks associated with transmission of infectious diseases (viruses and prions) from meat and fish containing FF , research w a s developed to explore the risks of detecting infectious prions in meat (from ruminant origin, and Low Pathogenic Avian Influerigins) containing food-grade FF. The results have showed the risk to be very low. Research was also concluded, focusing on the transmission of common viruses such as African Swine Fever, Classical Swine Fever, Foot-and-Mouth Diseasenza. In EFSA' s risk profile opinion prions were quoted as:

'Normal cellular prion proteins are not naturally expressed in insects. Therefore, no relevant risks exist in relation to insect-specific prions. For the same reason, mammalian prions cannot replicate in insects, and therefore insects are not considered to be possible biological vectors and amplifiers of prions.

'In general, insects fed on substrates of non-human and non-ruminant origin should not pose any additional risk compared to the use of other food or feed, while the risk posed by insects fed on other substrates should be specifically evaluated'.

In conclusion, insect pathogenic viruses occurring in insects produced for food and feed are specific for insects and therefore are not regarded as a hazard for vertebrate animals and humans. This risk could be mitigated through proper choice of substrate and effective processing.'

Safe Insects Project's preliminary results indicated t**he infection risk as very low, with very low levels of BSE infectivity reaching cattle**. In this study, **broiler manure was used for BSF** rearing and was piked with foot-and-mouth disease virus, classical swine fever virus, low pathogenic avian influenza virus and swine vesicular disease virus, **these viruses were rapidly inactivated in broiler manure,** and **subsequently not detected in BSF (Safe Insects Policy Roadmap).**

The Secure Feed Project recorded that **low risk of transfer of salmon pathogens from sludge to Black Soldier Fly Larvae**. None of the pathogens spiked to the sludge were detected in the BSF larvae, i**ndicating a low risk of transfer from aquaculture sludge to insects (Belghit et al. 2024).**

Results indicated that the infection risks originated from viruses as very low, with very low levels of BSE infectivity reaching cattle. A low pH is expected in substrates containing high volumes of former foodstuffs, which could contribute to the inactivation of viruses if present. Furthermore, heat treatment during processing of insects was efficient to inactivate the viruses (as discussed for 'typical' vegetative bacteria in processing of insects).

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).

Insect biorefinery is an emerging bioconversion tool for circular bioeconomy due to the feasibility of insects to profitably convert organic matter into value-added source of proteins and fats in the form of food and feed. On the other hand, by product from the insects, such as biodiesel as an energy resource and at the same time contribute towards organic waste management.

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 unauthorized 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 intotechnical applications in theEU context has not as evolved due to legislative constraints[32].

1.1.3. The research needs of the European insect sector

Safety of insect-based products

The previous chapter has indicated that there **is a growing body of evidence supporting the potential authorisation of meat and fish containing FF as a substrate for farmed insects.** It is essential that specific research priorities are set by companies and academia taking into account the various categories of new substrates that are both available and feasible, while also aligning with their business objectives. The EFSA scientific opinion from 2015 and recent scientific findings (see above) offer valuable insights on this matter.

Moving forward, future research can play a crucial role in further expanding the understanding of the potential utilisation associated with insect-derived products reared on meat, fish, and catering waste.
Specific research needs shall be prioritized 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 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.

Several studies were conducted to investigate the chemical safety of insect larvae that ingest packaging materials, with a particular interest on the transmission and bioaccumulation **of heavy metals. The results have indicated the findings were below the EU limits.** Notwithstanding these findings, prospective EU authorisation for the use of meat and fish containing former foodstuff (FF) as substrates for insect rearing is not expected to introduce additional chemical hazards relative to currently authorised substrates. Safe Insects project results *(Hoek-van den hil & co. 2022)* recorded that even the highest measured concentrations remained below the EU regulatory limits for animal feed with 12% moisture content, as outlined in Directive (EC) 2002/32. Entobiota project results highlighted that Lievens et al. 2024 black soldier fly larvae (BSFL) exhibited a moderate intake of disononyl phthalate (DINP) during a 10-day rearing phase, with concentrations ranging from 82 to 273 ng/g. Notably, BSFL demonstrated the capability to biotransform DINP into its primary biotransformation product, monoisononyl phthalate (MINP), within 24 hours. There was not any clear biotransformation pattern identified. Additionally, no secondary oxidative biotransformation products were detected in the larvae, recommending that microorganism-mediated biotransformation of plasticisers may have occurred.

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.

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 **optimizing the fitness of farmed insects[41]** - and implicitly the efficiency of insect farming.

The case of 'packaging materials'

While certain foodstuffs are already authorized 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 bio transform certain plastic-derived 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'[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 optimization 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].

Integration of insects into the biobased industry marks a significant advancement towards more sustainable and innovative resource management. Recent research and EU regulatory updates highlight the substantial potential of insects in converting byproducts into valuable technical inputs. Species such as *Tenebrio molitor* (yellow mealworm) and *Hermetia illucens* (black soldier fly), which are authorized by the EU for use in animal feed (processed animal proteins), have shown considerable promise in producing biofuels and bioplastics. For instance, a 2023 study published in *Waste Management* demonstrated that *Hermetia illucens* larvae can efficiently convert organic waste into high-quality proteins and lipids suitable for biofuel production. Similarly, research featured in the *Journal of Cleaner Production* (2024) has highlighted that *Tenebrio molitor* can transform agricultural byproducts into valuable bioplastics. Preliminary studies on other species, such as *Acheta domesticus* (house cricket), which are not yet authorized for food or feed, also suggest their potential in bioconversion processes, with a 2024 study in *Resources, Conservation & Recycling* indicating their ability to produce bio-based chemicals from organic waste. While there are some challenges to overcome, such as the complex and lengthy regulatory approval process and the need for substantial infrastructure investment for large-scale production, these issues are manageable and do not negate the significant benefits.

Insects offer a highly efficient method for converting organic waste into high-value products, reduce reliance on fossil resources, and support circular economy goals by recycling waste materials. Recent EU regulatory advancements, and updates to the Circular Economy Action Plan, reflect a growing recognition of the role insects can play in sustainable waste management and resource recovery. These developments underscore the EU's commitment to advancing innovative, insect based solutions within its biobased industry strategies, aiming to address challenges.

2. UNLEASHING THE CIRCULARITY POTENTIAL OF THE INSECT SECTOR THROUGH THE REUSE OF INSECT BY-PRODUCT: FOCUS ON THE PROMISING CONTRIBUTION OF INSECT FRASS TO AGRICULTURE

OBJECTIVE A:

Better characterize the benefits of frass application on soils properties

OBJECTIVE B:

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

2.2.1 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 valorize. 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.

In recent months, significant regulatory progress has been made in shaping the future of insect frass within the European Union, with pivotal developments aligning with broader goals of sustainability and circular economy. The adoption of Regulation 2023/1605, which defines an 'end-point' for processed insect frass, marks a crucial achievement for the sector. This regulation ensures that insect frass, when processed in line with standards for heat treatment and microbiological safety, will be recognized as an organic fertiliser and soil improver across all EU Member States, pending its registration under Regulation 2019/1009 on the placing on the market of EU fertilisers – the so called EU fertilisers' products Regulation (see below for further details). It effectively eliminates the need for additional sanitary checks, facilitating the free movement of insect frass as a commercial product across the EU internal market. The regulation provides the legal certainty required to boost the insect farming industry's growth, ensuring that products derived from farmed insects can be marketed more easily within the EU.

The ongoing Q-Lab study, commissioned by the European Commission, which is currently evaluating the environmental and agronomic efficiency of processed insect frass should pave the way to the registration of processed frass under the aforementioned Regulation. This study is indeed assessing the potential impacts of insect frass as a fertiliser product and ensure it meets the required standards for inclusion under the **Fertilisers Products Regulation (FPR)** (under Component Material Category 10 'animal by-products'). The final version the study is which has been presented and discussed before the Commission expert group on fertilising products , iill recommends to register processed insect frass under the EU Fertilisers' Regulationf The Commission's strategic aim is to finalize this evaluation and adopt the necessary amendments by the end of 2025, a move that will open the door for insect frass to become a mainstream component of EU fertilising products, thus contributing to the EU's broader environmental and agricultural objectives

Global Context

It is expected that the global market of mineral fertilizers 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 characterization of this byproduct would contribute to certifying its excellent fertilizing potential – while also generating a complementary revenue for insect producers.

The European Commission Communication from 9 November 2022 on 'Ensuring availability and affordability of fertilisers' (see through the following link): provisions some strategic orientations to support the 'partial replacements of mineral fertilisers by organic fertilisers like manure, sewage sludge and biowaste, from methanation processes or biological and thermal treatments' (...) to reduce the EU's dependence on gas

We could also refer to the approval of insect frass in EU organic crop production, i.e. Commission Implementing Regulation (EU) 2021/1165

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 fertilization strategies (more information is available 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.

2.2.2 State of research

Recent research has further highlighted the benefits of insect frass for soil and plant health, highlighting its potential as a sustainable organic fertilizer. Studies have demonstrated that frass brings essential macro- and micronutrients to the soil, including nitrogen, phosphorus, and potassium, which are vital for plant growth. Additionally, frass contains beneficial bacteria that promote plant health and enhance nutrient absorption (IPIFF, insect frass)

The composition and efficacy of insect frass are influenced by both the insect species and their diet. For instance, frass from the black soldier fly (Hermetia illucens) has been found to vary in nutrient content depending on the larvae's feed substrate. This variability underscores the importance of considering both species and diet when utilizing frass as a fertilizer.

Moreover, the presence of chitin in frass, derived from insect exoskeletons, has been shown to stimulate the growth of beneficial soil bacteria, further enhancing soil fertility and plant health.

These findings suggest that the properties of insect frass are indeed diet and species-specific, necessitating tailored approaches to its application in agriculture to maximize its benefits

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 insects' 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 fertilizer 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 vigor 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.

2.2.3 Research needs of the European insect sector

Recent research has advanced our understanding of the chemical and microbiological properties of insect frass, highlighting its potential as an organic fertiliser. Studies have shown that the nutrient composition of frass, including its nitrogen, phosphorus, and potassium (NPK) contents, varies significantly dependingon the insect species and their diet. For instance, frass from black soldier fly larvae (Hermetia illucens) has been found to contain substantial amounts of these essential nutrients, making it a valuable soil amendment. The microbiological profile of frass is also influenced by the insect's diet and gut microbiota. This variability necessitates further research to establish standardised processing methods that ensure the safe use of frass as a fertiliser. Current European Union regulations (Annex XI, chapter I section 2 of Regulation (EU) No142 /2011 requires heat treatment of frass at 70°C for 60 minutes to reduce potential pathogens.

However, studies suggest that alternative treatments at lower temperatures or shorter durations may also be effective, provided they adhere to the necessary microbial safety standards.

Additionally, the role of frass in enhancing plant resilience to abiotic stresses, such as drought and salinity, is an emerging area of interest. Preliminary findings indicate that frass application can improve soil structure and water retention, thereby aiding plant adaptation to challenging environmental conditions.

In light of recent regulatory developments (see above), ongoing research is crucial to monitor its long-term effects on soil health and carbon sequestration. Understanding these impacts will foster sustainable agricultural practices and contribute to climate change mitigation efforts.

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 prioritize taking into account the general guidelines and technical elements for the evaluation of fertilisers and bio-stimulants[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 t 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.

3. EXPLORING THE NUTRITIONAL AND HEALTH BENEFITS OF INSECTS FOR FOOD AND FEED AND ADDRESSING ALLERGENICITY ISSUES

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

3.1.1The 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, lesser mealworm larvae and the house cricket (note: this document was updated in August 2024)[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 semi-meatatarian[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.

Nutritional and Health Benefits of Insects

Recent scientific advancements underscore the remarkable nutritional advantages of incorporating insects into food and feed systems, aligning with current policy goals of enhancing sustainability and nutritional security. Research from 2022 to 2024 confirms that insects, such as crickets (Acheta domesticus) and yellow mealworms (Tenebrio molitor), offer high-quality protein, with concentrations between 60% and 70% on a dry weight basis. This positions insect protein as a complete source of essential amino acids, essential for human health (FAO, 2023; Sánchez-Muros et al., 2024).

Insects are also rich in key micronutrients; for instance, 100 grams of crickets can fulfill over 100% of the recommended daily intake for vital vitamins and minerals including vitamin B12, iron, and zinc (JRC, 2024). Mealworms are particularly noted for their high vitamin D3 content, crucial for bone health and immune function (Van Broekhoven et al., 2023). Moreover, insects provide beneficial fats, including omega-3 and omega-6 fatty acids, with crickets offering omega-3 levels comparable to those found in fish oils, thereby supporting cardiovascular health (Klassen et al., 2024). Additionally, chitin in insect exoskeletons, when processed into chitosan, has been shown to support cholesterol management and gut health (Berggren et al., 2022).

These findings are consistent with recent policy initiatives that advocate for the incorporation of insect-based foods as part of a sustainable and nutritionally secure food system. By embracing insects, we are advancing our commitment to both improved global health outcomes and environment.

Insects as food in the EU

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 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 instance, their capacity to positively influence gut microbiota—by fostering beneficial bacteria, curbing harmful pathogens, and enhancing overall digestive health—has been acknowledged as a promising approach to improving animal well-being. This, in turn, could significantly reduce reliance on pharmaceuticals in animal farming91.

The authorization of insect PAPs in aqua, poultry and pig feed represent a strategic move that could significantly reduce the EU's dependency on imported animal feed, aligning with broader political goals of sustainability and food security. Supported by growing scientific evidence, including key findings from literature[92] insects offer a rich source of proteins, lipids, vitamins, and minerals, making them a viable solution to the increasing global protein shortage. Insect-derived proteins have the potential to partially replace conventional feed ingredients like soybean meal and fishmeal, thereby reducing reliance on imports and enhancing the EU's agricultural resilience. Studies also highlight the health benefits of insects, emphasizing their bioactive compounds—such as chitin, antimicrobial peptides, and specific fatty acids—which have been shown to possess immunostimulatory, antimicrobial, and anti-inflammatory properties. These compounds can improve animal health, boost disease resistance, and reduce the need for antibiotics, aligning with the EU's objectives to combat antimicrobial resistance and promote sustainable farming practices. As research continues to explore the potential of insects as immunostimulants, their role is likely to expand beyond protein supplementation, positioning them as a key component in the future of sustainable animal agriculture.

3.2.1 The state of research

Insects are increasingly acknowledged for their exceptional nutritional composition, which consists of high levels of proteins, essential amino acids, diverse fibers, and fatty acids, along with a wide range of vitamins and minerals that offer significant health benefits for both humans and animals. Recent research, including findings from the Food and Agriculture Organization (FAO), highlights the potential of insects to replace traditional feed ingredients with a more sustainable option. Their efficient resource useand minimal environmental impact further support their role in advancing sustainable agriculture. This evidence underscores the potential of insects to contribute significantly to food security and agricultural resilience, aligning with the EU's strategic goals for a more sustainable and robust food system .

The composition of unsaturated omega-3 and omega-6 fatty acids in mealworms can be comparable to that in fish and is higher than in cattle and pigs. Additionally, mealworms have a protein, vitamin, and mineral content similar to that found in fish and meat. However, it is important to note that the fatty acid composition of insects is highly dependent on the species and the rearing substrate used, which can significantly influence their nutritional profile. Furthermore, insects can provide omega-3 fatty acids.

In the context of functional foods, supplements, and tailored animal feed, further research is required to establish concrete benefits linked to the inclusion of insects in human or animal diets. Educating consumers about the scientifically validated advantages of insect-derived ingredients could help bolster industry growth, emphasising the added value of insects not just as a whole food but also as a functional ingredient. However, such claims should carefully reflect the limitations and variability in their nutritional profiles.[94-95-96]

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 anemia - one of the most frequent non-communicable diseases102. 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, a structural polysaccharide found in the exoskeletons of insects, is an insoluble fiber present in quantities ranging from **2.7 mg to 49.8 mg per kg** (fresh weight). This modified polysaccharide has been shown to influence immune responses, with studies suggesting that it may exhibit prebiotic properties that enhance gut microbiota. However, excessive dietary intake of chitin may lead to constipation, underscoring the need for a balanced approach to its consumption[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 globally as animal feed. For instance, studies on silkworm pupae highlight its potential to replace fishmeal in poultry diets for egg production, successfully supplementing up to half of the feed without adverse effects. Amid rising feed costs—exacerbated by market disruptions such as the COVID-19 pandemic and the ongoing conflict in Ukraine—numerous insect species offer a promising alternative to partially substitute or complement vegetable meal in animal feed.

In particular, species such as *Hermetia illucens* (black soldier fly) and *Tenebrio molitor* (mealworm) have demonstrated considerable potential as alternative feed sources and are already being produced at an industrial scale within the European Union. These insects are recognised for their high nutritional value, sustainability, and versatility in feed applications. They provide mono- and saturated fatty acids, which contribute to their functional profile; however, it is crucial to highlight that they lack EPA and DHA, the long-chain polyunsaturated fatty acids characteristic of fish meal and fish oil. These compounds play a vital role in cardiovascular disease prevention and are central to meeting specific nutritional requirements.

This distinction underscores the necessity of a strategic, complementary approach when integrating insect-derived ingredients into feed formulations, ensuring they augment rather than wholly replace traditional fish-based components, particularly in contexts where human health outcomes are a priority.

Recent reviews, such as those by Cunha et al. (2023) and Nowakowski et al. (2021), further underscore the potential of edible insects not only in animal feed but also in human nutrition, emphasizing their health benefits and their capacity to contribute to a sustainable food system. Continued research is crucial to unlocking the full potential of insects in feed and food systems, particularly in light of their adaptability to varying production methods and environmental benefits.

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 in insect larvae is well known for its antiviral and antibacterial properties. In vitro trials with *Hermetia illucens* (black soldier fly) on pigs have shown antibacterial effects against *Streptococcus* infections. Additionally, insects are known to have a broad range of antimicrobial peptides, which are among the most diverse found in nature. These peptides play a crucial role in promoting digestibility, enhancing gut health, and supporting immunity, while also contributing to improved growth performance.

Recent studies, such as Ji et al. (2016), have demonstrated that the inclusion of yellow mealworm, giant mealworm, and housefly meal in the diet of weaning pigs can help reduce incidences of diarrhoea. This effect is not limited to pigs, as similar benefits have been observed in rabbits, with the incorporation of insect-based meals improving gut health and reducing gastrointestinal issues Furthermore, insect-derived antimicrobial peptides have shown efficacy against a variety of bacterial strains, including *Escherichia coli* and *Salmonella* species, indicating their broad-spectrum antimicrobial potential.

These findings underscore the promising role of insect-based feed in enhancing animal health, particularly in weaning animals, by not only providing nutritional value but also offering natural antimicrobial properties that support overall gut function and immune system performance.

3.2.2 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 vitamins[122], minerals[123], 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[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 Program and future EU funding programs) 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 optimized 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 immune-saccharides might offer more answers regarding their immune-boosting potential128. 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 fish, 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.

BETTER CHARACTERISATION OF THE ALLERGENIC PROPERTIES OF INSECT FOOD PRODUCTS

INTRODUCTION

Insects are increasingly recognised as a sustainable and nutrient rich alternative to conventional animal proteins. As global food demands rise and environmental concerns intensify, the insect industry's potential to contribute to both human diets and animal feeds has never been clearer. To ensure a safe and effective integration in the food systems, this section of the brochure explores the allergenic properties of insects as food.

Allergic Reactions and Cross-Reactivity

Ensuring consumer safety in the evolving landscape of insect-enriched foods is a priority that aligns with the industry's clear commitment to innovation and public health. As the world increasingly embraces insects as a sustainable and nutritious food source, understanding and managing their allergenic potential becomes crucial to their successful integration into global food systems.

Recent scientific research underscores the progress made in identifying and addressing potential allergenic risks associated with insect consumption. While insect allergies are comparatively rare, and are generally less prevalent compared with those of traditional animal proteins, vigilance remains a priority, particularly with regards to cross reactivity with crustaceans due to shared allergenic proteins such as tropomyosin (EFSA, 2024; van Leeuwen et al., 2023). This evolving understanding highlights the importance of comprehensive allergen profiling and transparent labelling - two aspects of the European insect farming industry that have pivoted it as a global leader in agri-food safety and labelling practices.

Insect-enriched foods present a promising and sustainable addition to our diets. Recent studies have pinpointed specific insect proteins, such as tropomyosin and arginine kinase, that could potentially trigger allergic reactions in sensitive individuals (Boulianne et al., 2024; Kulig et al., 2023). These findings are crucial to developing rigorous safety measures and ensuring that insect-enriched products are thoroughly evaluated. While cross-reactivity with shellfish proteins is an important consideration, research indicates that the overall allergenic risk of insect proteins is relatively low compared to more prevalent allergens, such as peanuts and soy (EFSA, 2024; Lee et al., 2023). For instance, a 2024 study by Mason et al. highlighted that the allergenic potential of insect proteins is significantly lower than that of traditional allergenic foods. Additionally, Liao et al. (2023) demonstrated that advanced processing techniques, including heat treatment and enzymatic hydrolysis, can effectively mitigate allergenicity. Complementary research by Zhang et al. (2024) further supports this by showing that insect proteins generally provoke less severe allergic reactions compared to common allergens. These advancements underscore the commitment to a balanced and proactive approach, integrating innovative solutions with robust allergen management strategies to maximize the nutritional and environmental benefits of insect-enriched foods while safeguarding public health (Smith et al., 2024; Johnson et al., 2023). This proactive stance reflects our dedication to advancing food security and sustainability through science-driven, consumer-focused policies.

EFSA opinions relating to insect food products (Novel Food applications) recommended carrying out further research on the allergenicity of the concerned products, notably on the potential of these products to cause primary sensitisation.

With this in mind, we urge the European Commission services to unlock funding opportunities so the European agri-food industry and academica can carry out the necessary research. As an industry umbrella organisation for the insect sector, IPIFF is committed to supporting these efforts . As the insect food sector continues to grow and gain recognition for its sustainability and circular practices, addressing these concerns is an important step towards ensuring the sector's long-term success onthe European market. In light of this, there is an opportunity for the European Commission to support research in this area through dedicated funding, and the insect sector stands ready to contribute to these efforts, confident that such initiatives will foster a safe and promising future for European job-creating industries such as Novel Foods.

Regulatory and Safety Measures

Robust regulatory and safety measures are critical in facilitating the safe and successful integration of insect-enriched foods into the market, reflecting our commitment to both innovation and public health. In 2024, the EFSA enhanced its guidelines to mandate clear and comprehensive allergen labelling for insect-enriched products. This progressive update ensures transparency, enabling consumers to make informed choices while aligning with broader public health objectives (EFSA, 2024). Additionally, recent policy initiatives from the European Commission underscore the importance of consumer education. By advancing awareness of the potential allergenic properties and promoting safe consumption practices, these initiatives support the broader adoption of insect-enriched foods and highlight their substantial benefits. Educational campaigns and precise labelling play a crucial role in ensuring that the advantages of insect-based nutrition are widely recognized and safely accessed, reinforcing our commitment to a sustainable and healthful food future (European Commission, 2023).

4. IPIFF COMMITMENTS TOWARDS ENSURING LEADING STANDARDS IN ANIMAL WELFARE PRACTICES AND IN THE PREVENTION OF INFECTIOUS DISEASES IN INSECT PRODUCTION

OBJECTIVE A:

Understand viral threats to insects in mass rearing systems

OBJECTIVE B:

Develop integrated strategies for the prevention and management of viral outbreaks

4.2.1. Why does this matter?

The rapid growth of mass insect rearing systems represents both a significant opportunity and a complex challenge in the context of global food security and sustainability. As the demand for alternative and sustainable food sources rises, insects, particularly in the European Union (EU), are emerging as a viable and increasingly consumed source of protein. Presently, over a quarter of the global population includes edible insects in their diet, with this trend gaining momentum, particularly in Europe, where evolving regulations facilitate the market for insect-derived food and feed products.

However, alongside the potential benefits, there is a challenge that meritsattention: the potential presence of pathogens in mass rearing systems. These pathogens can pose a risk to insect populations and, in turn, to the broader sustainability goals of the EU's food security agenda. Studies have shown that viral infections can lead to mortality rates as high as 90% in certain insect species, which can can have an adverse effect on production capacity. Over 30 distinct viral pathogens have been identified affecting key insect species, including *Tenebrio molitor* (yellow mealworms) and *Hermetia illucens* (black soldier flies), highlighting the growing challenge of these infections. The implications are both economic and operational, as viral outbreaks may reduce insect yield and affect the quality of insect-derived products, with potential consequences for food security (Belluco et al., 2023; Bertola et al., 2021; Chavez, 2021; Vergara et al., 2021).

Recent research, such as that conducted by Lim et al. (2024), highlights the importance of rapid, reliable pathogen detection to safeguard insect populations. Using nanopore-based metagenomics, this study demonstrated the ability to detect *Acheta domesticus* densovirus (AdDV) in crickets, illustrating the potential of advanced diagnostic tools in preemptively identifying and managing viral outbreaks. This underscores the need for heightened surveillance systems capable of detecting pathogens at early stages, thus enabling timely intervention to prevent large-scale disease transmission.

Given these developments, IPIFF highlights that rapid and coordinated action is necessary to mitigate the viral risks confronting the insect farming sector. This includes fostering substantial investments in research and development aimed at improving insect health, disease management, and biosecurity measures to protect against pathogen proliferation, ensuring its resilience in the face of viral outbreaks is critical for meeting the EU's broader sustainability, agriculture, and biodiversity goals.

4.2.2. State of Relevant Research

Despite a growing body of research, strategies for the diagnosis, prevention, and management of viral outbreaks present opportunities for further exploration.. Existing diagnostic methods, including conventional PCR and microscopic examination, are primarily based on prior knowledge of disease symptoms and remain limited in scope to identifying known pathogens. In contrast, nanopore sequencing, as demonstrated by Lim et al. (2024), provides a rapid and scalable approach to detecting a wide range of entomopathogens, thus expanding diagnostic capabilities and offering an efficient means for routine surveillance of insect populations.

Furthermore, the study of symbionts in insect populations, such as those conducted by Slowik et al. (2023), offers important insights into the balance between harmful and beneficial microorganisms. The review highlights the role of both parasitic and beneficial symbionts in Tenebrio molitor production, underlining the importance of managing microbial communities to ensure healthy populations and mitigate disease outbreaks. These findings suggest that symbiont management may be a promising avenue for enhancing insect health and productivity in rearing environments.

At present, no single solution exists to combat viral diseases in insects. Instead, an integrated and multifaceted approach is required, encompassing a range of strategies, from biosecurity protocols to advanced biotechnological innovations such as RNA interference (RNAi) and genetic engineering. Moreover, drawing lessons from other agricultural sectors, such as aquaculture and shrimp farming, could provide valuable insights for managing viral outbreaks in insect farming systems.

The IPIFF stresses the need for sustained funding and support for research that deepens our understanding of viral transmission dynamics and the genetic factors that influence insect susceptibility to pathogens. Collaborative research efforts between industry, academia, and government will be crucial in developing resilient insect farming systems capable of withstanding viral threats. Political leadership is equally vital to ensuring that policies prioritise biosecurity and innovation in pathogen detection and management.

Future research must focus on understanding the intricate relationships between viral infections, environmental factors, and the genetics of insect species. This includes the development of tailored biosecurity protocols specific to each insect species and rearing environment. Understanding how temperature, humidity, and population density influence the occurrence and spread of viral infections is particularly urgent. As demonstrated by Takacs et al. (2023), environmental factors such as temperature and rearing density significantly impact the prevalence of *Acheta domesticus* densovirus (AdDV) in cricket colonies. These findings suggest that optimizing environmental conditions can reduce viral abundance, which is critical to minimising outbreaks and maintaining the health of mass-reared insect populations.

Additionally, the exploration of immunostimulatory compounds and the gut microbiome as potential contributors to disease resistance presents a promising research avenue. Carlotta Savio et al. (2022) reviewed how probiotics and prebiotics can positively influence insect health, reducing the incidence of diseases and promoting optimal growth and reproduction. These findings highlight the potential for microbiota-based interventions to improve biosecurity and sustainability in insect farming systems.

The IPIFF acknowledges the importance of a holistic approach to research, one that integrates epidemiological studies, genetic analysis, and environmental factors to develop comprehensive strategies for viral disease management. By fostering collaborations between research institutions, policymakers, and the insect farming industry, Europe can enhance its capacity to manage viral risks effectively and ensure the long-term sustainability of insect farming as an integral part of the European food system.

Animal welfare best practices

In light of the growing global population and the increasing demand for sustainable sources of protein, insects are emerging as a critical solution to meet the needs of human consumption, livestock, and aquaculture. As insect production gains momentum across Europe, IPIFF and its members have developed the world's most sophisticated animal welfare practices to ensure high standards of care.

IPIFF's Commitment to High Standards of Insect Welfare
IPIFF has recognised the importance of promoting animal welfare in insect farming, acknowledging that insects, while fundamentally different from vertebrates, require tailored practices to ensure their well-being. The welfare standards proposed by IPIFF aim to reflect the physiological needs of various insect species and their specific characteristics.

In the November 2022 IPIFF Factsheet, the organisation outlined key principles for ensuring the welfare of insects, which can also mitigate the risks of disease transmission through better management practices. These principles are based on the Five Freedoms proposed by the Brambell Report, adapted for insect species:

1. **Freedom from Hunger and Thirst:** Ensuring sufficient food and water during housing and transport. Proper environmental conditions, including temperature control and ventilation, are crucial for optimal insect health and disease resistance.

2. **Freedom from Pain, Injury, or Disease**: Tailored husbandry techniques are needed to prevent injuries and disease in insect populations. Insect producers should focus on minimising harm by maintaining clean facilities, applying effective pest control, and ensuring rapid euthanasia methods to reduce pain, such as freezing or heating.

3. **Freedom from Discomfort:** The insect environment must allow normal behavioral patterns, with conditions such as light, humidity, and temperature being optimized for each species. This also includes preventing overcrowding and adapting conditions to meet the specific needs of different life stages.

4. **Freedom to Express Normal Behavior:** Recognising that some insect species may experience stress or fear, the welfare practices should respect their natural behaviors, while minimising risks associated with cannibalism or aggressive interactions. Proper space and population control are essential to allow insects to thrive without distress.

5. **Freedom from Fear and Distress:** Understanding the sensory capabilities of insects is still developing, but it is important to ensure that practices reduce stress and fear. Research into insect cognition is ongoing, and industry standards should evolve based on the latest scientific findings to ensure the well-being of insects in production environments.

These welfare practices are designed not only to promote ethical treatment but also to reduce the likelihood of disease spread. By creating optimal conditions, insect producers can mitigate the risks of zoonotic diseases and improve the health of the insects, which can ultimately enhance the safety and sustainability of insect-enriched food and feed.

Further Research on Insect Welfare

The IPIFF Factsheet also underscores the need for more peer-reviewed research into insect welfare, particularly in the context of disease transmission. The current lack of scientific evidence on insect cognition, nociception, and pain response poses a significant challenge in creating science-based welfare standards. To address this, IPIFF calls for:

More funding to support research into insect welfare and its role in disease prevention.

Continuous dialogue with EU policymakers and non-institutional partners to ensure that policies consider the specific needs of insect species and support best practices in the industry.

IPIFF Goals and Collaborative Research Platform to be supported by the EU insect-farming industry.

To address these knowledge gaps, IPIFF is working towards the establishment of a dedicated research platform. This platform will bring together experts from various fields, including entomology, veterinary science, and public health, to advance the understanding of animal welfare in insect production. It aims to fill the existing research gaps and develop standards that reflect both the biological characteristics of insects and the technical realities of industrial production.

Implications for Disease Transmission and Policy

As the insect production sector expands, maintaining high animal welfare standards is not only an ethical obligation but also a public health necessity. The better the welfare conditions, the less likely the spread of diseases within insect populations, which could otherwise pose risks to humans and other animals. Therefore, ensuring robust animal welfare practices in insect farming is an integral part of controlling the spread of zoonotic diseases and ensuring a sustainable and ethical food system.

5. EXPLORING THE SYNERGIES AND COMPLEMENTARITIES BETWEEN INSECT, ALGAE, AND FERMENTATION PRODUCTS

With the growing recognition of sustainable protein sources, research has intensified to explore the synergies and complementarities between insects, algae, and fermentation products.

These three bio-based resources offer unique nutritional and functional properties, and their integration can enhance efficiency, reduce environmental impact, and unlock new opportunities in the food, feed, and biotechnological sectors.

Collaborative initiatives like the InnovProtein EU Alliance bring together industries and researchers to develop innovative solutions, leveraging the strengths of each component for a more resilient and sustainable future.

By combining the high protein content and rapid growth cycle of insects, the rich omega-3 fatty acids and bioactive compounds of algae, and the enhanced digestibility and functional benefits of fermentation products, this integrated approach paves the way for next-generation sustainable solutions. The synergy between these elements can optimize resource use, reduce waste, and create circular production models that align with the principles of a green economy. As industries and researchers continue to collaborate, the potential for novel food and feed applications, biomaterials, and bioactive compounds expands, driving forward a more sustainable and innovative bioeconomy.

Recent studies have highlighted the potential of combining these resources to enhance their individual benefits. For instance, research on the fermentation of microalgal biomass has demonstrated that fermenting microalgae with lactic acid bacteria and yeast can improve their nutritional profile and health benefits, leading to innovative functional foods. Additionally, studies on microbial factories have explored synergies between yeast and algae bioreactors, where the waste output from one serves as a resource input for the other, leading to overall efficiencies in bio factories (Y). These findings underscore the importance of interdisciplinary research in developing sustainable solutions that leverage the strengths of insects, algae, and fermentation products.

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.
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.
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
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)
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
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’ – B.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’ - M. Canakci et al., 2008, Journal of Industrial Microbiology & Biotechnology.
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.

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: A. 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' – B.Pastor et al., 2015, Journal of Insects as Food and Feed
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
52 IPIFF fact sheet on insect frass
53 'Mealworm frass as a potential biofertilizer and abiotic stress tolerance-inductor in plants' – J. Poveda et al., 2019, Applied Soil Ecology.
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 at 3.5-1.5-1.5 – however, these figures are likely to vary taking into account the substrates used. The NPK balance of Tenebrio molitor frass was estimated by Houben et al. 2020 at 5-2-1.7 and was estimated by Poveda et al., 2019 based on different TM diets.
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' – J. Poveda 2021, Agronomy for Sustainable Development
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' – D.J. Fielding et al., 2013, Biology and Fertility of Soils.
63 'Mealworm frass as a potential biofertilizer and abiotic stress tolerance-inductor in plants' – J. Poveda et al., 2019, Applied Soil Ecology.
64 'Chemical interference among plants mediated by grazing insects' -J.A. Silander et al., 1983, Oecologia
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' – D.J. Fielding et al., 2013, Biology and Fertility of Soils.
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.
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' – J.House, 2019, Sociology.
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 Biasato et al., Gut microbiota changes in insect-fed monogastric species: state-of-the-art and future perspectives. Anim Front. 2023 Aug 14;13(4):72-80. doi: 10.1093/af/vfad025. PMID: 37583797; PMCID: PMC10425147.Beyond the protein concept: health aspects of using edible insects on animals (Gasco et al., 2020).
92 'Edible insects: Future prospects for food and feed security' - Food and Agriculture Organization of the United Nations - Rome, 2013.
93 Taking into account the different dietary needs of animal species.
94 For instance, fried larvae in human food and raw insects in the diet of farmed animals
95 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.
96 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.
97 '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).
98 'Choice of foods and ingredients for moderately malnourished children 6 months to 5 years of age' - Michaelsen et al., 2009, Food and Nutrition Bulletin.
99 'Combating Micronutrient Deficiencies: Food-based Approaches' - Food and Agriculture Organization of the United Nations - Rome, 2011.
100 '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.
101 WHO has flagged iron deficiency as the world's most common and widespread nutritional disorder.
102 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.
103 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.
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?' – L.Gasco et al., 2018, Journal of Insects as Food and Feed.
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, Poultry Science.
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, Aquaculture.
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, Fish & Shellfish Immunology.
116 Naturally found in coconut oil.
117 'A review of monolaurin and lauric acid. Natural virucidal and bactericidal agents' - Lieberman et al., 2006, Alternative Complementary Therapies.
118 '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.
119 'The medical potential of antimicrobial peptides from insects' - Tonk and Vilcinskas 2017, Current Topics in Medicinal Chemistry.
120 'Review of Black Soldier Fly (Hermetia illucens) as Animal Feed and Human Food' -Wang et al., 2017, Foods.
121 'Use of insect powder as a source of dietary protein in early-weaned piglets' – Ji et al., 2016, Journal of Animal Science.
122 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).
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, Insect Science.
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.
130 Food and Agriculture Organization (FAO). (2022). Edible insects: Future prospects for food and feed security. Rome: FAO.

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