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JOURNAL OF INSECTS AS FOOD AND FEED (2024) DOI:10.1163/23524588-00001264

Journal of Insects as Food and Feed
brill.com/jiff

RESEARCH ARTICLE

Exploring edible insects as feed in the UK: current challenges and future prospects

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Received 9 May 2024 | Accepted 18 June 2024 | Published online 5 July 2024

Abstract

Edible insects are gaining attention within the UK's feed industry, driven by their environmental and nutritional advantages. However, the UK insect sector is still relatively new. Therefore, this study aims to explore the primary challenges and opportunities faced by insect farmers, insect-related businesses, and feed operators in the UK, with the goal of formulating strategic plans to foster the growth of the insect sector. Ten in-depth interviews from key stakeholders highlight the several benefits of insect-based feed including contributing to the circular economy, advancing value-added product development, and enhancing livestock welfare. Despite these advantages, obstacles like limited research, ambiguous regulations, production constraints, and public acceptance concerns hinder progress. The study recommends strategic solutions involving tailored regulations, financial incentives, industry collaboration, awareness campaigns, and research investments. Implementing these strategies holds the potential to nurture the expansion of UK's insect farming industry, bolstering sustainable agri-food systems, resource efficiency, and environmental consciousness.

Keywords

animal feed – black soldier fly – edible insects – insects as feed – UK

1 Introduction

With a projected doubling of global demand for livestock products by 2050, the environmental impact of livestock production becomes a pressing concern, constituting 18% of global carbon emissions and utilising 70% of global agricultural land (FAO, 2020). The United Nations' Sustainable Development Goals, particularly Goal 12 (Responsible Consumption and Production) and Goal 13 (Climate Action), highlight the urgency of addressing the food system's impact on climate change and sustainability (UN, 2023). This confluence emphasises the need for strategies aligning heightened demand with ecological preservation.

In response to this issue, insects like Black Soldier Flies (BSF) offer a viable solution by efficiently converting organic waste into protein, thereby providing a sustainable protein source and reducing the environmental impact of livestock production (van Huis, 2015; Raman *et al.*, 2022; Oonincx and Finke, 2021). Their rich nutritional content also makes them a suitable substitute for traditional protein sources such as fishmeal and soybean meal (Dörper *et al.*, 2021). This growing interest in insect-based nutrition has driven

Published with license by Koninklijke Brill BV | DOI: 10.1163/23524588-00001264
 | ISSN: 2352-4588 (online)

innovative research and policy changes (Drew *et al.*, 2020), leading to global regulatory shifts. For example, the U.S. Food and Drug Administration (FDA) has been developing guidelines for insect-based feed ingredients, and some have achieved the Generally Recognized as Safe (GRAS) status, ensuring safety and quality. However, the regulatory framework for insect feed is dynamic and context-dependent (Lähteenmäki-Uutela *et al.*, 2021). In 2017, the EU granted approval for the use of selected insect meal in aquaculture feed, signifying a shift towards acknowledging insects as a valuable protein source (IPIFF, 2021). This approval has been further extended to include the use of processed insect protein in pig and poultry feed, demonstrating a growing recognition of insects' role in sustainable animal nutrition (*abide*). In Asia, particularly in Thailand, one of the world's biggest insect producers (Halloran *et al.*, 2017), Thai Ministry of Agriculture and Cooperatives (2017) has established Good Agricultural Practices (GAPs) for cricket farming sets standards for cricket production to ensure the production of safe, high-quality crickets for consumers and exports, including their use as animal feed and pet food.

In the UK, insects as feed have garnered increasing attention due to environmental benefits and a focus on sustainability (Bear, 2021; FSA, 2020). However, the post-Brexit landscape has introduced a distinctive shift in regulations from those of the EU. The Food Standards Agency (FSA) has currently played a pivotal role in overseeing these regulatory developments (Tiwasing, 2022). Under the authorisation of FSA, the use of insect-processed insects, particularly insect protein, for livestock feed is currently prohibited in the UK, except in Northern Ireland (WWF, 2021). This regulatory stance reflects a complex interplay of factors impacting the use of insects as feed in the UK. WWF (2021) suggests that if the UK feed regulations on insect protein were lifted, the total demand for insect meal from the UK's pig, poultry, and salmon sectors is projected to be 540,000 tonnes annually by 2050, with the allowance expected to cover the use of processed insect protein in pig and poultry feed.

This shift has the potential to diminish the UK's dependence on soya imports and other protein sources, given the current heavy reliance on imports from both EU and non-EU countries in its feed industry (Wiltshire *et al.*, 2020). Notably, there is a growing inclination within UK agriculture to decrease dependence on soya since its production and trade significantly contributes to greenhouse gas emissions and it is a major driver of deforestation (WWF, 2021). Therefore, transitioning to locally produced protein not only aligns with sustainability goals but also addresses potential supply issues and could lead to a reduction in protein prices. Specifically, insect farming, like BSFs, presents an opportunity to fill the protein gap in the country (Clark, 2021; Raman *et al.*, 2022).

However, insect farming and insect-processed feed industry in the UK are still relatively new compared to some other regions (Tiwasing, 2022). This industry is still in its infancy and is primarily composed of micro- and small-scale facilities that focus on research and production of insect-derived products for a variety of uses, including feed for birds, reptiles, and hedgehogs (WWF, 2021). As global demand for insects as food and feed rises, the UK insect sector, including insect farmers and business operators, could benefit from this promising opportunity.

To help navigate the growth of this industry in the UK, this study aims to explore the challenges and opportunities associated with insect farming and feed industry, particularly BSFs. Semi-structured interviews were conducted to explore in-depth insights into potential challenges and opportunities for the UK's insect feed industry. A total of ten interviewees were carefully selected from diverse backgrounds, including insect farmers, business operators, feed businesses, and academics in the UK and the EU, representing different aspects of the insect industry. Strategic plans are formulated based on valuable insights from insect farmers, industry experts, and stakeholders, which shed light on the opportunities and challenges associated with insect farming and insect-based animal feed. Given the limited research evidence, these insights can guide policymakers, governments and relevant stakeholders in developing effective strategies for harnessing insects as a sustainable feed source in the UK and other countries.

This study is structured as follows: Section 2 discusses relevant literature. Section 3 details the data and methodology. Key findings are discussed in Section 4. Section 5 concludes with recommendations.

2 Literature review

Global demand for insect-processed products for animal feed

The global demand for insect-processed products, particularly insect protein for animal feed, has witnessed significant growth in recent years. Several academic studies have highlighted the potential of insect protein as a sustainable and alternative protein source

in animal feed (Sánchez-Muros *et al.*, 2016; Chia *et al.*, 2019; Hawkey *et al.*, 2021). Insects, such as BSF, are rich in protein and can serve as a viable substitute for traditional protein sources like fishmeal and soybean meal (WWF, 2021). This has led to increased interest in the use of insect protein in animal feed formulations to address the growing demand for animal protein (Sánchez-Muros *et al.*, 2016). Furthermore, the report from WWF (2021) indicates that the use of insect protein in animal feed can contribute to reducing the environmental impact of livestock production, such as greenhouse gas emissions and land use. As the global demand for animal feed rises, the demand for insect-processed products, including insect protein, is expected to grow in the future.

In 2020, according to Polaris Market Research (2021), the global insect protein market was valued at US $271 million (about £217 million in 2021 prices), with a projected growth of US $1,480 million (about £1,184 million) by 2028 worldwide. In this report, the EU is expected to be one of the fastest-growing markets in this sector. The expansion of insect-processed products for animal feed is driven by several factors. For example, Oonincx and Finke (2021) highlight the nutritional benefits of insect protein for livestock, including its high protein content, balanced amino acid profile, and potential positive effects on animal growth and health. This makes it an attractive ingredient for animal feed formulations. Additionally, Shah *et al.* (2022) show that incorporating insect protein in animal feed can reduce feed costs and improve feed conversion rates. Pinotti and Ottoboni (2021) also support that insects, with their efficient feed conversion ratios, convert feed into protein more effectively compared to traditional livestock. This cost-effectiveness and efficiency have sparked interest in using insect protein as an ingredient in animal feed.

Looking toward the future, the global demand for insect protein in animal feed and other insect-processed products is poised for continuous growth. Hawkey *et al.* (2021) indicate that the increasing global population and the rising demand for animal protein can drive the need for sustainable and alternative protein sources in animal feed. Insect protein has the potential to fill this gap, offering a sustainable solution with a lower environmental footprint compared to the protein sources that are currently used. Ffoulkes *et al.* (2021) also suggest that advancements in insect farming technologies will further enhance the scalability and efficiency of insect protein production for animal feed. However, challenges such as regulatory frameworks, consumer acceptance, and the establishment of insect protein supply chains need to be addressed for the full realisation of the future potential of insect-processed products for animal feed (Tiwasing, 2022; Żuk-Gołaszewska *et al.*, 2022).

Current legislation and regulations related to insects as feed in the UK

In the UK, the use of insects in animal feed is mainly retained by EU regulations (e.g. Regulations (EC) No 178/20021 (General Food Law) and 183/20052 (Feed Hygiene)). This is because the UK's rules for feed and food are based on EU laws, which are now part of "Retained EU Law" since the UK left the EU (Animal and Plant Health Agency (APHA), 2022). In 2017, Regulation (EU) No 2017/893, amended Regulations (EC) No 999/2001 and (EU) No 142/2011, made a significant change in the use of insects for animal feed, allowing for the feeding of seven insect species to aquaculture animals in the EU, which has been applied to the UK (EUR-Lex, 2017a,b). These species include (1) black soldier fly (BSF) (*Hermetia illucens*), (2) common housefly (*Musca domestica*), (3) yellow mealworm (*Tenebrio molitor*), (4) lesser mealworm (*Alphitobius diaperinus*), (5) house cricket (*Acheta domesticus*), (6) banded cricket (*Gryllodes sigillatus*), and (7) field cricket (*Gryllus assimilis*) (Animal and Plant Health Agency (APHP), 2024). In November 2021, following Regulation (EU) No 2021/1925, Silkworm (*Bombyx mori*) was added to this list (EUR-Lex, 2021). However, this change has not yet been implemented in Great Britain (GB).

More significantly, FSA is currently conducting a novel foods authorisation process to evaluate the safety of edible insects within the scope of the existing transitional measures retained from the EU after Brexit (FSA, 2022a). During this period, they launched a public consultation on transitional arrangements for edible insects in the GB market. To keep the product on the market during the evaluation, applications for the authorisation of eligible edible insects must be submitted to FSA (or Food Standards Scotland) by 31 December 2023. As a result, from 1 January 2024, only yellow mealworm (*Tenebrio molitor*), house cricket (*Acheta domesticus*), banded cricket (*Gryllodes sigillatus*) and BSF (*Hermetia illucens*) may remain on the market without pre-market authorisation (FSA, 2024).

Regarding processed animal proteins, the EU made a significant move in September 2021 by authorising their use in poultry and pig feed through Regulation (EU) No 2021/1372 (WWF, 2021). However, GB strictly maintains its prohibition on feeding farmed animals processed animal proteins under the "Feed Ban Rules" (IPIFF,

TABLE 1 Current permitted and prohibited uses of insect protein in UK animal feed

Type of animal	Processed insect protein (all species)	Processed insect protein (7 species)	Live insects
Ruminants	×	×	N/A
Poultry	×	×	–
Pigs	×	×	–
Fish	×	–	–
Pet food	–	–	–
Fur animals	–	–	–

Sources: IPIFF (2020) and WWF (2021).
Notes: × = prohibited, – = permitted, and N/A = not applicable.

2022). These rules encompass prior restrictions on the utilisation of certain materials, such as insect protein, in animal feed intended for animals that are destined for human consumption (EC, 2021). This means that GB still prohibits the use of processed insect protein in animal feed for any farmed livestock intended for human consumption, including pigs, poultry, and cattle (WWF, 2021). Table 1 illustrates an overview of the current permitted and prohibited applications of insect protein in UK animal feed.

Moreover, GB extends this limitation to cover the types of substrates that insects may be raised on, thereby excluding numerous surplus food products from their potential diet, which would otherwise be categorised as waste (Michelmores, 2023). These regulatory restrictions could potentially impede the expansion of the insect protein industry in the UK. Consequently, this legislative development creates an uneven playing field between the EU and GB markets in terms of regulations governing animal feed.

Insect farming industry in the UK

The insect farming industry in the UK is currently in its nascent stage, primarily comprising micro- and small-scale facilities. These establishments are dedicated to research, development, and the production of insect-derived products with diverse applications. Among these uses, insects are processed into feed for various animals, including birds, reptiles, and hedgehogs (WWF, 2021). As of now, there are small-scale implementations of processed insect protein in aquaculture and pet foods, while live insects are being experimented with on poultry farms (WWF, 2021).

Following the rapid risk assessment report from FSA (2022b), the UK has carved out a distinctive niche in this field, capturing about 8% of the European edible insect and insect protein market, with an estimated market revenue of approximately US $4.13 million (£3.34 million). The largest share of this market in the UK is attributed to insects used as animal feed, with other applications including pet food, biomass production, and research activities (Insect Biomass Task & Finish Group, 2019; WWF, 2021; Tiwasing, 2022). Despite these promising figures, the UK's insect farming industry still faces challenges on regulatory hurdles and societal stigmas (Bear, 2021). Nonetheless, with the ongoing growth and innovation in this sector, the UK is poised to play an increasingly substantial role in this dynamic and promising industry in the near future.

Considering the insect farming landscape in the UK, according to Better Origin (2021), insect farming involves the breeding and cultivation of various insect species for various purposes, such as food, feed, and fertiliser. If breeding or rearing activities involve using more than 5 kg of animal or vegetable matter per week, they will be regulated and considered as a prescribed activity following the Pollution Prevention and Control (PPC) Regulations 2012 for Scotland and PPC Regulation 2000 for England and Wales (Clark, 2021). Particularly in Scotland, a PPC Part B permit from the Scottish Environment Protection Agency (SEPA) is required (SEPA, 2000), along with compliance with DEFRA statutory guidance on insect installations (Clark, 2021). Similarly, if farmers produce insects intended for animal feed use (for aquaculture or pet food), they (including an insect feed business or process insects for feed) must be registered as a 'Feed Business Operator' (FeBO) with national competent authorities such as trading standards (FSA, 2020). They may also require a Waste Management Licence and have to register as a collector and transporter of waste depending on the nature of their business and substrate (Clark, 2021).

In line with Regulation (EU) No 2017/893, farmed insects adhere to regulations equivalent to traditional

livestock, including rearing and breeding practices, prohibitions, feeding, and feed restrictions. Insect feed often utilises pre-consumer agri-food waste with nutritional value, sourced from retailers and bakeries (Clark, 2021). The 'Catalogue of Feed Materials' under Regulation (EU) No. 2017/1017 serves as a reference for permitted feedstocks (EUR-Lex, 2017a). This document provides guidelines for the feed use of food not intended for human consumption to ensure responsible repurposing as animal feed (EUR-Lex, 2018). However, the materials used must be obtained from only FeBO-registered businesses and adhere to the feed businesses' registration and approval standards. Also, approval from The UK's Animal and Plant Health Agency (APHA) is also required for using animal by-products at compost and biogas sites (DEFRA and APHA, 2020). To support insect businesses, FSA (2020) also provides guidance on the type of activity and registration requirements that businesses need to follow when they plan to start their animal feed businesses.

To sum up, the insect farming industry in the UK faces challenges related to existing regulations, particularly after Brexit, as the legislative framework surrounding the use of processed insect protein in animal feed differs between the EU and Great Britain. Despite these challenges, the UK has the potential to become a leading player in the insect industry, aligning with the government's circular economy objectives and efforts to reduce food waste. However, further developments in legislation and supportive measures are required to fully harness the benefits of insect farming and incorporate insects into sustainable agri-food systems.

3 Data collection and methodology

Interviews

This study aims to explore the challenges and opportunities associated with insect farming and the feed industry, particularly BSFs. To achieve this aim, semi-structured interviews were used to provide the flexibility to explore emergent themes related to insect farming and businesses, given the limited research in this area in the UK. The questions in the semi-structured interview script included sections on the participants' backgrounds, current practices, challenges, opportunities, and perceptions of regulatory and market trends. These interview questions (Appendix) were developed based on both non-academic literature (i.e. professional report, government documents) and academic literature. The interview questions also provided flexibility for participants to share their experiences and insights, which enabled a thorough exploration of various dimensions that could be related to the challenges and opportunities in their businesses/industries.

TABLE 2 Participants' profile

Participant	Expertise of the participant
1	Feed business operator
2	Insect farmer
3	Insect farmer
4	Feed business operator
5	Academic researcher
6	Insect farmer
7	Insect farmer
8	Academic researcher
9	Feed business operator
10	Academic researcher

Participant selection and sampling methods

Following Holloran *et al.* (2017), due to the limited number of insect farms and time constraints for our project, we applied a purposive and non-random sampling technique to carefully select our interviewees from diverse backgrounds, including insect farmers, business operators, feed industry representatives, and academics in the UK. This broad selection represented various facets of the insect industry. Additionally, we conducted an interview with an insect farming business located in the EU, which aimed to capture advancements, particularly relevant due to lagging UK legislation (Tiwasing, 2022). A total of ten interviewees participated in our study (Table 2). The interviews were conducted using Zoom and Microsoft Teams to accommodate interviewees' preferences and availability. Each interview lasted between 45 to 60 minutes. All interviews were audio-recorded with participants' consent to ensure accurate transcription and analysis. Conversations were carefully recorded and transcribed verbatim to ensure the anonymity of the participants.

Data analysis

In this study, Thematic Analysis was employed to derive meaningful insights from our qualitative data. This technique involves identifying, analysing, and reporting patterns within qualitative data (Braun and Clarke, 2006). It offers a structured approach to systematically dissect the collected data and uncover key themes. Given the limited participation within the insect sector, participant confidentiality was paramount. Thus, to safe-

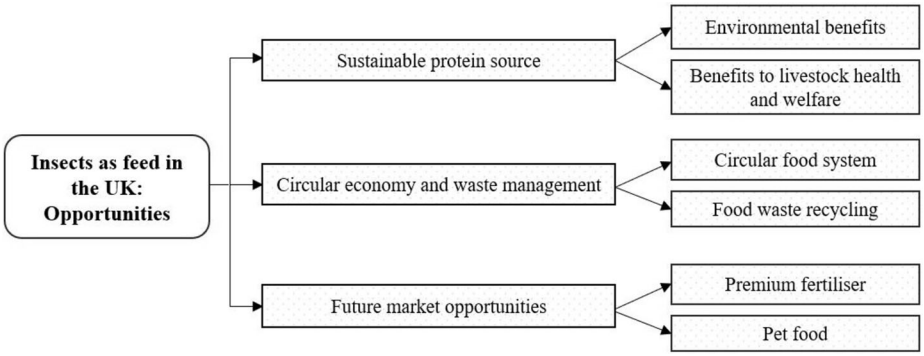

FIGURE 1 Diagram of themes on potential opportunities developed from thematic analysis.

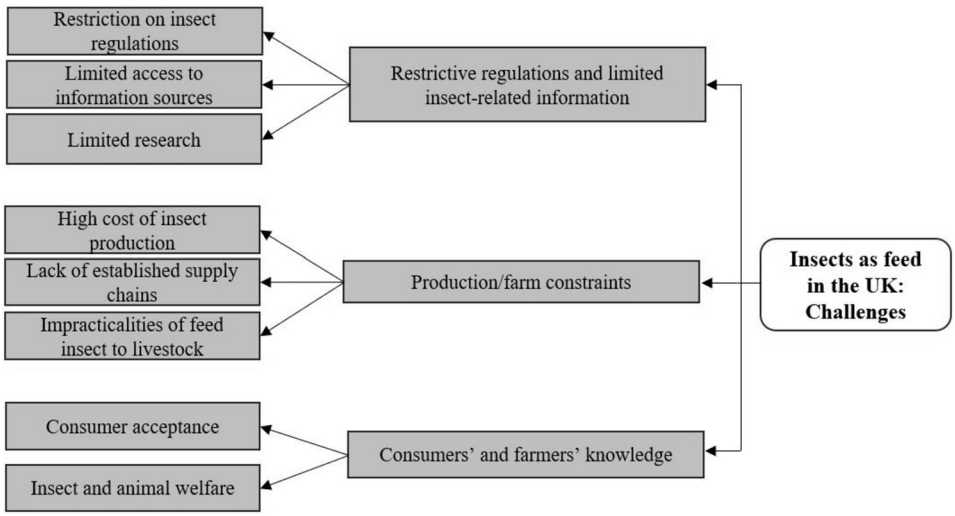

FIGURE 2 Diagram of themes on potential opportunities developed from thematic analysis.

guard their anonymity, the interviewees were identified by participant numbers.

The data analysis involved an iterative approach, where key themes were extracted from the transcribed interviews. The transcripts were read thoroughly to familiarise the researchers with the content and develop a comprehensive understanding. During this stage, we embarked on a process of identification, discerning recurring patterns, shared ideas, and consistent topics across the interviews. Following Yang and Cooke (2021), we refined and organised themes, cross-referencing interpretations with the interview transcripts to, ensuring that our thematic framework accurately represented the participants' perspectives. The interviewees were also enabled to raise additional themes and to vary the thematic order based on their expertise. This final set of themes captured the significance of our findings, forming the core of our subsequent analysis and discussions.

During our analysis, refraining from attributing quotes to specific interviewees preserves the depth and validity of our thematic analysis. Adhering to thematic analysis principles (Braun and Clarke, 2006; Yang and Cooke, 2021), we navigated data intricacies, discovering meaningful insights. Our goal was to remain attuned to unique voices, shaping a narrative highlighting challenges and opportunities in insects as feed within the UK. We reviewed defined themes for insect farming opportunities and challenges, ensuring coherence and avoiding redundancy, as summarised in Figures 1 and 2.

4 Key findings and discussion

The results of our interviews are presented into two main sections: first, we explore the themes of key opportunities, followed by an examination of the challenges in insect farming industry.

Opportunities for insect farming industry for animal feed

In Figure 1, key opportunities mentioned by the interviewees were distinguished into three main themes, which

are: (1) insects as a sustainable protein source, (2) circular economy and waste management, and (3) future market opportunities.

Insects as a sustainable protein source

Environmental benefits

The interviewees highlighted the environmental benefits of using insect as feed. One of the primary motivations expressed by most of the interviewees for incorporating insects into livestock feed was the desire to replace unsustainable protein sources, particularly soya, with a more environmentally friendly alternative.

> "Animal feed is currently using soya, which has quite a detrimental effect on the environment and you have byproducts that you can't utilise like you can do with insects … 100% can be used for useful end products such as, let's say, fertiliser."
>
> [Participant 4]

> "… being able to specifically avoid things like soya, which does have such a big environmental footprint in terms of habitat destruction."
>
> [Participant 8]

Additionally, the substitution of edible insects for soya has the potential to reduce the country's dependency on soya imports. This approach not only enhances sustainability but also mitigates potential supply issues associated with protein sources like fish meal or rapeseed meal:

> "One of the big motivations for the farmers is reducing reliance on imports … So they are soya free, but they don't ideally want to feed fish meal or rapeseed meal."
>
> [Participant 3]

The insights collected from the interviews resonate with findings from academic research, affirming the environmental benefits of using insects as feed and replacing traditional soy-based options. Bosch *et al.* (2019) report that insect production, including BSF larvae, can result into lower greenhouse gas emissions and lower land use compared to conventional protein-rich feed ingredients including soya production. Raman *et al.* (2022) also document that BSF larvae offer superior nutrition compared to soya and are well-suited for animal feed, which has the potential to decrease reliance on imported and high-cost animal feed, including fishmeal and soya, in Malaysia.

Livestock's health and welfare benefits

Interviewees who had direct experience of feeding BSF larvae spoke at length about the benefits to their poultry both in terms of nutrition and welfare when fed live as a form of enrichment. Particularly, Participant 2 mentioned that "They [BSF larvae] are an amazing source of nutrients for the hens. They up-cycle this waste into a brilliant nutrient package high in protein and good fats which benefits the hens eating them live, so the larvae have this amazing gut microbiome … that gets passed on to the hens. And there's been studies showing that gut health of hens that have been fed BSF larvae is improved and then in terms of welfare benefits, it's just such a great source of enrichment. They're so high value to the hens, like it's just such a joy to see the hens eating them. They go crazy when they see you coming."

In fact, recent studies have demonstrated the advantages of including BFS larvae in poultry diets to enhance animals' health and well-being. Ipema *et al.* (2022) found that adding larvae to broiler diets improves leg health and overall welfare. Also, Dörper *et al.* (2021) pointed out that incorporating BFS larvae into feed can lead to positive health and welfare effects for poultry due to bioactive compounds and the natural appeal of these larvae to the birds. Therefore, this presents an opportunity to capitalise on the production and distribution of BSF larvae as a sustainable and beneficial feed choice for livestock. This approach caters to the needs of farmers who are aiming to boost the health and welfare of their animals and poultry.

Circular economy and waste management

Circular food system

The concept of a circular economy, specifically the potential to rear insects on food waste and then use them as feed for livestock, resonated strongly with the interviewees. They were keen to promote this cyclical approach, emphasising the importance of minimising waste and maximising resource efficiency in insect farming. The prospect of utilising waste food to produce valuable feed for livestock was viewed as a highly desirable aspect of insect farming practices (Bosch *et al.*, 2019). During the interviews, some interviewees brought up the concept of a circular food system:

> "There are very few barriers and the regulators have seen a very proactive approach and would applaud, you know, Animal Plant Health Agency,

> Food Standards Scotland and the other UK operators in terms of seeing this as an opportunity in working with the industry really to move from a linear standpoint in terms of the regulations across the circular possession. You know they're thinking about waste management. So really the regulators are always happy to help. The system is already in place and those businesses who are in a position to help."
>
> [Participant 8]

> "Keeping that food waste in the food system seems to be a really big deal. Rather than using it for energy production or something like that, you know it seems the food system can be circular."
>
> [Participant 9]

Recent studies have also asserted that rearing insects for livestock feed creates a circular food system by upcycling resources that are frequently lost or underutilised within the food chain (Bosch *et al.*, 2019; Beesigamukama *et al.*, 2022). This closed-loop cycle can, in turn, create a protein-rich feed ingredient that can be used to feed livestock. This practice reduces waste, lessens environmental impact, and diversifies protein sources, aligning with circular principles of sustainable resource utilisation and resilient food systems.

Recycling food waste

Interviewees highlighted the dual role of insects in both reducing food competition and facilitating waste management within the food system.

> "So it's yeah, it's reducing food competition, but also recycling waste back into the food system using nature as a solution in nature, there's no such thing as waste, and insects are part of that system where they are waste recyclers."
>
> [Participant 10]

Wang and Shelomi (2017) also supported that BSFs are portrayed as nature's solution to recycling waste, reflecting nature's inherent principle of minimising waste. Some interviewees also mentioned that using insects to recycle waste offers significant advantages in terms of greenhouse gas emissions reduction when compared to landfill disposal or composting.

> "… using insects to recycle waste and it's more you avoid the greenhouse gas emissions from just discarding that waste into landfill, but also comparing it to composting."
>
> [Participant 5]

Thus, by utilising insects to repurpose waste, the food system benefits from waste reduction and minimises greenhouse gas emissions that would result from discarding waste in landfills. This approach is seen as more sustainable than alternatives like composting, underscoring insects' capacity to effectively address waste management while contributing to a circular and ecologically balanced food system.

Future market opportunities

Premium fertiliser

Interviewees identified numerous business prospects for insect-based products. The main focus was on frass, which refers to insect excrement which is currently being used as a fertiliser. According to Delgado *et al.* (2022), insect frass contains beneficial bacteria that act as plant growth microorganisms, improving plant health and facilitating nutrient absorption. Beesigamukama *et al.* (2022) also reveal that using frass fertiliser generates higher profitability for maize production than using existing commercial organic fertilisers, emphasising the higher price associated with frass fertiliser.

Some interviewees emphasised the increasing value of frass, highlighting that it often holds greater commercial potential than the larvae itself. This is primarily due to the flexibility it offers in terms of commercialisation, particularly for fertiliser purposes. Furthermore, frass is subject to fewer restrictions compared to other insect-derived products, making it an attractive market opportunity.

> "… of course insect protein is very important to upcycle, but the frass is actually becoming more and more valuable and in many cases it's even more valuable than the larvae itself because I mean the frass has more flexibility on how to commercialise especially for fertiliser and there's less restrictions."
>
> [Participant 9]

> "We can talk about the insect protein as feed, we can talk about avoiding emissions from that land use change and the soya, but it really propagates through the whole system and fertiliser is the big story at the moment … we're working with SRUC [Scotland's Rural College] colleagues to

understand the full characteristics of the frass, particularly Black Solider Fly, but also the benefits of the application of the field and there's some really interesting things coming out of that."

[Participant 5]

"When we talk about using insect frass as fertiliser, we're looking at products that can fetch prices of around $10 per kilo or even $10,000 per tonne. Now, with a more sustainable product that's upcycled, you've got a real advantage. It opens up significant opportunities."

[Participant 4]

Premium pet food

Some interviewees identified the pet food sector as offering substantial opportunities for insect-based products. Premium pet food, in particular, was recognised as a significant market segment since these products including insect protein can legally be sold in the UK and EU market (WWF, 2021).

"I think many insect companies have shifted their focus from animal feed to premium pet food. They've come to realise that competing with traditional animal feed is all about price, and that's a tough game. I think sustainability offers a chance to increase prices. So, they're really putting their bets on pet food."

[Participant 1]

"I think pet food is the most like the biggest opportunity and maybe they (insect companies)'re are shifting their focus towards making edible insects a part of premium pet food as well as edible human protein supplements like protein bars and these kinds of things."

[Participant 9]

One interviewee also mentioned the potential expansion into edible human protein supplements such as protein bars. Pipinoto *et al.* (2020) highlighted that the demand for protein supplements could increase among consumers who engage in sports regularly or follow balanced diets, owing to their high essential protein content and environmental benefits. Therefore, these emerging market areas provide avenues for insect companies to tap into a diverse range of consumer demands and capitalise on the sustainability benefits offered by insect-based products, particular pet food and insect frass fertiliser as well as insect protein supplement.

Challenges for insect farming and industry for animal feed

In Figure 2, there are three themes on key challenges for insects as feed highlighted by our interviewees, which are (1) restrictive regulations and limited insect-related information, (2) insect production and farm constraints, and (3) consumers' and farmers' knowledge.

Restrictive regulations and limited insect-related information

Restriction on insect regulations

Interviewees mentioned how insects have been used as animal feed in the UK compared to the EU. Many of them emphasised that regulations have been developing more slowly in the UK because of many reasons, including safety, risk assessments, and consumer acceptance. After Brexit, the regulations have made it even more difficult for farmers to use insects as feed, since farmers can only feed insects to livestock live. Most interviewees did not feel that there was a rush to change legislation and regulations soon. One interviewee said that they had written to a politician about the challenges in the insect farming sector and received the response "It is on the agenda to look at this legislation and we can't give you a timeline" [Participant 2]. Also, most interviewees felt that the legislation needed to be the same as in the rest of the EU. One interviewee stressed that "They just need to align it [UK legislation] with European legislation. It's taking a bit longer than we'd hope. Just get it done" [Participant 4].

Moreover, the constraints imposed by regulatory frameworks in the UK are not only confined to the use of insects as feed but also encompass stricter rules governing insect feedstock substrates which can be used to rear insects (WWF, 2021). Some interviewees pointed out that these regulations impose limitations on the types and quantities of waste that can be used as feed for insects, potentially placing the UK industry at a disadvantage.

"At the moment it's just crazy that there're sources of feed that we could be using for larvae that we're not allowed to use, and so I think the research around that to de-risk it, to show that it can be done safely, then legislative change."

[Participant 10]

> "Feedstock can't be animal manure or postconsumer food waste, it can't be abattoir waste."
>
> [Participant 8]

Therefore, this section emphasises the need for research on the risks associated with different insect feedstocks and how these risks can be mitigated. Robust evidence is essential as a requirement for any legislative change that broadens the permissible substrates for insect rearing. Once insect meal is approved for use in pig and poultry feed, the availability of materials needed for insect rearing (substrates) could become limited. This limitation might pose a challenge to the ability of UK-produced insect meal to compete with imported insect meal.

Limited information sources

Many interviewees, particularly insect farmers, reported that it was hard to find information on how to farm insects and the implications of using them as animal feed. A few interviewees felt that the difficulties surrounding access to information were deliberate as it provided a competitive advantage to some groups, this is summed up well in the following quote:

> "There are a lot of venture capitalists and private equity involved in this industry so it's limiting the amount of information spread – they want to keep all the IP [intellectual property] to themselves."
>
> [Participant 4]

> "There's so much going on around intellectual property rights and so on."
>
> [Participant 7]

To overcome the information gaps, many interviewees relied on informal networks, such as WhatsApp groups, to obtain new insights and resources. Also, the interviewees reported that acquiring information was primarily through networking and contacts, stating:

> "We have a WhatsApp group … so people share ideas and links and things."
>
> [Participant 2]

> "… really was through kind of networking and contacts. I didn't … really find any kind of useful information, just from a farmer's perspective I suppose."
>
> [Participant 6]

The internet was identified as a valuable source of information, with interviewees mentioning online platforms and resources like YouTube videos – "it's all online based", "lots of YouTube videos" [Participate 2]. However, only three participants said that they had accessed more formal training, one had attended a course in Holland, one received training through seminars at their work and another felt that groups including innovative farmers had more recently been putting on webinars.

Limited insect-related research

During the interviews, several gaps in knowledge about insect farming and the use of insects as feed for livestock were highlighted. Many interviewees referred to these gaps generically, stating "not been enough research." This sentiment was explicitly stated by most interviewees, referring to a lack of sufficient research. They emphasised that research evidence could have played a significant role in driving the growth of the insect industry in the UK, as robust evidence is essential for regulatory development. In particular, Participant 3 highlighted the specified specific research gaps on the benefits of feeding insects to livestock animals like pigs: "We know the benefits of feeding them to hens looking at feeding the pigs, but we need evidence from research to support this". Also, Participant 8 mentioned the need for research that explores the entire life cycle of BSFs with a particular focus on the early stages such as breeding, laying eggs, hatching, etc.: "… still gaps in knowledge about the life cycle assessment of the whole process, including the fresh side, some people have done LCA's [life-cycle assessments], but only focusing on the insects." This approach is crucial for understanding the environmental impact and sustainability of the insect farming process.

Additionally, a few interviewees talked about robust evidence on potential substrates that can be used and cannot be used in insect rearing since only insect substrates that are permitted to feed insects such as cereal grains, legume seeds, roots, fruits, forages and algae, and non-animal-containing industry by-products, such as by-products from bakery, breakfast cereal and confectionery industries, and from processing fruit and vegetables (WWF, 2021). For example,

> "I think some studies to de-risk feeding other types of waste that we can't feed directly to vertebrate livestock, but we could feed to insect livestock. I think those studies are really needed because at

> the moment there's still a lot of waste that is getting wasted because we can't feed it to insects."
>
> [Participant 3]

These insights from the interviews highlight the limited availability of information and research in the field of insect farming. The reliance on informal networks, online sources, and the identification of specific research gaps highlight the need for more accessible and comprehensive information resources, as well as targeted research efforts to address knowledge gaps and drive the development of insect-based livestock feed systems.

Insect farm and production constraints

High cost of insect production

Currently, the UK only permits feeding insects live to livestock. This means that insects need to be produced near to where they will be consumed, thus making UK-based insect production essential. However, producing insects within the UK comes with its own challenges, primarily due to the need for controlled environments that incur significant costs in terms of energy consumption and labour. One interviewee expressed the difficulty of breeding insects, highlighting its financial inviability:

> "The breeding side of things is quite challenging … quite costly and it's not viable financially."
>
> [Participant 2]

> "Cost that's been a big deal… So much of it is about, well, part of it is about automation to bring the labour costs down but then the other part is about getting the nutrient profiles right and consistent. I think achieving that seems to be potentially a big cost barrier. So I think actually scaling the industry up is the is the other big thing. I think it really comes down to cost and making it appealing to farmers on that basis."
>
> [Participant 9]

On the other hand, a few interviewees believed that with the right equipment, insect production could be carried out in an energy-efficient manner. For example, Participant 4 mentioned that "I found that I can do it in a not energy-intensive way… I think having the right is set up so you know, for instance my setup, it's in an insulated container, so you might have to have some heat on in the winter, but it's insulated and the insects themselves produce heat." Following own farming experience, Participant 7 felt that the high energy costs could be overcome by the use of renewable energy, stating that "One of the farmers with one of the X1 units is using renewable energy to supply that, so they're not paying big energy rates." However, sustainable farming practices still require careful consideration of resource-efficient technologies and environmentally friendly cultivation methods to achieve low-cost production.

Lack of established supply chains

The lack of established supply chains was identified as another contributing factor to the high costs of insect production in the UK. The delayed interest in the industry until recent years has resulted in significant gaps and the absence of a well-developed supply chain. For the growth of insect farming industry, some interviewees expressed the need for more BSF larvae producers in the country. They also suggested establishing a system for distribution and knowledge sharing among farms of various scales, catering to different requirements, including potential use in pig feed alongside poultry feed.

> "There needs to be more producers of black soldier fly larvae in the country and figure out some kind of system for distribution or for learning or so if farms want to do it because like better bugs do starter kits and it's much more aimed at very small scale. But you know just different scales, basically of producers using it. And I don't really know how it works in terms of pig feed, but if it could also fulfil some pig feed requirements as well as poultry."
>
> [Participant 2]

> "There's a serious lack of supply chain and that's because there hasn't been any interest until the last five years, I suppose."
>
> [Participant 3]

> "There's a lot of the gaps structurally or there's no supply chain setup for this at all."
>
> [Participant 9]

Despite the challenges, most interviewees expressed optimism that production costs could be reduced in the future. The collective belief was that if there was sufficient demand from farmers, prices could decrease by leveraging breeding operations in different regions, such as Scotland, where lower costs could be achieved.

> "I think ultimately if there were enough farmers wanting to do it, the price would come down because you could get somebody breeding in Scotland and for lower cost."
>
> [Participant 6]

This outlook suggests that as the industry grows and gains momentum, there is potential for cost optimisation through increased demand, regional specialisation, and improved supply chain infrastructure.

The impracticalities of feeding (live) insects to livestock

The current restriction on feeding insects to livestock only in live form was not favoured by many interviewees, who expressed concerns about the associated expenses, inconvenience, and additional time to feed livestock. Those who highlighted these issues felt that incorporating dried or powdered insects into existing feeding systems, such as pelleted feed, would be a preferable method. The following quotes highlight this perspective.

> "We are only allowed to feed live insects … we would ultimately prefer to use dried insects."
>
> [Participant 2]

> "It would probably mix quite well with pelleted feed and most of the farmers want pelleted feed, especially ones on the islands because of transporting and just being able to get bags of it. And you know, and for this and for it to keep longer storage, just all those things it it's just a much easier system obviously."
>
> [Participant 3]

While some interviewees acknowledged that feeding live insects could have benefits for livestock, such as chickens and pigs, including behavioural enrichment and nutritional health, they also recognised the advantages of incorporating processed insect forms.

> "… and sort of behaviour if they're fed live insects over. … that's missing is sort of the insect protein which would be what they would normally eat. So yeah, I guess it's healthy for the animals."
>
> [Participant 1]

On the other hand, there were additional benefits associated with feeding insects in live form, particularly in terms of energy efficiency. Processing insects into meals or pellets was considered more energy-intensive and potentially compromised the sustainability benefits.

> "A study showed that the hens do prefer the live insects to the processed ones. And so it's an enrichment and preference issue, it's also a health issue. You're taking away those guts benefits of the live larvae and then it makes it more energy intensive … when we took the larvae process and turned it into meal … feed that that step so energy intensive like drying, the insect meal it takes a huge amount of energy, so it takes away some of the sustainability benefits as well."
>
> [Participant 8]

These perspectives emphasise the potential drawbacks and limitations of exclusively feeding insects to livestock in live form. The integration of dried or processed insect forms into existing feeding systems is seen as a more practical, efficient, and sustainable approach, providing benefits in terms of convenience, storage, energy usage, and overall livestock well-being.

Consumers' and farmers' knowledge toward insects for animal feed

The acceptance of insects to livestock feed

A few interviewees did not raise any major concerns about consumer acceptability of feeding insects to livestock, considering the environmental benefits and expecting fair practices from producers, including providing clear labelling for customers. For instance, Participant 5 stated that "a study a few years ago and I think it was 85% Scottish consumers are more than happy for insects to be included in the feed for salmon and to buy those products as long as they fully understand the sustainability story behind that and the materials are labelled appropriately."

However, many interviewees acknowledged the need for outreach and consumer education to increase awareness and acceptance among both consumers and farmers. For example, to push this emerging sector forward, Participant 2 expressed that "I think a lot of work needs to be done to educate consumers but also the farmers."

It is noted that all interviewees discussed the feeding of insects to poultry and pigs, and not ruminants. The consensus among interviewees was that pigs and poultry are suitable candidates for insect-based feed due to their natural diet. However, interviewees expressed reservations about feeding supplementary protein from insects to ruminants, stating that it was not a route

they believed should be pursued. A few interviewees with agricultural experience admitted that they had not previously considered feeding insects to ruminants. For example:

> "I'm for doing it with pigs and poultry. They're obvious candidates because that's part of their natural diet. But I wouldn't wanna feed supplementary protein to a ruminant … I don't think that is a route we should be going down."
>
> [Participant 6]

Feeding insect protein to ruminants remains a topic of debate within the scientific community. Renna *et al.* (2022) contend that insects may be unsuitable for the digestive systems of herbivores. However, Ahmed *et al.* (2021) proposed that incorporating insects could mitigate methane production. Therefore, further research in this field is necessary to explore the potential benefits and considerations of incorporating insect protein into ruminant diets.

Insect and animal welfare

The welfare of insects was also discussed by some interviewees. The two main aspects that were discussed were how to farm insects to ensure good welfare and the other concerned the humane killing of them particularly when currently they are only being fed live to livestock in the UK. One interviewee believed that, with the right knowledge and understanding, the needs of farmed insects could be met to ensure their well-being.

> "I think with the right knowledge … we can meet the species-specific needs of the insects and we can keep them healthy."
>
> [Participant 6]

Another felt that insects were very different from other farmed species and therefore the use of the five freedoms which were devised with traditional livestock species in mind may not be appropriate for insect farming:

> "There are guidelines and standards and so on now for farming insects. They tend to draw on the five freedoms, but it's really problematic because … you know, freedom to express themselves well, you know, they might actually like to be in really close confinement … whereas for other animals you could probably say well, it's much better for them to have more space and so on. So … it's not a simple transposition [from traditional farmed animals to insect farming."
>
> [Participant 7]

Another aspect of insect welfare that was discussed by interviewees was that evidence points to insects being sentient therefore a humane death was important and required further research. There was discussion about conducting experiments to determine the most humane methods of killing insects, taking into account the hypothesis that they fall unconscious and are killed further down the digestive tract:

> "It's something I think about quite a lot because obviously I'm kind of an advocate of feeding them live. The definition of a humane death is one that's instant or they're rendered insensible first. … If we're gonna process them, I think they can be killed humanely. I'd really like an experiment done looking into feeding the larvae live. There's a hypothesis that so they're not macerated … they go into the crop, they fall unconscious, and then they're killed further down the digestive tract. So, if that happened, and if they fell unconscious quite quickly, that would meet the definition of a humane death. And I'd love to think that nature has developed, you know, devised humane deaths for everything."
>
> [Participant 9]

> "I think there's a bit more about, I don't know, feeding chickens and the possible welfare advantages and so on … but for the insect, I think there's so much ambiguity around, what good welfare is and whether it even whether it is even a thing, but the at the same time there's more research coming out about insects and pain and relationship between pain and nociception, and so on, and I think that how farmers deal with that and how consumers might feel about these things, I think they're probably all quite significant areas."
>
> [Participant 10]

Van Huis (2021) proposes that insects should be farmed and killed according to the precautionary principle, assuming their potential ability to experience pain. This assertion implies the necessity of binding insect farming practices to animal welfare regulations. However, insects are not currently classified as invertebrates

under EU animal welfare legislation, which typically pertains to animal breeders (Clark, 2021). Also, Bear (2021) and Delvendahl *et al.* (2022) underscore the challenges in establishing standards for insect welfare due to their diverse living environments and varied feed requirements.

However, one interviewee highlighted the importance of minimal intervention and a natural approach to insect farming, emphasising that such practices align with economic viability and sustainability:

> "Why we're thinking welfare? Because I mean if we do all the complexities and everything around them and legislation and all the rules, we're basically kind of restricting us to ever using them like economically or sustainable way … It has to be as naturally as possible with minimal technology, minimal intervention, and that's the natural way to do it."
>
> [Participant 9]

These insights from the interviews in this section highlight some under-researched areas on the welfare of the insects being farmed and the effect on the animals being fed them.

5 Conclusion and recommendations

This study aims to support the development of a farming and business strategy for insects as feed, particularly BFS, in the UK. The strategic plan is based on insights gathered from interviews, which have identified key opportunities and challenges associated with insect farming and the use of insects in animal feed within the UK. Notable opportunities in this sector include insects as a sustainable protein source, circular economy and waste management, future business opportunities including the development of value-added products (e.g. fertiliser, pet food) as well as the benefits to livestock welfare. However, the interviews also highlight some key obstacles including limited information sources and lack of research related to insects as feed, unclear insect-related legislation and regulations, the cost to produce insects, the costs and practicalities of feeding insects to livestock and the acceptability of feeding insects to livestock.

Based on the insights gained from interviews with industry experts and stakeholders, policymakers and the government can consider implementing the following key recommendations and strategic plans to develop insect farming and the insect feed industry in the UK. Firstly, it is urgent for the government to fast-track full authorisation of edible insects for animal feed to align with EU regulations. Also, the government should collaborate with industry experts and regulatory bodies to establish clear and transparent regulations and guidelines specifically tailored to insect farming and the use of insects in animal feed. These regulations should encompass licensing requirements, quality control standards, animal welfare considerations, food safety regulations, and environmental factors. This robust regulatory framework can ensure accountability, compliance, and the responsible development of the industry.

Secondly, there is a need for policy incentives, such as grants and subsidies, and other forms of support to encourage investment in insect farming and feed production facilities. These incentives can offer financial incentives and facilitate access to financing, business development services, and market opportunities. Consequently, this support can create a favourable environment for startups and encourage existing players to expand their operations. This will help stimulate growth and innovation within the insect farming and feed industry.

Next, facilitating industry collaboration and networking is essential for knowledge sharing, experience exchange, and collective problem-solving. Policymakers should foster platforms such as associations, working groups, conferences, and networking events that bring together stakeholders from the insect farming and feed industry. By promoting collaboration, stakeholders can share best practices, address common challenges, and drive innovation, ultimately enhancing the industry's overall development and competitiveness.

In addition, to accelerate the acceptance and adoption of insects as feed, the government and policymakers should focus on raising public awareness about the benefits of using insects as an alternative feed source. By promoting a shift in people's and farmers' perceptions, the demand for insect-based animal feed and edible insect market can be significantly expanded. Also, awareness campaigns, education initiatives, and targeted information dissemination can play a significant role in informing the public, consumers, and relevant stakeholders about the nutritional, environmental, and economic advantages of incorporating insects into animal feed.

Finally, it is crucial to prioritise further research in the areas of circular economy and waste management, animal welfare in insect farming, and insects for rumi-

nant feed. The government should allocate resources and support scientific studies to explore innovative approaches and technologies that enhance sustainability and resource efficiency within the industry. Investing in research and implementing these solutions can foster a more sustainable and resilient insect farming and feed industry, while creating new opportunities for farmers and business operators. This will not only contribute to environmental conservation and animal welfare, but also promote economic growth in a more sustainable manner.

Conflict of interest

The authors have no conflict of interest to declare.

Ethical approval

This study was approved by the Ethics Committee of Scotland's Rural College under Social Science Ethics Approval [Ref: 86/62563036] and the Scottish Government.

Funding

This study was funded by Scottish Environment, Food and Agriculture Research Institutions (SEFARI).

References

Ahmed, E., Fukuma, N., Hanada, M. and Nishida, T., 2021. Insects as novel ruminant feed and a potential mitigation strategy for methane emissions. Animals 11: 2648. https://doi.org/10.3390/ani11092648

APHP, 2024. Import of processed animal protein (PAP) derived from farmed insects not for human consumption. Available at: http://apha.defra.gov.uk/documents/bip/iin/abp-45.pdf

Bear, C., 2021. Making insects tick: responsibility, attentiveness and care in edible insect farming. Environment and Planning E: Nature and Space 4: 1010-1030. http://dx.doi.org/10.1177/2514848620945321

Beesigamukama, D., Mochoge, B., Korir, N., Menale, K., Muriithi, B., Kidoido, M., Kirscht, H., Diiro, G., Ghemoh, C.J., Sevgan, S. and Nakimbugwe, D., 2022. Economic and ecological values of frass fertiliser from black soldier fly agro-industrial waste processing. Journal of Insects as Food and Feed 8: 245-254. https://doi.org/10.3920/JIFF2021.0013

Better Origin, 2021. How does insect farming work? Available at: https://betterorigin.co.uk/2021/10/how-does-insect-farming-work/

Bosch, G., Van Zanten, H.H.E., Zamprogna, A., Veenenbos, M., Meijer, N.P., Van der Fels-Klerx, H.J. and Van Loon, J.J.A., 2019. Conversion of organic resources by black soldier fly larvae: legislation, efficiency and environmental impact. Journal of Cleaner Production 222: 355-363.

Chia, S.Y., Tanga, C.M., van Loon, J.J. and Dicke, M., 2019. Insects for sustainable animal feed: inclusive business models involving smallholder farmers. Current Opinion in Environmental Sustainability 41: 23-30. https://doi.org/10.1016/j.cosust.2019.09.003

Clark, W., 2021. Guidance on regulations on farming insects in Scotland to produce sustainable protein. Zero Waste Scotland. Available at: https://cdn.zerowastescotland.org.uk/managed-downloads/mf-c_6jxfbm-1678698804d

DEFRA and APHA, 2014. Guidance: using animal by-products at compost and biogas sites. Available at: https://www.gov.uk/guidance/using-animal-by-products-at-compost-and-biogas-sites

Dörper, A., Veldkamp, T. and Dicke, M., 2021. Use of black soldier fly and house fly in feed to promote sustainable poultry production. Journal of Insects as Food and Feed 7: 761-780. https://doi.org/10.3920/JIFF2020.0064

EC, 2021. Feed ban: commission authorises use of certain animal proteins. European Commission. Available at: https://ec.europa.eu/newsroom/sante/items/718842/en

EUR-Lex, 2017a. COMMISSION REGULATION (EU) 2017/1017 of 15 June 2017, amending Regulation (EU) No 68/2013 on the Catalogue of feed materials. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R1017&from=EN

EUR-Lex, 2017b. COMMISSION REGULATION (EU) 2017/893. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32017R0893#:~:text=Commission%20Regulation%20(EU)%202017%2F,(Text%20with%20EEA%20relevance.%20)

EUR-Lex, 2018. Guidelines for the feed use of food no longer intended for human consumption. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018XC0416(01)&from=EN

FAO, 2020. Emissions due to agriculture. Global, regional and country trends 2000-2018. FAOSTAT Analytical Brief Series No 18, Rome. Available at: https://www.fao.org/3/cb3808en/cb3808en.pdf

Ffoulkes, C., Illman, H., O'Connor, R., Lemon, F., Behrendt, K., Wynn, S., Wright, P., Godber, O., Ramsden, M., Adams, J., Metcalfe, P., Walker, L., Gittins, J., Wickland, K., Nanua, S.

and Sharples, B., 2021. Development of a roadmap to scale up insect protein production in the UK for use in animal feed. Technical Report prepared by ADAS and Michelmores for WWF-UK and Tesco. Available at: https://www.wwf.org.uk/sites/default/files/2021-06/the_future_of_feed_technical_report.pdf

FSA, 2020. Starting an animal feed business: guidance on the type of activity and registration requirements. Available at: https://www.food.gov.uk/print/pdf/node/133

FSA, 2022a. FSA consultation on transitional arrangements for edible insects in Great Britain. Available at: https://www.food.gov.uk/sites/default/files/media/document/Consultation%20on%20transitional%20arrangements%20for%20edible%20insects%20in%20Great%20Britain.pdf

FSA, 2022b. Rapid risk assessment: what is the risk to consumers from consumption of the seven edible insects' products currently available in the UK market? Available at: https://www.food.gov.uk/research/novel-and-non-traditional-foods-additives-and-processes/rapid-risk-assessment-what-is-the-risk-to-consumers-from-consumption-of-the-seven-edible-insects-products-currently-available-in

FSA, 2024. Edible insects guidance. Available at: https://www.food.gov.uk/business-guidance/edible-insects-guidance#edible-insects-as-novel-foods

Halloran, A., Hanboonsong, Y., Roos, N. and Bruun, S., 2017. Life cycle assessment of cricket farming in north-eastern Thailand. Journal of Cleaner Production 156: 83-94.

Hawkey, K.J., Lopez-Viso, C., Brameld, J.M., Parr, T. and Salter, A.M., 2021. Insects: a potential source of protein and other nutrients for feed and food. Annual Review of Animal Biosciences 9: 333-354. https://doi.org/10.1146/annurev-animal-021419-083930

Insect Biomass Task & Finish Group, 2019. The insect biomass industry for animal feed – the case for UK-based and global business. Available online: https://www.fera.co.uk/media/wysiwyg/Final_Insect_Biomass_TF_Paper_Mar19.pdf

Ipema, A.F., Bokkers, E.A., Gerrits, W.J., Kemp, B. and Bolhuis, J.E., 2022. Provision of black soldier fly larvae (*Hermetia illucens*) in different ways benefits broiler welfare and performance, with largest effects of scattering live larvae. Physiology & Behavior 257: 113999.

IPIFF, 2021. Insect producers must conform with the same general rules that apply to operators in other sectors. Available at: https://ipiff.org/insects-eu-legislation/

Michelmores, 2023. Insect protein for animal feed. Available at: https://www.michelmores.com/agriculture-insight/insect-protein-animal-feed/

Oonincx, D.G.A.B. and Finke, M.D., 2021. Nutritional value of insects and ways to manipulate their composition. Journal of Insects as Food and Feed 7: 639-659. https://doi.org/10.3920/JIFF2020.0050

Pinotti, L. and Ottoboni, M., 2021. Substrate as insect feed for bio-mass production. Journal of Insects as Food and Feed 7: 585-596. https://doi.org/10.3920/JIFF2020.0110

Polaris Market Research, 2021. Insect protein market share, size, trends, industry analysis report, by product (Coleoptera, Lepidoptera, Hymenoptera, Orthoptera, Hemiptera, Diptera, Others), by application (food & beverages, animal nutrition, personal care & cosmetics, others), by regions; segment forecast, 2021-2028. Available at: https://www.polarismarketresearch.com/industry-analysis/insect-protein-market

Raman, S.S., Stringer, L.C., Bruce, N.C. and Chong, C.S., 2022. Opportunities, challenges and solutions for black soldier fly larvae-based animal feed production. Journal of Cleaner Production 373: 133802. https://doi.org/10.1016/j.jclepro.2022.133802

Sánchez-Muros, M.J., Barroso, F.G. and De Haro, C., 2016. Brief summary of insect usage as an industrial animal feed/feed ingredient. In: Dorsey, A.T., Morales-Ramos, J.A. and Rojas, M.G. (eds.) Insects as sustainable food ingredients production, processing and food applications. Elsevier, Waltham, MA, USA, pp. 273-309. https://doi.org/10.1016/B978-0-12-802856-8.00010-7

SEPA, 2000. The pollution prevention and control (Scotland) regulations 2000: a practical guide for Part B activities. Available at: https://www.sepa.org.uk/regulations/pollution-prevention-and-control/

Shah, A.A., Totakul, P., Matra, M., Cherdthong, A., Hanboonsong, Y. and Wanapat, M., 2022. Nutritional composition of various insects and potential uses as alternative protein sources in animal diets. Animal Bioscience 35: 317-331. https://doi.org/10.5713/ab.21.0447

Thai Ministry of Agriculture and Cooperatives, 2017. Thai agriculture standard: good agricultural practices for cricket farm. Available at: https://www.acfs.go.th/standard/download/eng/GAP_CRICKET_FARM-ENG.pdf

Tiwasing, P., 2022. From yuck to yum: unlocking the potential of edible insects. Policy Spotlight, No. 8. SRUC's Rural Policy Centre. Available at: https://pure.sruc.ac.uk/ws/portalfiles/portal/57754657/October_2022_Policy_Spotlight_Edible_Insects_FINAL.pdf

UN, 2023. Take action for the sustainable development goals. Available at: https://www.un.org/sustainabledevelopment/sustainable-development-goals/

van Huis, A., 2015. Edible insects contributing to food security? Agriculture & Food Security 4: 1-9. https://doi.org/10.1186/s40066-015-0041-5

van Huis, A., 2021. Welfare of farmed insects. Journal of Insects as Food and Feed 7: 573-584. https://doi.org/10.3920/JIFF2020.0061

Wang, Y.S. and Shelomi, M., 2017. Review of black soldier fly (*Hermetia illucens*) as animal feed and human food. Foods 6: 91. https://doi.org/10.3390/foods6100091

Wiltshire, J., Freeman, D., Willcocks, J. and Wood, C., 2020. The potential for leguminous crops in Scotland. ClimateXChange Publications. Available at: http://dx.doi.org/10.7488/era/763

WWF, 2021. The future of feed: a WWF roadmap to accelerating insect protein in UK feeds. Available at: https://www.wwf.org.uk/sites/default/files/2021-06/The_future_of_feed_July_2021.pdf

Yang, Y. and Cooke, C., 2021. Exploring the barriers to upscaling the production capacity of the edible insect sector in the United Kingdom. British Food Journal 123: 1531-1545.

Żuk-Gołaszewska, K., Gałęcki, R., Obremski, K., Smetana, S., Figiel, S. and Gołaszewski, J., 2022. Edible insect farming in the context of the EU regulations and marketing – an overview. Insects 13: 446. https://doi.org/10.3390/insects13050446

Appendix: Interview questions

1. Can you explain your interest and involvement in the insect feed sector?
2. What do you think are the main benefits of insect farming and using insects as feed? Do you think more work needs to be done on this?
3. What are the main barriers of insect farming and using insects as feed? Do you think more work needs to be done on this?
4. What are the main rules that govern insect farming and the use of insects as feed?
5. How could the legislation and regulations be changed to encourage this industry?
6. What are your thoughts or concerns regarding animal welfare for insects?
7. What are your thoughts on the likelihood of insects being incorporated into animal feeds in the near future, and how do you see this process unfolding?
8. Finally, what urgent actions or factors do you believe are necessary to advance this sector now?