A Nuffield Farming Scholarships Trust Report

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Can carbon neutral insects be farmed profitably?

Dr Olivia L. Champion

August 2023

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Nuffield (UK) Farming Scholarships Trust Report

Date of report: August 2023

"Leading positive change in agriculture. Inspiring passion and potential in people."

Title	**Can carbon neutral insects be farmed profitably?**
Scholar	Dr Olivia L. Champion
Sponsor	The Richard Lawes Foundation
Objectives of Study Tour	1) To assess market readiness for insect ingredients for food and feed. 2) To identify the main costs associated with insect farming and identify mechanisms to drive down costs. 3) To understand how the regulatory landscape intersects with farm success.
Countries Visited	England, N. Ireland, Scotland, Germany, Netherlands, Zimbabwe, Botswana, South Africa, Canada.
Messages	1. The cost and carbon footprint of insect farming is dependent on the farming system used, especially the substrate used to feed the insects. Currently most commercial insect farms use soy or cereal based livestock feed as a substrate. 2. Waste streams that cannot be fed to humans or animals should be explored as approved substrates for insects farming. 3. The cost price of insects per tonne is 5-10 times the cost price of soya. Price is the main barrier to market acceptance of insect ingredients for both food and feed.

EXECUTIVE SUMMARY

As the global population increases, the demand for meat and animal products is growing, leading to a greater need for protein in both human and animal diets. Soya is a key solution for the growing global protein demand but the entire process of cultivating, processing, and transporting soya-based feed contributes to significant carbon emissions.

Edible insects offer an alternative protein source suitable for both humans and animals. Insects require less space, water, and emit fewer greenhouse gases.

My Nuffield study tackles the central question: *"Can we profitably farm carbon-neutral insects?"*

My research journey has revealed that producing insects for food and feed is constrained by limitations in scale, high costs, and inconsistent quality. Improvements like automation, enhanced insect genetics, and optimized diets are crucial for advancing insect farming. Understanding insect diseases and pests is also vital.

After exploring various farms globally, I've found that carbon-neutral insect farming is possible when waste unsuitable for animal consumption becomes insect food. However, using valuable resources intended for animals or humans for insect farming is inefficient and costly. Many insect farms presently utilize soya-based materials, which contradicts the goal of reducing soya in animal feed. Utilizing livestock manure as insect food could be a strategic alternative, subject to careful risk assessment. Blending waste as a substrate for insects and integrating renewable energy can establish carbon-neutral insect farming as a viable option.

In the UK, supermarkets and feed producers alike are exploring soy alternatives in livestock diets. Both feed mills and livestock producers seek consistent, sustainable ingredients without soya. Currently, soya costs approximately £350 per tonne. For insect ingredients to compete, offering comparable protein content as soya (50%) at around £350 per tonne is crucial. However, insect meal's present price hovers around £3,500 per tonne. The cost price of insect products is the key barrier to success.

Prominent companies like AgriProtein, Enterra, and Ÿnsect have encountered profitability challenges or closures despite substantial investments. With rising living costs and changing spending patterns, the demand for costly and unfamiliar insect-based foods and feeds might stay limited.

In conclusion, Africa offers significant prospects for insect farming, serving as animal feed and human food sources. Overcoming challenges through ongoing research and innovation could position insect farming as a pivotal player in constructing sustainable and nutritious food systems.

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DISCLAIMER

The opinions expressed in this report are my own and not necessarily those of the Nuffield Farming Scholarships Trust, or of my sponsor, or of any other sponsoring body.

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Introduction

Figure 1. Dr Olivia Champion on Dartmoor, Devon with her beloved border terrier, Bella. *Source: author*

Born in London and having lived in North America, I now live in Torquay, Devon. I am married to a Welshman, and we have three children, a ginger tomcat and a border terrier (Figure 1).

Classically trained as a Molecular Microbiologist, my broad area of expertise is public health, food safety, infectious disease, and insect technology. I was as a research scientist for 20 years in Europe and North America, starting my career as an intern at the Food Safety Unit of the World Health Organisation (WHO) in Geneva. After working at WHO I became a Clinical Scientist for Public Health England, working on outbreak investigations. Following on from an MSc in Clinical Microbiology at Queen Mary and Westfield University, I completed a PhD in Molecular Microbiology at the London School of Hygiene and Tropical Medicine working on the important foodborne pathogen *Campylobacter jejuni*. I worked on a vaccine development research programme before commercialising my academic research to found Exeter-based insect biotechnology company, BioSystems Technology in 2015. BioSystems Technology provided tools for scientists carrying out research into infectious diseases. Realising the potential of insects as a source of food and feed I founded Entec Nutrition Ltd, an Agri Tech company. Through Entec Nutrition (EN) I explored the development and adoption of insects farmed using circular economy principles for waste management to produce sustainable ingredients for animal feed. Recently I became Research Commercialisation Manager at the University of Bristol, supporting the commercialisation of academic research, including AgriTech and veterinary innovations.

During my career I have published over 25 peer reviewed research articles that have been cited over 2,800 times, six book chapters, filed four patents and given a TedX talk about my work and motivations, against a background of three career breaks and ongoing parental responsibilities. I have been a microbiology consultant on several television documentaries. Previously I was an Entrepreneur in Residence at the University of Exeter and the University of Bristol SETSquared, which is the global number one university spin-out company incubator.

I'm passionate about the intersection of science, agriculture and entrepreneurism and the innovations that can be created in this space to solve some of the planet's most pressing problems. I'm particularly interested in how we can feed a growing global population with healthy, nutritious food while also reducing carbon emissions to mitigate climate change. Honesty and integrity are critical ingredients when tackling both the challenges and opportunities that arise to ensure that financial gain isn't the only motivating factor in the development of solutions.

Background to my study subject

As population levels rise, it is expected that livestock consumption will increase, generating a greater demand for nutritious protein sources for humans as well as animal feedstocks, and therefore animal-feed ingredients. Currently, the global feed industry is energy-intensive, reliant on international imports and at risk of commodity price hikes. Soya is often a major component of livestock feed, which accounts for around 75% of soy production, largely because soy is very high in protein (50%) and promotes high livestock yields. Soya can have a high carbon footprint because large areas of land, often in regions with valuable natural ecosystems, are cleared to make way for soybean cultivation, releasing stored carbon in the form of CO_2, and resulting in the loss of important carbon sinks. In some regions, soybean cultivation has been linked to deforestation, especially in the Amazon rainforest. Deforestation releases significant amounts of CO_2 into the atmosphere, as well as reducing the ability of the forest to absorb CO_2 through photosynthesis. Large-scale soybean farming often relies on monoculture practices that can deplete soil nutrients and increase the need for chemical fertilizers. Nitrogen-based fertilizers release nitrous oxide (N_2O), a potent greenhouse gas, when applied to the soil. Processing soybeans into soy-based livestock feed requires significant energy inputs leading to additional carbon emissions. Finally, transportation of soybeans from farms to processing facilities and then to livestock operations may involve long distances, increasing the carbon footprint associated with the feed. Life Cycle Analysis (LCA) is a systematic approach used to evaluate the environmental impacts of a product, process, or activity throughout its entire life cycle. This analysis takes into account all stages of the life cycle, from raw material extraction and production to use, disposal. LCA on the average poultry farm reveals that livestock feed and account for as much as 85% of the total carbon footprint of the farming operation, and the inclusion of soy as a protein source is the main culprit. The UK needs to increase feed production resilience and find alternatives to soy-based feed to move the UK's livestock production towards a sustainable and productive future.

In the UK many major supermarkets are aiming to achieve a 50% absolute reduction in carbon emissions associated with UK food and drink by 2030[1]. Livestock feed used to produce their food and drink products and supermarkets are urgently seeking tools for farmers in their supply chains to help them achieve their targets. Farmed insects for animal feed are viewed as an important part of the solution. From a nutritional perspective, insects have the correct protein, fat and carbohydrate profile to both feed humans and farmed animals. On average, the protein content of edible insects ranges 35%–60% dry weight or 10%–25% fresh weight which is higher than plant protein sources, including cereal, soybeans, and lentils[2]. From an environmental perspective, edible insects require very little land to produce as they can be vertically farmed at high density. Insects require very little water and are reported to emit low levels of greenhouse gases. A report published by the World Wildlife Fund (WWF) and Tesco in 2021 entitled *The Future of Feed: a WWF roadmap to accelerating insect protein in UK feeds*[3] projects the total demand for insect meal from the UK's pig, poultry and salmon sectors could reach around 540,000 tonnes a year by 2050. This could result in about 524,000 tonnes of soy being replaced – equivalent to one fifth of the UK's projected soy imports in 2050, or Tesco UK's entire 2018 soy footprint. Edible insect ingredients have also been proposed as a nutritious, sustainable protein source for human food.

Given the size of the opportunity, hundreds of millions of pounds worth of investment, in the form of government grants and private investment, have gone into developing commercial insect farms, particularly in Europe and North America. However, despite the strong case for insect farms, there have been some notable failures. High profile insect farm pioneers, such as AgriProtein and recently Enterra have gone into administration, despite receiving hundreds of millions of dollars of investment between them. Why have these businesses failed when there is such a compelling story to support the success of insect farms? Why aren't edible insects reaching the human food chain when supermarkets, farmers and consumers alike claim to be seeking feed products that are nutritionally rich and have a low carbon footprint? And how low is the carbon footprint of insect farming in reality?

The real question lies in the economics of insect farming, specifically the cost of production, value of product and the carbon accounting of the farming system.

My Nuffield study topic explores the central question *"Can carbon neutral insects be farmed profitably?"*

Chapter 1: Is the market ready for edible insects?

1.1 Government support for insect farming

Edible insects have formed part of the diet of humans and animals for millennia. Livestock such as pigs and poultry, and fish eat insects as part of their natural diet and in many parts of the world, including Africa and South East Asia, insects are harvested seasonally by local people and eaten as a delicacy. Insect farm small and medium-sized enterprises (SMEs) are appearing across sub–Saharan Africa. Kenya and Uganda have set national standards for insects as feed and food and the International Centre for Insect Physiology and Ecology (ICIPE) in Kenya is a world leader in edible insects. Dried edible insects contain up to 60% protein and realising their potential some EU countries, such as the Netherlands and France, have included insect farming as part of the government's strategy to meet the growing demand for protein in alignment with their net zero commitments. These countries have invested financially into the sector to support its development, as well as driving regulatory changes to open insect animal feed and human food markets. In Canada, insect farming is a key priority for government investment. This strategic support of insect farming has led to the Netherlands, France and Canada becoming leaders in insect farming with multimillion investment deals leading to technology development and scale up. For example, French based Ÿnsect have been reported to have raised $175M in investment and is currently building Ÿnfarm, projected to be the largest insect farm in the world with an annual production capacity of 100,000 tonnes.

Similarly, French insect farming company InnovaFeed produces black soldier fly larvae, predominantly for the aquafeed market. InnovaFeed is reported to have raised £250M in 2022 and is planning to open 10 new production sites by 2030, both in France and abroad. American agribusiness ADM have invested in Innovafeed with an aim to accelerate insect protein production through an insect vertical farm next to the world's largest corn production site in Decatur, Illinois.

In the UK, insect farming has been supported by government grants but in a piecemeal way, through programmes such as Innovate UK's Transforming Food Production Systems and the Industrial Challenge Strategy Fund. Funding for insect farming competes with other agri tech projects across the full gamut of farming sectors. Entocycle is one of the leading edible insect farming companies in the UK and have been reported to have received tens of millions of pounds in government grants and private investment. However, Entocycle has now pivoted from a business producing insects for animal feed to a company providing consultancy and technology solutions to other insect farmers. Better Origin is another leading UK insect technology company reported to have raised millions in grants and investment. Co-Founder Miha Pippin (Figure 2) explained to me that Better Origin's focus is on insects for waste management rather than producing insects as a protein source. I was interested to understand why insect farming as a source of protein was not being pursued in the UK. My research indicated that a high-cost price of the final insect product due to substrate costs, labour and high energy costs combined with a complex and restrictive regulatory landscape were the biggest barrier for the success of UK insect farmers (see chapter 3).

Figure 2. Meeting Miha Pippin, co-founder of Better Origin, in the insect research laboratory in Cambridge. *Source: author*

1.2.i Market demand – insects for human food

Figure 3. Entomo Farm Cricket products for sale as human food in Canada. Human food edible insect products only form 20% of the company's sales. *Source: author*

In the UK, insects for human consumption fall under the novel food regulations and for the most part the human edible insect market is not accessible in the UK (more detail in Chapter 3). Interestingly, although regulations permit the sale of edible insects as human food in Canada, there is very little demand for edible insect products. This was made clear from discussions with Ryan Goldin at Entomo Farms in Canada who produce cricket flour and whole, dried, flavoured crickets as human food (Figure 3). Although the regulations permit the sale of the product, the demand isn't there yet and only 20% of Entomo's edible insect product is sold into the human food market, with no offtake agreements in place with customers. Similarly, Monkfield insect producers in the UK have started selling insects for human food products and they told me that the market is tiny. In the EU, edible insects fall under the novel food regulations but some insect products have been approved for sale. Uptake of edible insects as human food in the EU has been slow and this is largely due to low customer acceptance and the high cost of insect products. Ivan Albano of Italian Cricket Farm states: *"If you want to buy cricket-based food, it's going to cost you. Cricket flour is a luxury product. It costs about €60 (£52) per kilogram. If you take cricket pasta for example, one pack can cost up to €8."*

Figure 4. Mopane worms displayed (centre) as one of many food ingredients in Zimbabwe, Africa. Mopane worms are eaten regularly and are not considered unusual. *Source: author*

However, in Africa it's a different story (Figure 4). Insects are considered a delicacy in much the same way that seafood is in the UK. There are no regulatory restrictions for edible insects and the market acceptance and low-cost price have created a thriving environment for insect farming. There are already some major insect farming SMEs in sub Saharan Africa: For example, Mag Protein (Nigeria), Cycle Farms, Aspire (Ghana), Maltento, Nambu, Susento, Agriprotein, Inseco and Biocycle (South Africa), Bobo Eco Farm and Proteen (Uganda); Insectipro, The Bug Picture, Nutriento, Eco Dudu, Sagel Oik Ventures, Envibuzz, Sanergy, Demi Farm, Protein Master and Buhler Group Nairobi (Kenya) and several more in Tanzania and Rwanda. The human food edible insect market is accessible in Africa. The Democratic Republic of Congo has the greatest variety of insects consumed by humans and investigators are still discovering insect species consumed by people across Africa that were previously unknown. For example, the mopane worm (*Gonimbrasia belina*) is a caterpillar that is commonly eaten in southern Africa, palm weevil (*Rhynchophorus ferrugineus*) eaten in parts of Asia and Africa is rich in protein, calcium, and iron. The bamboo worm (*Omphisa fuscidentalis*) is another example of an edible insect that is consumed in parts of Asia.

1.2.ii Market demand - insects for animal feed for the human food chain

In the UK, supermarkets are putting increasing pressure on feed producers to eliminate soya from poultry diets, and feed mills and poultry producers are looking for consistent, sustainable, soya-free ingredients; soya currently costs around £350/T. Assuming insect ingredients contain the same crude protein content as soya (50%) then the price of insect meal must be comparable with soya to be competitive. Currently, insect meal is selling for around £3,500/T. As pressure increases, some of the premium supermarkets may be prepared to pay a premium to eliminate soya (e.g. Waitrose and M&S) whereas other supermarkets will probably stick to conventional soya diets. This is unless the carbon footprint of feed ingredients is accounted for in the cost.

Aside from the high cost of insect meal, if edible insect producers are marketing products as a protein replacement, it must be available on a sufficient scale with reliable supply (20-50,000T p/y). However, production of insects is still predominantly small scale. If demand for insect protein for animal feed grows then there will be competition for the edible insects that are produced with large feed companies able to rapidly buy up all the edible insect stock, causing difficulty for smaller companies that don't have the buying power.

The final piece of the 'insect ingredients for livestock feed' jigsaw was to meet with feed mills and livestock farmers using, or interested in using, edible insect products including, Humphreys Feed and Pullets and St Ewes. At present, insect-based protein replacement products (which may include added functionality) are valued at around £3,500/tonne, which is not economical for farmers or feed mills. However, edible insects are used on Kipster farms in Netherlands for layer flocks as part of their strategy to reduce carbon emissions and they produce the most sustainable egg!

1.2.iii Market demand - Pet food

Pet food is the most accessible market into which insect ingredients can be sold as it is less price sensitive and not subject to the same regulations as the human food chain. All the insect farms that I spoke to are selling predominantly into the pet food market and many small companies have set up, producing insect pet products such as dog treats. However, as bigger companies, such as Pets Corner, move into the insect pet food market the demand for insects is creating problems for the smaller companies. This is already happening with one UK based insect dog treat producer that I spoke with. The founder of the company told me that dried mealworms can be sourced from China, but with the rising costs of shipping and the sharp increase in the product itself they are beginning to look elsewhere for supply. Their current supply costs £5,500 per tonne, which has risen greatly due to increased shipping costs and a major supply shortage.

1.3 Insects for smallholdings in poor rural areas

During my Nuffield travels I was interested to discover how insect farming is being used in unusual and innovative ways to improve poor communities. One such meeting was with Dr Karol B. Barragan-Fonseca who has founded “Insects for Peace”, a project that drives social transformation, circular economy and food security in rural communities in Columbia. ‘Insects for Peace’ has trained former insurgents in Icononzo, Tolima, Columbia to farm edible insects which are used for feeding their own livestock as well as a source of income when excess edible insects are sold to other livestock farmers in the area. This concept has now been rolled out successfully in Kenya.

1.4 Smart Insect solutions

Insects are also being used as a waste management solution in different contexts. In Kenya, Sanergy provides latrines in ghetto areas as a sanitation solution. Michael Lwoyelo explained how Sanergy collects 72000 metric tonnes of human latrine waste per year and as a substrate for BSFL. In this waste management model unusable nutrients from human waste are upcycled by BSFL into 3600 T insect protein for animal feed, 7200 T of organic frass fertiliser and 8400 T biomass briquettes. I was very impressed with this elegant business model in which insects are being used for waste management, improving public health whilst also promoting sustainable organic agriculture. Although the concept is clever, there is a risk of infection both to the labour as well as the risk that pathogens may infect and wipe out the insect colony and/ or be passed through the food chain. It is also difficult to get staff to work with human waste.

In the UK, insect technology company Better Origin also has a waste management business model and is partnering with Morrisons supermarket to provide a solution for Morrisons’ farmers to reduce their carbon footprint. The Better Origin X1 system uses automation and AI to produce multiple 20 kg trays of black soldier fly larvae inside containers. The high-tech containers cost around £80K to buy or £18K per year to rent. The concept is that waste vegetal matter from Morrisons supermarkets or the farm, that would otherwise go into landfill, is used as a substrate to feed the insects, providing a carbon offset for the farm. The insects are fed to poultry, not to offset their usual feed rations but to improve poultry welfare. I met Matt and Tim Blaken who run a poultry layer farm in York and supply eggs to Morrisons supermarkets. The Blaken brothers are using the Better Origin X1 insect system on their farm (Figure 5) and they told me that although the technology is proven in terms of automated production of 20 kg of BSFL inside the container, the system failed to integrate well on the farm.

It’s hard for farmers to get staff and they don’t want to walk up the hill to pick up a heavy tub of maggots, and no one will do the job of taking the insects to the birds. This is because when staff do take the tray of BSFL into the barn, the birds know they are coming and there is a smother risk as they clamour for the BSFL. Any welfare benefits are outweighed by the smother risk. The BSFL do

Figure 5. Black soldier fly larvae (BSFL) for poultry farmed in Better Origin X1 automated containers in the UK. The business model here is to offset the carbon footprint of the farm by using waste vegetables that would go to landfill to feed the BSFL. Crates of whole, live BSFL can be fed to poultry as a welfare feed but this does not reduce the poultry feed requirements. ***Source: author***

not provide any offset of feed and most importantly, the system that I saw in action was not using waste vegetal matter from supermarkets or the farm as a substrate for the insects. Instead, Better Origin were supplying liquid feed made from barley or wheat that worked with their automated insect production system inside the containers to feed the insects. Since the waste management component of the concept wasn't working, there was no reduction in carbon. Moreover, I was informed that the containers are made in Greece and have not been well insulated for British winters so heating costs are high. I was told that the system in the farm in York had used 151000 kw from Oct 2021 to May 2022 which was paid for by the farmer. High energy costs to heat the container paid for by the farmer at a time when egg prices were low, along with the problems with labour and smother risk had led the Blaken brothers to switch off their X1 container.

1.5 Conclusions

Taken together the human food market for edible insects is tiny in the UK, EU and Canada. This is due to lack of appetite for the product and high-cost price, coupled with prohibitive regulations which are barriers for insect farmers who could drive innovation. Insect farming has not been a key priority in the UK government's strategy to achieve net zero but one of many possible solutions that must compete for funding. This approach has provided an opportunity for a range of technologies supporting net zero farming to be tested, but at the cost of the UK lagging behind the EU, Canada and Sub-Saharan Africa in the insect farming sector.

Regulations are more supportive of insects as ingredients for animal feed in the EU and Canada but the price of the final product is prohibitive compared to other feed ingredients with a similar protein level, such as soya bean meal. Insect meal is approximately ten times the price of soya bean meal meaning that insects as a mass ingredient are too expensive to be competitive. This is due to a combination of expensive labour, high energy costs and costly substrate used to feed the insects.

Africa and other regions in which insects form part of the culinary culture are better suited for insect farming for food and feed as there is acceptance in the market, cheaper products due to cheap labour and materials, and regulations aren't prohibitive.

Chapter 2: What are the main costs associated with insect farming and how can these be driven down?

Since insects are championed as a sustainable protein source, I was interested to understand not just the financial cost of farming edible insects, but also the carbon cost. Are edible insects really a silver bullet to provide a healthy protein for food and feed with lower emissions than existing protein sources?

To better understand the financial and carbon costs of edible insect farming, I visited a range of edible insect farm businesses including Better Origin (UK), Winsect (Netherlands) and Entomo Farms (Canada) and met many people working within industrial edible insect farms such as Protix (Netherlands), Ynsect (France) and Entocycle (UK).

2.1 Economic costs underpinning insect farming

From my Nuffield research I discovered that the main costs associated with edible insect farming vary depending on the scale and the species of insect being farmed. Listed below are some general costs associated with insect farming that are common to all as well as mitigation strategies that could be used for each.

1. Capital costs: The cost of setting up an insect farm can be high, especially for larger scale operations. This includes the cost of equipment, facilities, and infrastructure. Common items include climate control chambers, crates, trolleys, cooling systems, transport and forklift vehicles, crate washer, carrot chopper and industrial sieves. Finance options such as investment or debt are usually required to get started. There are significant differences in capital costs between insect farms depending on the level of automation. Second hand equipment and technical knowledge can drive down the initial capital costs. Ÿnsect, an edible insect farm which has had a strategy of large scale, highly automated mealworm farms to drive down high labour costs, has announced a new strategy for the company that includes a more asset-light business model with smaller facilities and subsequently lower capital costs. Ÿnsect closed its Netherlands production facility acquired from Protifarm in 2021 in line with this asset light strategy. Founder of Ÿnsect was reported to state, “We found we would need to invest tens and tens of millions to break even on the [Dutch] sites.” [3]

2. Feed/ substrate costs: different edible insects species require specific substrates to grow. The cost of feed varies depending on the type of insect being farmed and the availability of feed sources. Insect feed/substrate was identified by all insect farmers as the biggest cost, ranging between 40-80% of production costs with an average of 70% of production costs. Insect feed is also critical in terms of the carbon footprint and will be discussed later in the chapter in more detail.

3. Labour costs: Insect farming requires skilled labour which can be costly and also scarce. As insect farming is a relatively new industry few people have the skills associated with insect reproduction,

feeding and harvesting as well as insect processing and so costs include not only hiring but also training staff to manage the farming operation. Insect farming can be labour intensive if not automated. Research into insect farms by Hilde Niyonsaba at Wageningen University and Research has found that an average of three full time staff were employed to produce an average of 37 tonnes of fresh larvae per year. Automation can drive efficiency and reduce labour requirements. I visited flower farms in the Netherlands and discovered that automation of their processes had increased efficiency and lowered labour costs (Figure 6). Winsect, a mealworm farm in the Netherlands has developed a completely new insect rearing system, moving away from the labour-intensive tray-based system used historically (Figure 7). However, the cost to produce a tonne of mealworms using the Winsect production system was not reduced compared to traditional racked tray system.

Figure 6. Automation used in flower farming has increased efficiency and reduced costs. In this tulip farm in the Netherlands bulbs are processed in crates, and similar technology could be adapted and applied to insect farming. ***Source: author***

Figure 7. Automation and technology in mealworm farming developed by Winsect in the Netherlands aims to drive down insect farming costs. This system moves away from crates to reduce handling and therefore labour costs. *Source: author*

4. Energy costs: Insect farms require energy for heating, cooling, and lighting. With soaring energy prices in many parts of the world, the cost of energy has increased the costs associated with insect farming. Since electricity is commonly required, renewable energy such as wind and solar can be used to heat and cool insect farms during farming and also for processing insects into ingredients.

5. Regulatory costs: As outlined in Chapter 3, insect farming is subject to regulations, which can be costly to comply with. This includes the cost and time taken to obtain licenses, permits, and certifications.

6. Marketing costs: Insect farming is a relatively new industry, and marketing is essential to educate consumers about the benefits of insect protein which can be costly.

The combination of these factors results in an expensive product with the sale price of fresh larvae averaging £3,500 per tonne. Pricing is sensitive, but it is widely acknowledged that insect ingredients are prohibitively expensive for use in livestock feed. The majority of insects produced are sold into the pet food market.

2.2 The carbon footprint of insect farming

Insect farming has the potential to produce lower carbon emissions than traditional forms of protein production. However, the carbon footprint of insect farming varies dramatically between farming systems and so must be considered if the aim of using insect ingredients is to reduce emissions. The main sources of carbon emissions associated with insect farming include:

1. Energy consumption: Insect farms require energy for heating, cooling, and lighting. Energy is also required to process insects into ingredients. Insect farming uses mainly electricity which can be provided by renewable energy sources such as solar, wind power and hydro, although none of the insect farms I visited were using renewable energy. The type of energy used can have a significant impact on the carbon footprint of the operation.

2. Production resources: The production of insect feed requires resources, such as land and water and feed. Insect farming uses 90% less land than soy production therefore more land remains available for food production. Although insects rely heavily on water for their growth, research has shown that the overall water requirements for industrial insect rearing are still significantly lower compared to conventional protein crop production. Feed for insects is a critical issue and will be discussed fully below.

3. Transportation: The transportation of insects to end users and transportation of the substrates used to feed the insects. Co-location of insect production or waste management systems on farms/ businesses is one way to reduce transportation costs of substrate and insect products.

2.3 Substrate: the highest financial cost and highest carbon cost in insect farming

My Nuffield research identified the substrate fed to insects as the most critical factor in commercial insect farming. The substrate fed to edible insects determines insect yield and health, consistency of the final product, profitability due to yield and costs associated with feed, as well as carbon emissions associated with the feed substrate.

As described in Chapter 3, regulations in the UK and EU restrict what can be fed to insects to materials of vegetal origin. Industry by-products and waste products can be used as substrates and some permitted examples include brewers spent grains, rapeseed press cake, palm oil press cake, spent mushroom substrate, apple pressings and potato peelings. However, there is often competition for these waste streams which can be used to directly feed livestock, such as brewers spent grains. Also, as the circular economy becomes more embedded in industry, new uses are being found for industry by-products such as packaging made from potato peelings. Some of these by-products are also sought after as fuel in anaerobic digesters. Competition for by-products drives up the price and creates challenges when insect farmers seek a regular supply of a consistent by-product. Edible insects, such as BSFL, have the ability to upcycle waste nutrients such as animal manure and slurry. During my visit to the Netherlands I witnessed the farming community at arms with their government's plans for the future of agriculture in the country. In 2021 a £21bn plan was unveiled to radically reduce the number of livestock in the country as 80% of livestock farms produce more manure than they can legally use on their land. Insects have the potential to halve total nitrogen concentrations in agricultural soils if animal manure is permitted as an insect substrate.

Since the health of the insect colony and consistency of the product is critically affected by the substrate used to feed the insects, seasonal substrates are not a good solution. For example, Miha Pippin from Better Origin explained to me that the substrate is so important for black soldier fly larvae that the colony will die after a few generations if not given the correct balance of nutrients. Similarly, tests carried out by researchers at Queens University Belfast with Moy Park found that the parameters of the edible insects, especially chitin levels, changed with different diets (Figure 8).

Figure 8. Prof Nigel Scollan, Director of the Institute for Global Food Security (IGFS) and Dr Katerina Theodoridou, associate Professor of Farm Animal Nutrition at Queens University Belfast (QUB) spoke to me about the challenges and opportunities of developing novel animal feed ingredients from insects and seaweed. *Source: author*

Therefore, despite the ability of many edible insects to upcycle waste ingredients with the associated potential cost and carbon savings, ALL of the commercial insect farms that I visited and spoke with were using livestock feed as a substrate to feed the insects. Most were using soya-based poultry, pig feed or aquaculture feed. The use of soya-based substrates fed to the farmed insects makes a nonsense of scaling-up production of edible insects to reduce the amount of soya used in livestock feed. It is merely shifting the problem further up the supply chain: Soya fed to insects > insects fed to livestock.

2.4 Subsidies for insect ingredients: opportunities and challenges

The concept of subsidies for insect ingredients could involve putting a monetary value on the carbon emissions generated during the production of goods and services. The aim could be to create an economic incentive for producers and consumers to reduce their carbon footprint by choosing lower-emission alternatives. For example, substituting high carbon footprint soya to low carbon footprint insect ingredients in animal feed.

Applying a carbon tax to food and feed ingredients that have high carbon emissions could serve several purposes:

1. Encouraging emission reduction: By putting a price on carbon emissions, producers would be incentivized to adopt more sustainable and efficient production practices to reduce their emissions. This could lead to a shift towards more environmentally friendly methods of production.

2. Promoting innovation: Producers may invest in research and development to find ways to lower their carbon emissions in order to avoid higher tax costs. This could spur innovation in the food and agriculture industry, leading to more efficient and eco-friendly production methods.

3. Consumer behaviour shift: With higher costs for high-emission ingredients, consumers might be more inclined to choose alternatives that are lower in carbon emissions. This could lead to a shift in consumer preferences towards more sustainable food options.

4. Competitive advantage for low-carbon alternatives: As mentioned, the higher cost of ingredients with high carbon emissions would make lower carbon alternatives more competitive in the market. This could drive demand for products that are produced with lower emissions, potentially fostering a more sustainable food industry.

However, there are also potential challenges and considerations:

1. Equity and affordability: A carbon tax on food could potentially increase the cost of living for some consumers, particularly those with lower incomes. There would need to be measures in place to address equity concerns and ensure that essential foods remain affordable.

2. Complexity and implementation: Implementing a carbon tax on food and feed ingredients would require accurate assessment of carbon emissions associated with various production processes. This could be complex, and there would need to be a need for transparent and reliable methods for measuring emissions.

3. Global supply chains: The food industry often relies on complex global supply chains. Implementing a carbon tax would require cooperation and coordination among various countries and producers to ensure that emissions are accurately measured and taxed.

4. Behavioural response: The effectiveness of a carbon tax would depend on how producers and consumers respond. If there are easy alternatives to reduce emissions, the tax could be successful in driving change. However, some industries might face limitations in rapidly transitioning to low-emission practices.

2.5 Frass: a potential revenue generating insect farming by-product

Insect farms have multiple products that generate revenue including live insects, defatted insect meal, insect oil as well as frass (a highly potent organic fertiliser). Frass is the waste product from insect farming and research has demonstrated its potency as an organic fertiliser. A study published in 2020[5] reported a pot experiment in which the soil was supplemented with either mealworm frass (10 Mg ha^{-1}), with mineral fertilizer (NPK) at equivalent nutrient level to frass or with a mixture of 50% NPK and 50% frass. The authors found that frass was as efficient as mineral NPK fertiliser to improve biomass and N, P and K uptake by barley. Compared to mineral fertiliser, water soluble P concentration was five times lower in the presence of frass, preventing P from loss and adsorption into soil. Interestingly, frass also stimulated the soil microbial activity, especially when it is mixed with mineral fertilizer. The use of frass as fertilizer in conventional and organic agriculture is in line with the target to achieve 25% organic land by 2030 as well as the Organic Action Plan. Most insect farmers that I met planned to sell frass as a revenue-generating product but were not currently doing so as there was no demand from the market.

2.6 Conclusion:

a) Substrate is the main cost associated with insect farming– to obtain a reliable source of industry by products that are the correct nutritional balance is difficult. Diversifying the authorised substrates permitted for edible insects, for example include foodstuffs and catering waste as approved insect substrates is key to reducing the costs and carbon footprint of insect farming while presenting a solution to tackle food waste that would otherwise go into landfill or be incinerated.

b) Soya based livestock feed is currently being fed to insects on most commercial insect farms that I visited.

c) Labour – automation drives efficiency in other industries and has the potential to do the same for insect farming.

d) Energy – renewable energy can reduce costs and carbon associated with insect farming. Farming in warm countries to reduce heating costs is a sensible strategy.

Chapter 3

How does the regulatory landscape intersect with insect farm success?

Figure 9. Prof Andrea Vilcinskas is Director of the Institute for Insect Biotechnology at Justus-Liebig-Universität Gießen, Germany shared his insight into insect farming, regulations and high value ingredients derived from insects as the INSECTA conference in Germany. *Source: author*

The regulatory landscape that shapes the edible insect farming industry is complex, constantly evolving and varies significantly between countries. To better understand this critical, but rather dry subject, I attended the international INSECTA conference in Germany (Figure 9) and the Royal Entomological Society *Insects as Food and Feed* conference in the UK where I engaged with many stakeholders in this area. Regulations govern every aspect of insect farming including which insects can be industrially farmed, substrates that can be fed to farmed insects, who/what can eat insects and their products and measures taken to ensure that edible insects and their products are safe. Regulations vary greatly between countries and have a critical impact on the carbon footprint and profitability of insect farming.

3.1 Regulations around species of insects that can be farmed in the UK

Of the thousands of edible insect species eaten across the world, only seven are permitted to be farmed in the UK and EU and three dominate industrial insect farming around the world; mealworms, black soldier fly larvae and crickets. The seven edible insect species currently permitted are:

- lesser mealworm (*Alphitobius diaparinus* larvae),
- yellow mealworm (*Tenebrio molitor*),
- house cricket (*Acheta domesticus*),
- banded or decorated cricket (*Gyllodes sigallatus*),
- bird grasshopper or desert locust (*Schistocerca gregaria*),
- migratory locust *(Locusta migratoria*), and
- black soldier fly (*Hermetia illucens*).

Figure 10. Insect farming has become a focus area for the Food and Environment Research Agency (FERA). I met Damian Malins and Dr Maureen Wakefield to learn about FERA's insect research and where they see the future of insect farming in the UK. *Source: author*

Insects are not currently protected under any animal welfare legislation although there is increasing interest in the topic with talks on insect welfare featuring at several conferences that I attended during my Nuffield travels. Insect welfare focussed on humane methods to euthanise insects such as freezing and carbon dioxide. There are several potential markets for edible insects, and their derivative products, including human food, poultry and swine feed, aquaculture feed and pet food. The regulatory landscape for edible insects entering the human food chain is quite treacherous to navigate. To learn about the UK's strategic plans for insect farming and regulatory landscape I visited the Food and Environment Research Agency (FERA) (Figure 10).

3.2 Regulations around substrates that can be fed to farmed edible insects

Figure 11. Adult stage black soldier fly in containers in the Netherlands. Black soldier fly larvae can eat almost any organic material, upcycling waste streams, but regulations in many countries are restrictive on what can be fed to insects. *Source: author*

A major benefit of farming insects, such as black soldier fly larvae (Figure 11), is their ability to upcycle waste nutrients. Only materials of vegetal origin may be fed to farmed edible insect under UK and EU regulations. Some exceptions may be made for materials of animal origin such as milk, eggs and their products, honey, rendered fat or blood products from non-ruminant animals. However, regulations prohibit the use of many waste nutrients such as slaughterhouse or rendering derived products, manure, or catering waste to feed farmed insects. This is because the risks of introducing hazardous or pathogenic materials into the food chain from insects fed on these waste products are unclear. The same ban applies to the use of unsold products from supermarkets or food industries such as unsold products in reason of manufacturing or packaging defects if these contain meat or fish. UK and EU regulations outline health and biosecurity requirements of insect farmers in the 'EU Animal Health Law'.

Insect farmers in countries outside the EU intending to export edible insects or their derived products into the European Union must comply with equivalent standards. During my Nuffield travels I visited edible insect researchers at Wageningen University and Research in the Netherlands to understand more about the risks and opportunities of commercially farmed edible insects. Research is underway to understand the microbiological, chemical and other health risks associated with industrial farming edible insects for both the insect colonies and end consumer of the insects. For example, can pathogens be passed from the substrate through the insect into the final consumer to cause illness? Or, could insect farming practices cause decimation of the insect breeding colony? More research is needed in this area to mitigate the risks.

3.3 Edible insects for human food

Novel Food Regulations prohibit the sale of insects as human food in the UK and the EU, except for a few species consumed either within the UK or EU before 1997, when the regulation came into effect. Post-Brexit, edible insects were not clearly covered by the UK novel food regulations which had been imported over because transitional measures had not been put in place in the UK. This came to a head in October 2021 when the FSA provided clarity on the issue by stating that there was no legal basis for insects to be placed on the market which meant that edible insect species that had been approved as novel foods in the EU were no longer authorised in the UK[6]. As a direct consequence of that announcement several edible insect companies stopped trading or postponed launches, including start-ups companies Kric8, Eat Grub, Yum Bug and Horizon Insects. Adam Banks from Instar Farming told me: *"Instar Farming continued trading, albeit with the risk of our insurance not being valid. We do now have UK-specific transitional measures, but these limit the species which can be sold, currently seven but only those with applications submitted can remain after 31 December 2023. Overall the novel food approval process is the same as it was in the EU, just five years behind on the route to approving species. The process is very expensive, slow and mostly unnecessary."* After 1 January 2024, edible insect human food products can continue to remain on the market if a novel food application has been received in relation to that species before 31 December 2023. Costly approval (UK cost est. £80K - £100K per authorisation) is required by the FSA (UK) and EFSA (EU) for human food edible insect products, and the process is lengthy, some cases taking longer than five years. For example, a novel food application for house crickets was submitted by the Belgian insect industry Association (BiiF) in 2018 and had not been granted at the time of writing. If a novel food application is submitted by a private company and granted, permission to sell the approved edible insects is limited to only the company that submitted the application and will not benefit the edible insect sector as a whole.

In North America edible insects are not considered to be novel food and the import and sale of edible insects is permitted. However, despite the lack of restrictive regulations in Canada, there is very little demand for edible insect human food products. In Africa there are currently no regulations around sale of edible insects for human food, although insects such as mopane worms and termites tend to be harvested from the wild seasonally rather than industrially farmed.

3.4 Edible insects for animal feed

After the 'mad cow disease' BSE disaster, regulations were introduced in the UK and EU to prevent processed animal proteins (PAPs) from being fed to farmed animals in the human food chain. Products from edible insects such as insect meal are included in insect PAP regulations. On 18th August 2021, the EU authorised the use of insect PAPs in poultry and pig feed. At the time of writing this authorisation was not mirrored in UK law, although UK legislation does permit the feeding of whole insects or insect-derived fats to poultry and pigs.

I visited feed mills in the UK including Humphreys Feeds and Pullet and Crediton Milling Company, as well as Triple C Pigs Feed Mill in Zimbabwe to understand why the issue of insect PAPs is so important. Essentially, defatted insect meal in dry powder form meets the specifications required for it to be included in animal feed as a major ingredient using the existing infrastructure. Insect PAPs also have a decent shelf life which facilitates their storage and transport. A business producing and selling insect PAPs is a whole different ball game to a business working with whole live insects, which have a short shelf life, cannot be stored and transported easily and cannot be included into feed as a major ingredient using existing infrastructure. This is not only a problem for UK insect farmers but also livestock farmers and supermarkets who buy their produce. The UK insect PAP regulations prohibit the substitution of soy with insect meal in UK livestock feed rations, which could significantly reduce the absolute carbon emissions associated with the sector.

Since the UK is no longer constrained by European law, Brexit provided an opportunity to position the UK as a leader in insect farming to lower the cost of production and environmental impact of the UK's livestock sector. However, complex and slow regulations around insect farming in the UK have compounded the problem for UK insect farmers as animal feed and human food markets are now open for EU insect farmers but legislation places UK insect farmers at a disadvantage. Another example of a UK edible insect company affected by the change in regulations since Brexit is Beta Bugs Ltd founded by Thomas Ferrugia in 2017. Beta Bugs is a genetics company that sells black soldier fly eggs called HiPerFly® claimed to have genetics favourable for improving yield in industrial insect farming. The business model of Beta Bugs is to sell BSF eggs to insect farms, the majority of which are located in the EU. Beta Bugs have experienced barriers to selling the eggs into the EU since Brexit which may have a detrimental effect on the prospects of the business. My Nuffield study tour indicates that the opportunity for the UK to leap frog ahead of the EU in the insect farming sector by changing restrictive regulations has been wasted. Instead the regulations, in terms of time, cost and uncertainty, have stifled the edible insect industry in the UK.

3.5 Conclusions

a) Regulation and Brexit are major obstacles to the success of the UK insect farming industry.
b) Edible insect products are prohibited for sale as human food under novel food regulations and applications are costly and time consuming.

c) In the UK and EU, Venture Capital backed companies have an opportunity to dominate the edible insect for food sector as the regulatory risk, in terms of cost of application, time taken to process the application and barrier to market entry, is too high for many entrepreneurs, investors and stakeholders.
d) To support UK insect farmers the UK must implement regulations to permit insect PAPs in poultry and pig feed, as has been permitted in the EU.
e) Determination of the safety of waste streams (such as slurry) as a substrate for insects must be prioritized to enable appropriate regulatory changes to be made to permit waste to be upcycled by insects into healthy, safe nutrients.

Discussion

Taken together, my Nuffield farming travel tour suggests that to be a meaningful ingredient for food and feed the total production of insects is currently too low, the cost-price is too high and the composition of the end product varies greatly. More work is required to improve efficiency of insect production. For example, automation of farming systems and genetic improvements in insect lines, as well as the development of optimised insect feed mixtures to improve FCR. The industry also needs a deeper understanding of diseases and pests in production systems, both pathogens that can cause infection in the insect colony as well as those that can pass through the food chain.

At the outset of my Nuffield travel tour I asked the question: "**Can carbon neutral insects be farmed profitably?**" From travelling the world to explore this question I have reached the conclusion that edible insects can be farmed in a carbon neutral way if waste streams (that cannot be fed to livestock) are used as a substrate to feed the insects. Otherwise, substrates that could be fed directly to livestock or humans, are converted into insects using an expensive and energy intensive process, for the insects to then be fed to humans or livestock. All of the insect farms I visited are currently feeding soya-based substrates to farmed insects. This makes no sense if edible insects are being reared to reduce soya in livestock feed. My Nuffield research has led me to the conclusion that manure produced by livestock should be used as a substrate for farming edible insects once the risks have been assessed. If waste streams are used as a substrate to feed insects, and renewable energy can drive down carbon emissions associated with farming and processing, carbon neutral edible insects are feasible. Whether insects can be farmed profitably is a much thornier question. Substrate forms around 70% of the costs associated with insect farming. Regulation is key to the success of insect farming and, if the evidence supports their safe use, waste streams should be approved for use as insect substrates. These measures will drive down the cost price of the final insect product which is the main barrier to uptake of insect ingredients in all markets. Similarly, for the edible insect industry to flourish, regulations must permit the use of insect PAPs and ingredients in food and feed. Currently, regulations have locked out UK insect farmers from large, potential food and feed markets. Even if regulations are relaxed, what is clear is that currently the cost price of insect feed products has caused the demise of some of the edible insect farm goliaths. Companies that were pioneers in edible insect farming such as AgriProtein and Enterra, which received millions in grants and investment have folded, seemingly as they couldn't make a profit. The current leader in the edible insect sector, French based Ÿnsect, which is reported to have raised hundreds of millions of dollars of investment, has also highlighted the low margins in the animal feed business, which Ÿnsect has historically targeted. Ÿnsect has yet to make a profit and has recently replaced the founder CEO with a commercial CEO, cut 20% of the company's labour force and closed the Dutch arm of its production facility, in an aim to drive profitability. Ÿnsect now seeks to sell into the pet food market which is the market that all insect companies I met with are selling into. Eventually Ÿnsect aims to sell insect ingredients for human food where margins are larger. However, as I learned from insect farmers in Canada, even when the human food market is open for edible insects, the demand may not be there until tastes change. The high cost of living driven by rising inflation and interest rates means that consumers are cutting back on their spending and this may further quell demand for novel insect food products that are costly and not perceived as desirable. However, there are huge opportunities for edible insect farming in Africa where the insect products are sought after and culturally acceptable.

Conclusions

1) Regulation in the UK is limiting the success of insect farms. Specifically, many substrates that could be fed to the insects are prohibited, creating a situation whereby soya bean meal is currently fed to insects. This not only increases the cost of production but increases the carbon footprint of insect farming. Regulations also limit the specification of the insect products that can be fed to livestock; insects ingredients currently cannot be integrated into the feed of livestock. Whole live insects have a short shelf life and it is difficult to export live insect products from the UK to the EU, such as eggs and larvae.

2) The substrate fed to the insects is critical for many reasons: consistency of final product, microbiota of insects which affects production of antimicrobial peptides, cost of production, growth rate, weight of larvae. Substrate is also the biggest cost, between 40-80% of production costs.

3) For animal feed, the cost price of insect products is too high (5-10X the cost of soy) to make it competitive with current high protein feed ingredients such as soy. Unless carbon footprint is costed into the equation making soya a more expensive product, the margins are too small for farmers to include high-cost insect ingredients.

4) The human food market in UK, EU and Canada is not ready for edible insects beyond a novelty ingredient. In the UK, EU and Canada the high cost of living caused by rapid inflation and high interest rates has meant that consumers are cutting back on luxury items. Given the novelty, and sometimes disgust, associated with insect-based food combined with the high cost price of products, there is currently no significant market for edible insects as human food. This may change as tasty and competitively priced edible insects enter the human food market.

5) In the UK small-scale, low-tech production of edible insects on farms to feed poultry or pigs, using farm vegetal waste as a substrate and renewable energy could be a viable option to drive down the carbon footprint of farms.

6) There are huge opportunities for insect farming in Africa, both as animal feed and human food. The key challenges for insect farming in Africa are setting up regulatory standards across other African countries to support the industry and mitigate the risks, scaling insect production, developing processing technologies, building partnerships and securing investment.

Recommendations

1) Once assessed for safety and risk mitigation strategies are in place, only ingredients that can't be fed to humans or livestock directly should be fed to insects to take advantage of the ability of insects to upcycle inedible nutrients e.g. slurry.

2) High value ingredients derived from insects are a strategy to increase revenue for insect farmers e.g frass as an organic fertiliser. More research is required beyond glass house trials to evaluate the value of frass.

3) Subsidies for feedstock ingredients such as insects which have the potential to drive positive change in the food industry by encouraging more sustainable production practices and promoting low-carbon alternatives. However, careful planning, consideration of potential impacts, and addressing equity concerns are essential for successful implementation.

After my Study Tour

Having identified regulatory hurdles and cost of production as major barriers to insect farming in the UK I decided to focus my attention on working with other academics looking to commercialise their research. I now work at the University of Bristol as Research Commercialisation Manager, a role that includes working with academics at Langford vet school. My Nuffield scholarship has provided me with a broad understanding of the agri tech sector and a strong network that I can utilise to support the translation of innovations in the field.

My interest in and knowledge about edible insects remains strong and I have appeared in the "Hungry for Change" documentary about the opportunities and challenges of edible insects to share my knowledge about the topic. I've also appeared in several Q&A panels about the topic and I continue to explore opportunities to disseminate my knowledge.

Acknowledgements and thanks

Figure 12. The Richard Lawes Foundation generously sponsored my Nuffield Farming Scholarship. Bobby Lawes takes great delight in getting to know the Nuffield Scholars that the foundation sponsors. He is a true gentleman and a fount of knowledge. He kindly took my family and me out on his beautiful yacht, Huahine. *Source: author*

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Abbreviations

BSFL = Black soldier fly larvae

FCR = feed conversion ratio

FERA= Food and Environment Research Agency

FSA = food standards agency

ICIPE= International Centre of Insect Physiology and Ecology

PAP = processed animal protein

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