Farming Insects for Food and Feed Around the World – Trends and Current Practices

Authors: Dr Nick Rousseau, René Shaeffer and Flo Rousseau

Unconventional Connections

July 2021

Version: Final

Acknowledgements

The research that informed this report was undertaken by Unconventional Connections Ltd on behalf of Spectrum – the Sustainable Development Knowledge Network of Myanmar and funded by the Livelihoods and Food Security Fund (LIFT).

We gratefully acknowledge the contribution of those that we interviewed who generously shared their knowledge and experience.

The work has been funded by the Livelihoods and Food Security Fund (LIFT), however the views expressed do not necessarily reflect official policies.

Final report of July 2021.

Glossary

We refer to a number of insect species in this report. We will use the English/local name but provide these with the scientific name here.

- Black Soldier Fly [BSF] - *Hermetia illucens*
- Housefly - *Musca domestica*
- Yellow Mealworm - *Tenebrio molitor*
- Superworm - *Zophobas morio*
- Palm Weevil - *Rhynchophorus phoenicis*
- Agave Weevil - *Scyphophorus acupunctatus*
- Diving Beetle - *Dytiscidae spp.*
- Longhorn Beetle - Cerambycidae
- Giant Water Beetle - Belostomatidae
- Scarab Beetle - Scarabaeidae
- Ants - Formicidae
- Weaver Ant - *Oecophylla spp.*
- Black Ant - *Carebara vidua*
- Navajo Nation Ant - *Liometopum apiculatum*
- Termite - *Macrotermes bellicosus* or *M. subhyalinus*
- Silkworm - *Bombyx mori*
- Cabbage Tree Emperor Moth - *Bunea alcinoe*
- Greater Wax Moth - *Galleria mellonella*
- Bean Hawkmoth - *Hyles zygophylli*
- Bamboo Caterpillar - *Omphisa fuscidentalis*
- Red Agave Worm - *Comadia redtembacheri* or *Xyleutes redtembacheri*
- Crickets - Grylloidea
- Field Cricket - *Gryllus bimaculatus*
- House Cricket - *Acheta domesticus*
- Grasshopper - *Ruspolia nitidula*
- Longhorn Grasshopper - *Ruspolia differens*
- Oriental Migratory Locust - *Locusta migratoria manilensis*
- Desert Locust - *Schistocerca gregaria*
- Bombay Locust - *Nomadacris succincta*
- Wasp - Hymenoptera
- Honey Bee - *Apis mellifera*
- Mealybugs - Pseudococcidae
- Chinese Wax Scale - *Ericerus pela*
- Chinese cicada - *Cryptotympana pustulata*
- Dragonfly - Odonata
- Stink Bug - *Halyomorpha halys*
- Cockroach - Blattodea

About Unconventional Connections and the Woven Network

Dr Nick Rousseau has worked for many years to support more sustainable food solutions – both locally and internationally.

In 2015 Nick founded the **Woven Network CIC** - UK's (international) network focused on supporting entrepreneurs and researchers working on the opportunities around insects for food and feed.

As a result of his work with Woven, Nick has built an extensive international network of contacts involved in insect farming and gained a broad understanding of the many issues facing the sector and the opportunities that insect farming offers. He was a guest speaker presenting on the potential of insect protein in the Houses of Parliament, at a policy think-tank event on the future of food and at academic and business conferences.

Within the WWF/Ikea/Skretting-funded Global FeedX challenge he assessed the many different submissions from insect farming companies.

Nick also leads **Unconventional Connections**, assisting local and national Government and associated bodies, businesses and universities to set up successful projects and initiatives. Nick is a very experienced strategic consultant with considerable experience of leading international projects and collaborations. He has worked across a wide range of domains bringing a diverse body of experience and insight.

His consultancy work has a strong focus on helping international food production to be more sustainable and he has developed a broad network of contacts and experts to support this.

Prior to his consultancy work, Nick worked for over 20 years in the UK Government often with foreign Governments and businesses including 5 years as Head of International Innovation Strategy at the Department of Business, Innovation and Skills. Nick worked with many organisations across the UK and international innovation landscape to develop ways to support innovation in practice.

Nick holds BA, MSc and PhD degrees in psychology from the universities of Cambridge, Sheffield and Loughborough with a focus on psychology and user centred system development.

https://uk.linkedin.com/in/dr-nick-rousseau-05a21a32

www.unconventionalconnections.co.uk

www.woven-network.co.uk

Contents

Executive Summary

Spectrum has asked Unconventional Connections to support their work investigating the potential for insect farming in Myanmar by drawing on what is known about this from experiences around the world.

There is a growing movement across the world to take advantage of the potential benefits that farming insects can bring in terms of economics, nutrition and sustainability. Societies across the world have eaten many different varieties of insect for centuries. Most edible insects are traditionally harvested from the wild but there is a growing interest in managed forms of cultivation across many different countries in order to meet demand and derive economic benefits.

We review the progress within the sector in recent years across:

- Increasing recognition that the global population needs alternative, sustainable methods of feeding itself in order to protect the environment for future generations;
- Mounting research evidence that shows farmed insect protein can be beneficial for livestock and human consumption, and provide a method with which to reduce waste and efficiently recycle nutrients back into food production, so long as reasonable measures are taken to mitigate risks;
    - The benefits of using farmed insects as aquaculture feed include them being more digestible, palatable and natural than vegetable-based feeds, demonstrating good feed to conversion ratios and growth performance as they are highly nutritionally suitable.
    - Similarly, for poultry, they are part of their diet in the wild or if they are free-range, meet their nutritional needs, can reduce pecking and disease and increase their immune responses.
- Growing concern about over-harvesting of insects in the wild possibly leading to degradation of vital ecosystems and biodiversity loss;
- Further understanding of how insects can be farmed and emerging solutions that can drive down the production costs, helping insect protein to become more competitive alongside alternatives;
- Increasing investment in the insect farming sector and growth in the number of companies producing farmed insect material - the investment going into the sector in 2018 was very much greater than in previous years and Barclays believe the global market for farmed insect material could reach 8 bn dollars by 2030;
- An ever-broadening range of insect-based products and sectors where insect material is becoming established;
- Within countries where eating insects is not traditional there is increased awareness and acceptance amongst consumers that insects could play a part in their food chain;

According to a number of sources, the main challenges facing the sector are:

- Regulations (in Europe);
- The need for funding;

- Scaling up production to increase availability and viability of insect protein as a mainstream commodity
- The price of insect material given production costs
- Consumer expectations
- The need for more research.

The differences between insects and their natural mode of growing means that specific farming methods and technologies are required for each species. We have created a simple taxonomy that shows the different levels of farming management that we have found evidence for, relating to the insects suitable to/available in Myanmar:

	No known farming techniques	Relocating plus insect management	Create natural breeding environment	Man-made breeding environment - fully manual operation	Man-made environment with some automation.	Man-made unnatural environment	Fully industrial with extensive automation
Crickets							
Grasshoppers							
Palm weevil larvae							
Giant water beetles							
Stink bugs							
Honey bugs							
Cicadas							
Mealworm Beetles*							
Bamboo worm							
Weaver Ants*							

There are risks associated with farming insects and these need to be managed, alongside efforts to ensure the quality of the product is as high as possible. The European Union has taken a very cautious approach and introduced a range of very tightly defined Regulations that restrict insect farming for livestock or human consumption, but that guarantee safety for consumers. The European insect farming sector hopes that these will be relaxed in time, as evidence of safety grows.

Europe is unique in having such a stringent regime for insect farming. Some other countries are also putting in place certain restrictions but these are in the minority. However, there is

plenty of guidance and sources of good practice available. In practice, insect farmers benefit from clubbing together as this will enable them to share experiences and good practice. There are many different ways this can happen but generally, when a sector is at an early stage the participants really value being connected to others so they can learn together.
For instance there are over 9,000 members of a Facebook group devoted just to small scale BSF farming.   The other benefit of insect farmers coming together is that they can share resources, establish common interests and seek support from others. Again, for a new and underdeveloped sector, forming a collective of some sort can give them all strength and increase their chance of success.

We have prepared a number of short case studies that illustrate the diversity of countries' responses to the opportunities of insect farming:

- China has extensive experience of insect farming, diverse with range of farming practices;
- Thailand has well developed cricket farming sector providing clear economic value to the country;
- Kenya has a very extensive experience of developing insect farming and has many similarities to Myanmar;
- Ghana has also actively explored how to develop BSF farming for livestock;
- In the UK, we have a very substantial fish farming sector, up in Scotland and have taken a keen interest in the potential for insect farming. The WWF and Tesco have commissioned the development of a roadmap for large scale insect farming for aquaculture – should be published in early 2021.

In conclusion, there is a great deal that Myanmar can learn from other countries as it develops its own insect farming sector but the opportunities for it to build a thriving sector that can support small scale farmers and develop a lucrative export industry.

Chapter 1: Overview of Global farmed insects market and trends

1.1 Introduction

There is a growing movement across the world to take advantage of the potential benefits that farming insects can bring in terms of economics, nutrition and sustainability. In 2013 the UN's Food and Agriculture Organisation (FAO) published a report on insect protein. It highlighted its potential to provide sustainable ways to increase the protein available to feed a growing global population[1]. This chapter provides an overview of this movement and some of the key trends.

Societies across the world have eaten many different varieties of insect for centuries. It is estimated that there are over 1,900 edible insect species, most of which are traditionally harvested from the wild[1]. However, as populations grow, over-harvesting can result in ecosystem damage. Recognition of the nutritional value of insects and their acceptance as food sources has led to managed forms of cultivation across many different countries in order to meet demand and derive economic benefits.

According to Meticulous Research[2], Asia-Pacific is the region with the greatest consumption of edible insects – they estimate it represents 43% of global total, followed by Latin America.

Not all insect species are suitable for "farming," and currently only a very small number are actually farmed compared to the total potential range of species. (Chapter 4 describes the different forms that insect farming can take).

This progress can be seen in terms of:

- Increasing recognition that the global population needs alternative, sustainable methods of feeding itself in order to protect the environment for future generations;
- Mounting research evidence that shows farmed insect protein can be beneficial for livestock and human consumption, so long as reasonable measures are taken to mitigate risks;
- Growing concern about over-harvesting of insects in the wild possibly leading to degradation of vital ecosystems and biodiversity loss;
- Further understanding of how insects can be farmed and emerging solutions that can drive down the production costs, helping insect protein to become more competitive alongside alternatives;
- Increasing investment in the insect farming sector and growth in the number of companies producing farmed insect material;
- An ever-broadening range of insect-based products and sectors where insect material is becoming established;
- Within countries where eating insects is not traditional there is increased awareness and acceptance amongst consumers that insects could play a part in their food chain;
- An emerging understanding of the particular challenges faced by the sector.

We explore each of these in turn.

1.2 Growing need for sustainable protein alternatives

In 2018 the United Nations Environment Programme described meat as "the world's most urgent problem" based on its growing negative impact on the environment[3]. The world population today is over 7.7 billion. It has doubled since 1972 and will exceed 9.5 billion by 2050. By then, according to figures from the FAO, meat consumption is expected to have increased by 73%.

The challenges the world faces to sustainably feed our population is a cause for increasing concern. For example, Barclays[4] reported that sustainability is either very important or somewhat important for over 56% of respondents in a 2019 survey of US consumers.

As meat consumption grows around the world, an increasing proportion of this demand will be for farmed fish. Fish farming, or aquaculture, is expected to provide 62% of the global fish supply by 2030[5]. Given the significance of fish farming in Myanmar, we have focused on some key trends affecting that sector world-wide and the potential role that farmed insects could play.

PWC published a Market Readiness Report[6] looking at the global need for sustainable feed ingredients for the aquaculture sector. This reports a combination of overall population growth and an increase in affluent middle-class consumers looking for healthy sources of animal protein. This means demand for marine protein will continue to exceed what can be sourced from wild catch. Based on expected income growth, there will be a seafood deficit by 2030 of around 79 million tonnes. As a result, aquaculture is forecasted to grow by 3.6% per year to meet increased demand[5]. However, while 41 million tonnes of aquafeed was produced globally in 2019[7], the volume of properly regulated fishmeal supplies has flatlined despite significantly increased demand among all major fish groups.

Thus, the growth of farmed fish production is severely constrained by the challenges of accessing sustainable feed ingredients at the right scale and with the right nutritional qualities. Furthermore, while what was originally the primary source of fish feed – fishmeal – is increasingly being replaced by alternatives, retailers have been incentivized to market fish based on quality by highlighting products with high levels of omega-3, which is normally achieved by including marine-based omega-3 in aquaculture diets.

Finally, there is widespread concern about the overuse of antibiotics within livestock farming and the impact that has on the quality of meat and the risk of Antimicrobial Resistance arising within diseases[8,9].

1.3 Growing evidence of benefits of farmed insects material

Global research is continuing to shed much-needed light on the realities and potential of farmed insects. A recent review by Prof Van Huis[10],the author of the original 2013 FAO report on edible insects, highlighted that since 2015, there has been exponential growth in the number of published articles describing research in this area.

Our chapter on farmed insects as fish feed sets out the current research on the benefits of insect protein in terms of meeting nutritional requirements of farmed fish.

From the original 2013 FAO report (Figure 1.1) onwards, proponents have claimed that farmed insects offer a route to a much less environmentally damaging source of protein based on comparisons of the environmental footprint of a kilo of insect material versus a kilo of beef, pork, chicken, etc. While these claims were originally based on laboratory studies, we now have a repository of practical evidence by which the sustainability of industrial-scale insect production can be assessed. As part of the European PROteINSECT programme (led by FERA in the UK), industry sustainability metrics were scrutinized, and it was concluded that many of the potential environmental benefits depend on what resources, particularly substrates, are used in the farming process and the environmental impact of sourcing and transporting them.

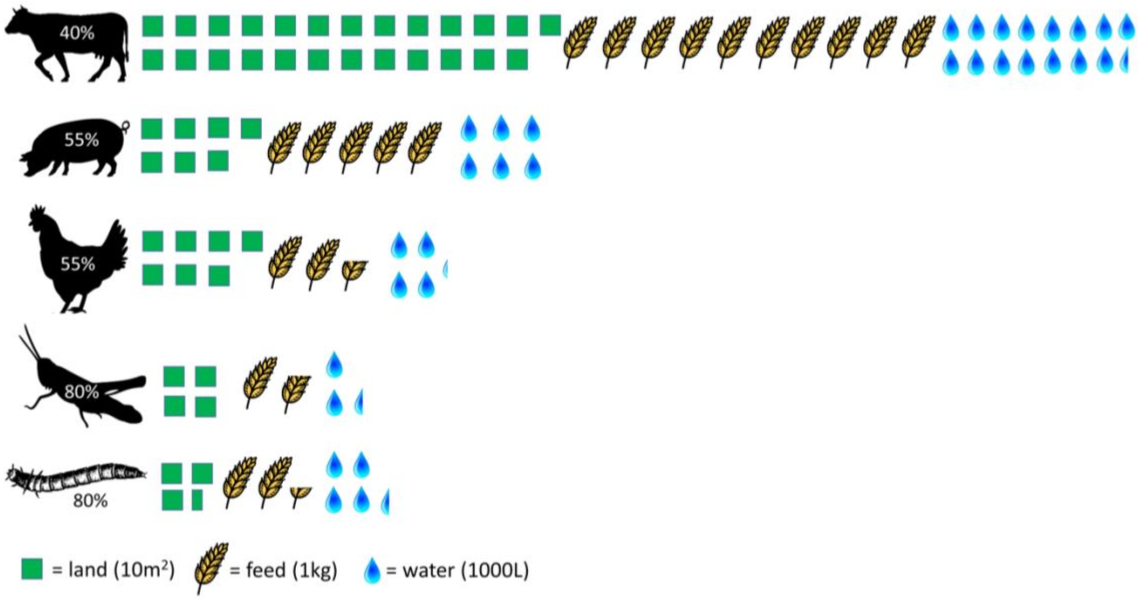

Figure 1.1: Amount of land, feed and water needed to produce 1 kg of live animal weight and percentage of the animal that is edible. (Original data from Hoekstra (2012), Hoekstra and Mekonnen (2012), Mekonnen and Hoekstra (2010, 2012), Oonincx and de Boer (2012) and van Huis (2013), graphic reproduced with permission (Dobermann et al, 2017))

However, when compared with many alternatives, the insect farming sector harnesses the natural processes of insect ecology not only to produce protein, but also potentially to have the dual value of converting organic waste materials and byproducts from related processes[11]. Insects form a natural part of the diet of fish, poultry, and other monogastric animals, making them highly appropriate as a component of their feed when they are farmed. Indeed, there is evidence that feeding poultry with live insects has additional benefits in terms of their welfare[12]. Finally, farming methods and technologies have developed considerably in recent years but is increasingly taking the form of proprietary and commercially sensitive technology that is guarded from scrutiny as a result of pressure from investors.

Returning to concern over the use of antibiotics in livestock farming; research has shown that insects can create natural Antimicrobial Peptides (AMPs) as part of their own immune response[8] and that livestock eating them benefit from increased resistance to disease. Indeed, UK-based IMBT has patented a mechanism for stimulating insects to increase the AMP production by exposing them to diseased material, which then further enhances the beneficial effects of feeding these to poultry[8]. It may be that, in time, insects can become part of a more natural solution to the question of how to safely reduce disease within herds.

1.4 Growing understanding of and technology for insect farming driving down prices

One of the major challenges for the farmed insect sector is the comparatively high price of insect material compared to alternatives – whether fishmeal or soy for livestock or meat and plant-based proteins for human consumption. These alternatives have benefitted from decades of research, innovation, and massive economies of scale that have enabled costs to be slashed, albeit at the cost of livestock welfare standards and of environmental damage which results from industrial scale monocrop farming, involving the clearing of huge areas of rainforest in Latin America and South Asia.

Therefore, there has been considerable effort to drive down the cost of farming insects. However, the high price of labour in Europe and North America can result in increased production costs, as insect husbandry is fairly labour-intensive. These circumstances are pushing companies to automate and streamline insect farming, as well as to increase efficiency by manipulating the actual insects themselves through selective breeding. Companies also hope to build an understanding of the genetics and epigenetics that determine insect characteristics with the aim of developing optimal variants for high levels of feed conversion efficiency.

We provide a short chapter on insect farming that sets out the main models that currently exist (see Chapter 4). The most technologically intensive approaches require substantial investment, but there are now a strong group of insect farming companies that have attracted significant capital in recent years. As these companies expand, they are looking for suitable locations to deploy their technologies where returns commensurate with the level of investments required can be delivered. We are in contact with a number of these companies, and we have carried out some initial explorations of potential markets/sites. One way for Myanmar to develop the insect farming sector within its economy would be to offer incentives for inward investment and to have a dedicated team of specialists who will work with interested companies to assess potential sites, find suppliers of suitable high quality feedstocks, etc.

Alongside this, there have been centuries of small-scale insect farming and many farmers around the world now farm BSF based on rudimentary equipment and emerging skills and understanding. Thailand has over 20,000 insect farmers operating at a small scale and selling to their national market (see Section C.2). These operations are subject to minimal regulation but the small scale of these operations mean the risks are probably minimal. However, challenges occur if they seek to export to markets such as the EU, which demand much more stringent quality controls than are currently in place within this relatively artisanal industry of small-scale farmers. Hence, many BSF farmers sell products locally or else co-locate BSF farming with other livestock rearing, so that they are essentially creating a ready source of protein for their main product. For example, there is now a Facebook group specifically for the exchange of BSF farming knowledge, now boasting over 9,000 members from across the world.

The Woven Network carried out an informal exploration of insect farming practices around the world, drawing on a range of sources including seeking input from various groups on social media. This created a striking picture of the diversity of insects being farmed, but with BSF being very clearly the most common (Figure 1.2). The data refers to the number of reports of an insect farm and does not include any measure of the scale of the farm

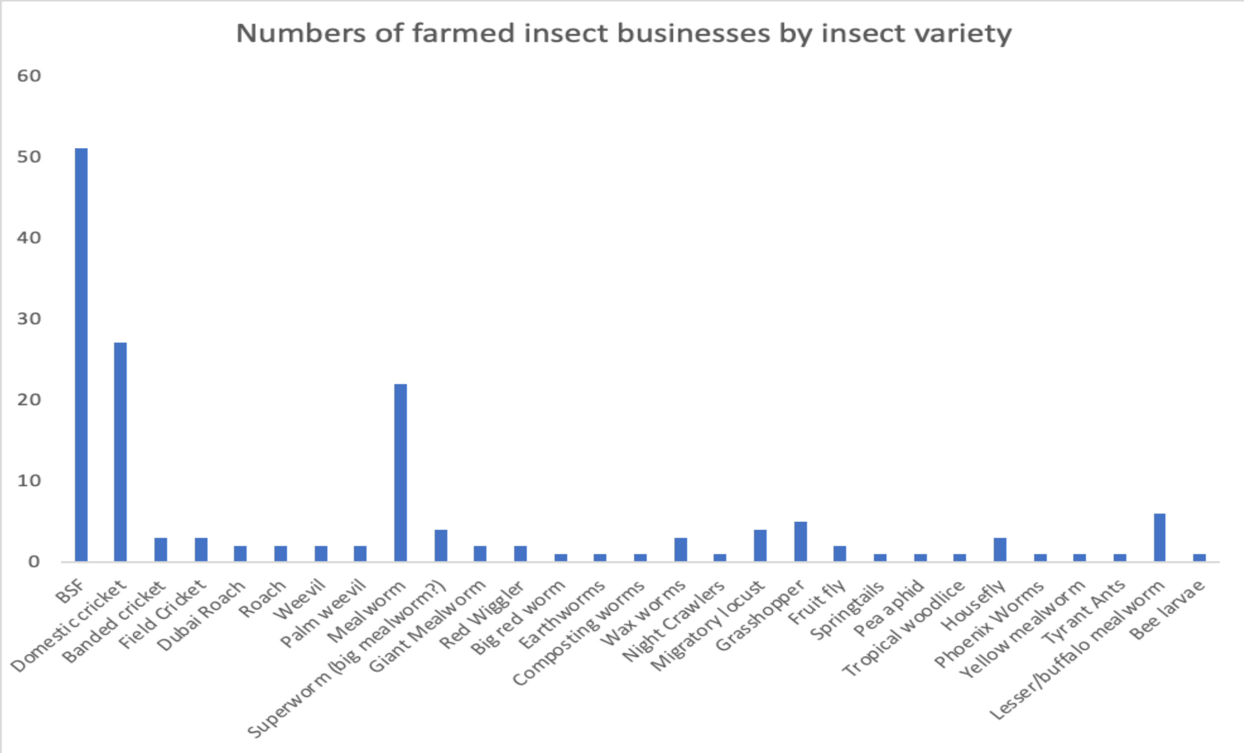

Figure 1.2. Woven Network findings regarding insects being farmed (Source:Woven Network)

One study is particularly worth considering as part of the PROteINSECT project – the DfID funded ENTOprise project (2015-2017) set out to investigate what steps would be needed to commercialize BSF production in Ghana. It explored locally available substrates and developed a "suitability matrix" based on costs, availability and risks. A whole range of criteria that would determine commercial viability was assessed. Key bottlenecks such as egg collection and separation from substrates were investigated and significantly improved. The used substrate and frass that resulted from BSF rearing were investigated for their potential as a bio-fertiliser and soil improver on Ghanaian cash and fodder crops. Not only did they improve yields, they have promising anti-microbial properties as well. But while the project made some good progress, there were still challenges regarding the labour effort required at key stages, which affected overall costs of making it a viable business.

However, the main impact of all this research is evident in the decreasing cost of insect material. A recent study by Barclays Investment Research[4] found the cost of cricket powder is dropping in a range of markets between 2017 and 2019 by between 33% and 50%, depending on the market.

1.5 Growing concern about harvesting insects

Worldwide, about 92% of edible insects are still harvested from the wild, with only small amounts being specially raised for consumption[13]. We know of a number of locations around the world where there are concerns about the extent to which insects are being harvested from the wild and the impact it is having on the ecosystem. The harvest of insects from the wild may cause the extinction of species such as the red agave worm used in mezcal, the *escamol* or Navajo Nation ant, and the agave weevil[14]. In addition, we have heard reports of this in China and in southern Africa in relation to the mopane caterpillar[15]. This is driving efforts to develop sustainable farming systems of these culturally and economically important species.

According to a study by Sánchez-Bayo *et al.*[16], one third of all insect species should now be classified as endangered. The focus now needs to be on developing sustainable farming systems for the rearing of edible insects at an industrial scale.

Informal communications with the global Wildlife Conservation Society have highlighted their interest in exploring whether insect farming could be used to provide a source of protein for indigenous communities around the world, especially in locations where expanding populations result in the overharvesting of many other forms of wildlife.

1.6 Growth in the farmed insect sector

The farmed insect sector is growing year-on-year and is projected to continue to see accelerated growth in the coming decade. There are a number of significant measures of this growth. While different studies use different methodologies and show some disagreement regarding questions about the basis for any projections into the future, the overall story is unambiguous and extremely encouraging.

Dr Rousseau's experience while judging entries to the WWF funded FEEDX challenge indicated that insect farming companies are still at a relatively early stage in the production of convincing evidence that they can deliver price-competitive livestock feed ingredients in a way that has robust environmental credentials. However, the ability of the sector to attract significant investment to enable growth shows that there is considerable optimism among stakeholders that insect farming will realise its potential and overcome the challenges it still faces.

In this section, we simply summarise a series of independent studies.

Barclays Research[4] was convinced that there is potential for insects to reduce the environmental burden of our food system as an alternative for both animal feed and food for human consumption. Despite a number of challenges (see Section 1.9), they see insects as a viable middle ground for consumers wanting to make their diets more environmentally-friendly without going entirely plant-based, as well as offering a more sustainable source of animal feed. Their analysis suggests that the insect protein market could be worth up to USD 8bn by 2030 (+24% CAGR).

A market assessment by **Meticulous Research**[2] predicts that the global edible insects (farmed and harvested) market will grow at a CAGR of 28.0% from USD 133.7 million in 2018 to USD 458.4 million by 2023. Within this, they found the Asia Pacific market is the largest worth $173.9 million in 2018 - predicted to reach $476.9 million by 2023. They suggest that this results from the diversity of insects, scale of production, positive attitude towards the insect as food and feed, and the absence of regulatory barriers to the use of insects as food and feed.

These reports exist for most sectors and always suggest extremely positive growth projections but often the methodology on which these are based lacks rigour. However, the message is consistent across a number of sources that the sector is expected to continue to grow, given the range of factors that underpin the growth already seen.

Woven's own survey (unpublished) identified over 130 different companies and farming operations around the world (Figure 1.5), but this did not reflect the numbers of cricket farms in Thailand that we were not able to measure.

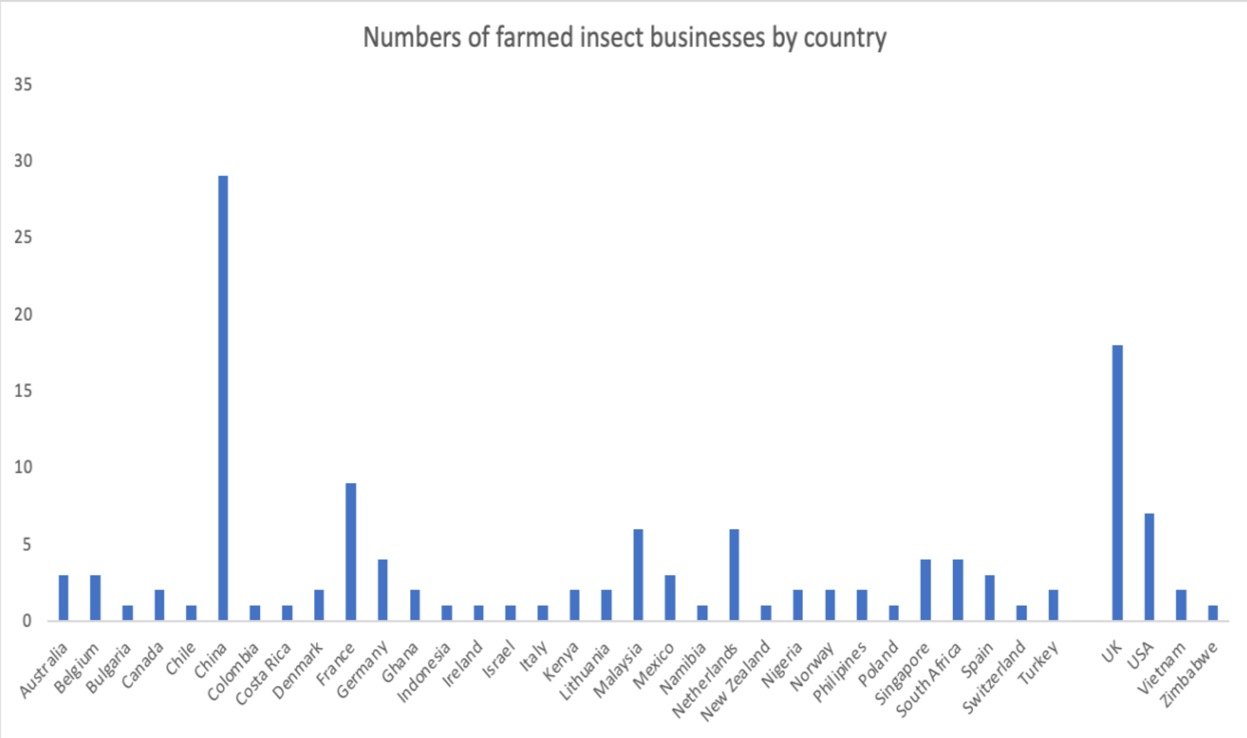

Figure 1.3. Global quantity and distribution of insect farming businesses (Source: Woven Network)

Report by **RaboResearch Food & Agribusiness** showed investments received by the sector in 2018 are 40% higher than the sum of investments received in the last four years.

The **International Platform for Insects as Food and Feed** (IPIFF – European industry association based on Brussels) estimates that 1,900 tonnes of insect protein were produced in Europe in 2018[11]. Their data is based on a survey of their members.

Figure 1.4. Map of IPIFF members. (Source: IPIFF)

By September 2019, European insect producers had raised more than €600 million through investments and are expecting to raise more than €2.5 billion by the mid-2020s. Above 5,000 tonnes of insect protein have been commercialised by European insect producers in total, since the authorisation of insect proteins for use in aquafeed. Their future projections depend on how much European regulations are relaxed in the future.

1.7 Growing consumer awareness and acceptance

While edible insects have been consumed around the world for centuries, in recent times consumer attitudes toward this form of food have changed significantly.

Populations of many countries that have traditionally consumed insects as a mainstream part of their diets are now shifting toward Western-style diets, which have a large proportion of fast food and imported ingredients; this can have damaging effects on local economies and health. The desire to adopt Western lifestyles associated with affluence and success has wide-ranging consequences, and there have been different attempts to counter it. For instance, as long ago as in 1972, The Malawi Cookbook[17] was produced with the intention to provide recipes to encourage cooks to make more use of locally available produce and ingredients. The book was compiled by a small group of expats from the UK but the dishes were sourced from people across Malawi. A chapter explained how to prepare and cook locally available insects such as bee larvae, large green bush crickets, grasshoppers, red locusts, flying ants, black flying ants, green caterpillars, sand crickets, large green shield bugs, lake flies, shield bugs and cicadas.

Meanwhile, across Europe and North America, there is growing media coverage of insects as a form of food, with articles on dishes, restaurants, products and the sustainability arguments associated with them. As a result, a great many people are now aware that insect-based food is a coming inevitability, and they have some curiosity to try them if they have not already. At present however, the range of products that are readily available is very limited.

A study by House *et al.*[18] shed interesting light on the challenges of convincing Western consumers to include insects as a regular part of their diet. He identified consumers in NL that had purchased a burger made from insect material in supermarkets and asked them about the factors that determined their purchasing decision. He found that the *initial* motivations for trying insect foods which those surveyed mentioned were substantially different from those leading to *repeat* consumption. Repeated purchasing of insect products was found to be a result of considerations including price, taste, availability, and 'fit' with established eating practices.

A recent YouGov survey found that a third of Britons, and nearly half of those aged 18-24, expected insect consumption to be commonplace by 2029[19].

1.8 Farmed insect products and markets

In terms of actual products made from insects, there is steady growth in both the food and feed sectors, but these lack fundamental breakthroughs to open up new possibilities.

Thus, in the food area, the challenge is to create ingredients that can be incorporated into familiar dishes for Western tastes. There are many companies all over the world producing various products from processed insects for both the human and animal food industry. These include:

- Edible insect flours[20].
- Addition of protein rich insect flour into meat emulsions and analogs, e.g. sausages[20].
- Pasta, bread and other bakery products[20].
- BSF larvae and pre-pupae when reared on materials of vegetal origin are allowed as pet food and, since mid-2017 in the European Union, also as an ingredient of fish feed[9].
- Processing milled BSF larvae into textured protein[9].
- Crickets in energy, protein bars and pork pâté[9].
- Termites and crickets in buns and pasta[9].
- Children's fortified blended food products with spiders, caterpillars, crickets, termites to combat iron deficiency[9].
- Burgers[9].

Meticulous Research[2] finds that whole insects have the largest share of Asian-Pacific markets, but protein bars and shakes are expected to see the largest growth.

Similar current projections have been reported regarding food-related products containing insects in Europe by IPIFF[11]. The companies working in these sectors are expecting the market share of whole insects and snacks (which currently dominate) to reduce while that of more mainstream food offerings are expected to increase – driven by increased innovation in how to incorporate.

The majority of products are based on whole or ground insect powder, but these offer limited ability to be used as ingredients. Some companies have developed more innovative ways to make insect material work as an ingredient in dishes familiar to the Western household; for example, C-fu Foods in Canada and Vexo from BugFarmFoods in Wales.

There are a range of potential markets for insect protein-based products, ranging from human food, livestock feed (primarily fish, poultry and mono-gastric livestock), pets (both mammals and exotic fish) and even wild birds where humans wish to put out feed trays, etc. A recent market study by Enterra TCG[20] identified the ease of accessing these different markets and their potential scale (Table 1.1).

Table 1.1. Market opportunities for insect-based animal feed. (Source: Enterra TCG 2020)

	More immediate opportunities	Opportunities that are further out
Pet food	Hypoallergenic and natural treats - 64k	Natural food - 136k
Commercial poultry		Natural feed - 286k
Commercial aquaculture	Natural feed - 24k	
Total	88k mT	422k mT

1.9 Drivers of and challenges to growth

There have been a number of reviews covering the factors driving growth in the insect farming sector and the barriers and challenges it faces.

An IPIFF survey of insect farming businesses in Europe, the largest proportion (64%) identified regulations as the largest barrier to growth of the sector, followed by the need for funding (60%)[11].

Scaling up production will also be important as this always drives competition and the search for ways to make production more efficient – both of these can then drive down the price of insect material and increase its competitiveness in the market. Experts expect the prices of fishmeal and oil to continue to rise, which will also help[6].

Consumer expectations are both a driver for growth and a challenge. Consumers around the world are increasingly looking for healthy, nutritious and safe food and yet, while they are looking for solutions to making food production more sustainable, there is very little evidence that they are willing to pay a higher price for this.

Research and Innovation: 40% of respondents in the IPIFF survey[11] identified the need for more research and the primary barrier to growth. A recently formed innovation programme funded by the European Commission – SUSINCHAIN – is aiming to directly focus research on the more immediate challenges[21] through collaboration between industry and academia. They have taken a whole life cycle view of the sector and will cover:

- Insect rearing innovations will be focused on organic side streams of vegetable origin that cannot be used directly as animal feed.
- For improving economic viability, possibilities for marketing of rearing by-products will be evaluated and strategies to avoid insect diseases will be developed.
- Transport, storage and processing technologies for insects will be optimised and demonstrated at large scale.
- Microwave and Radio Frequency drying, High Moisture Extrusion and protein recovery from fresh larvae by using enzymatic pre-treatment combined with continuous tricanter centrifugation will be validated and demonstrated.
- Controlled atmosphere packaging and cold atmosphere preservation for storage and transport of living insects will also be tested.

- The digestibility of insect meals produced by different processing methods will be assessed and insect meals will be included in feed formulae for large-scale level commercial diets to test optimal inclusion levels to maintain or increase livestock performance and health.
- Insect based food products will be designed and developed suitable for the domestic preparation of regular dinner meals.
- The microbiological, chemical and allergenic safety of insects and derived products will be addressed along the entire chain.
- Hygiene codes, HACCP protocols, and guidelines for safe insect production will be created and distributed among the supply chain actors.

Endnotes

1. van Huis, A., Van Itterbeeck, J., Klunder, H., Mertens, E., Halloran, A., Muir, G., & Vantomme, P. (2013). Edible Insects - Future prospects for food and feed security.

2. Meticulous Research. (2019). Edible Insects Market - Global Opportunity Analysis and Industry Forecast (2019-2030). https://www.meticulousresearch.com/product/edible-insects-market-forecast/

3. UN Environment Programme. (2018, September 26). Tackling the world’s most urgent problem: meat. UNEnviornment.Org. https://www.unenvironment.org/news-and-stories/story/tackling-worlds-most-urgent-problem-meat

4. Barclays. (2019). Insect protein: bitten by the bug. In Barclays Investment Bank. https://www.investmentbank.barclays.com/our-insights/insect-protein-bitten-by-the-bug.html

5. World Bank. (2013). FISH TO 2030: Prospects for Fisheries and Aquaculture - World Bank Report Number 83177-GLB. www.worldbank.org

6. PWC (2018) FeedX Market Readiness Report Summary. (December).

7. Alltech. (2020). 2020 Global Feed Survey. In RepTrak (Vol. 1, Issue March). https://www.reptrak.com/blog/2020-global-reptrak-study-executive-summary/

8. Rousseau, N. P. (2017). The use of insects in the animal production sector with an insight into consumer perception of insects as food or feed and potential to replace antibiotics. World Poultry Science Association/British Animal Science Association.

9. Bovera, F., Piccolo, G., Gasco, L., Marono, S., Loponte, R., Vassalotti, G., Mastellone, V., Lombardi, P., Attia, Y. A., & Nizza, A. (2015). Yellow mealworm larvae (Tenebrio molitor, L.) as a possible alternative to soybean meal in broiler diets. British Poultry Science, 56(5), 569–575. https://doi.org/10.1080/00071668.2015.1080815

10. van Huis, A. (2020). Insects as food and feed, a new emerging agricultural sector: A review. Journal of Insects as Food and Feed, 6(1), 27–44. https://doi.org/10.3920/JIFF2019.0017

11. IPIFF. (2019). The european insect sector today: challenges, opportunities and regulatory landscape IPIFF vision paper on the future of the insect sector towards 2030.

12. Biasato, I., Gasco, L., Marco, M. De, Renna, M., Rotolo, L., Dabbou, S., Capucchio, M. T., Biasibetti, E., Tarantola, M., Bianchi, C., Cavallarin, L., Gai, F., Pozzo, L., Dezzutto, D., Bergagna, S., & Schiavone, A. (2017). Effects of yellow mealworm larvae (Tenebrio molitor) inclusion in diets for female broiler chickens: implications for animal health and gut histology. Animal Feed Science and Technology, 234(August 2016), 253–263. https://doi.org/10.1016/j.anifeedsci.2017.09.014

13. Baiano, A. (2020). Edible insects: An overview on nutritional characteristics, safety, farming, production technologies, regulatory framework, and socio-economic and ethical implications. Trends in Food Science and Technology, 100(April), 35–50. https://doi.org/10.1016/j.tifs.2020.03.040

14. Ramos-Elorduy, J. (2006). Threatened edible insects in Hidalgo, Mexico and some measures to preserve them. https://doi.org/10.1186/1746-4269-2-51

15. van Huis, A., & Oonincx, D. G. A. B. (2017). The environmental sustainability of insects as food and feed. A review. In Agronomy for Sustainable Development (Vol. 37, Issue 5). Springer-Verlag France. https://doi.org/10.1007/s13593-017-0452-8

16. Sánchez-Bayo, F., & Wyckhuys, K. A. G. (2019). Worldwide decline of the entomofauna: A review of its drivers. In Biological Conservation (Vol. 232). https://doi.org/10.1016/j.biocon.2019.01.020

17. Shaxson A., Dickson, P. & Walker, J. (Rev. ed. 1978) The Malawi Cookbook, 1972

18. House, J. (2016) Consumer acceptance of insect-based foods in the Netherlands: Academic and commercial implications. Appetite. 107 (September 2015), 47–58.

19. Banks, A. (2019). Farming insects for food: Opportunities and Challenges. In Nuffield UK.

20. Gravel, A., & Doyen, A. (2020). The use of edible insect proteins in food: Challenges and issues related to their functional properties. Innovative Food Science and Emerging Technologies, 59(December 2019), 102272. https://doi.org/10.1016/j.ifset.2019.102272

21. TGC, & Enterra. (2020). Enterra TCG Market Study. North American Coalition for Insect Agriculture Member Meeting.

22. Veldkamp, T. (2020). SUSINCHAIN Project Introduction. SUSINCHAIN Sustainable Insect Chain.

Links for further reading:

IMBT - http://www.imbt.org

BSF Farming Facebook Group - https://www.facebook.com/groups/BSFFarming

ENTOprise Project - http://entopriseghana.blogspot.com/

C-fu Foods - https://www.f6s.com/c-fufoods

Vexo - https://www.bugfarmfoods.com/vexo-insect-protein-giving-welsh-schoolchildren-the-vip-treatment/

IPIFF membership: https://ipiff.org/ipiff-members/

Chapter 2 – Insects as feed for livestock and aquaculture

2.1 Introduction

This chapter presents an overview of the use of insects for animal feed. Insects are a highly nutritious, sustainable alternative to many conventional animal feeds. Use of insect feeds, particularly those made from BSF and yellow mealworm larvae, could be highly appropriate as an alternative to plant feed and fishmeal in Myanmar's established aquaculture and developing livestock industries. Feed insects can be farmed effectively on both small and industrial scales, making industry entry and growth highly accessible. Insects also provide a method with which to reduce waste and efficiently recycle nutrients back into food production while also promoting public health, making insect husbandry for feed highly suitable for countries such as Myanmar.

2.2 Context

Insect farming for aquaculture and livestock feed has elicited substantial investment interest in recent years[1,2]. Most animal feeds are either plant or fishmeal-based, production of which is increasingly associated with evidence of environmental damage (or at least cannot be increased without this). While limited research into the use of insects as poultry and aquaculture feed has occurred as early as the 1950s[3], only in the past decade have concerted efforts been made to investigate the suitability of insects as a nutritious, sustainable alternative to conventional animal feed[4,5,6]. As recent review articles - such those by Henry *et. al*[4], Gasco *et al.*[5], and Ojha *et al.*[6] - have shown, there is a very substantial body of research demonstrating that feed made from farmed insects is effective for the use in livestock rearing and aquaculture, and that they have the potential to be more sustainable than conventional feeds.

The livestock production industry in Myanmar has been developing since 1991. However, it is still mainly limited to the "backyard" herds of smallholders, with nutritional resources for feed being the major technical constraint to large-scale animal husbandry[7,8]. While most supplementary feed for livestock in South Asia comes from crop residues, alternative sources of high-quality feed will need to be explored as the Myanmar livestock sector grows.

In contrast to livestock husbandry, the aquaculture industry in Myanmar is highly developed. Fish is a staple food, and is by far the most important source of nutritional protein for humans nationally. It is expected that aquaculture will supply the majority of fish consumed in Myanmar in the next few decades[9]. Feed can account for almost 70% of the total cost of aquaculture production, and expenses for feed of substantial nutritional quality (usually made from fishmeal) have steadily risen in recent years. With fishmeal-based aquafeed becoming increasingly inaccessible, producers have fallen back on cheaper feeds made of vegetable byproducts, which are of much lower nutritional quality for fish[9].

2.3 Insects as an alternative to conventional feed

2.3.1 Livestock in general

Over a third of all crops grown on earth are used for animal feed, a proportion that is only expected to grow in coming years[10]. In the West, industrialized livestock rearing accounts for more than 85% of the use of all soy production[11]. The intensive monoculture associated with western-style industrial animal feed production can degrade soils, increase nutrient runoff into surrounding waterways, and reduce overall biodiversity as surrounding complex habitat is cleared for farming. By contrast, virtually no arable land is used in the production of farmed insects, and the water and energy inputs needed per unit of digestible protein are substantially lower[12]. Regarding land and water use alone, insect husbandry leaves a much smaller ecological footprint than traditional crop-based agriculture.

Furthermore, insect feeds have proven to be just as, if not more nutritious, than conventional feed materials made of crops when fed to livestock. The amount of digestible protein contained within insects is generally higher than most vegetable-based feeds[13], lending insects the potential to offer either comparable or even significantly higher food conversion ratios than traditional livestock feed[12].

2.3.2 Poultry

Insects are a part of the natural diet of almost all birds. Studies show that feeding insects to poultry, both in processed and whole-larvae form, can both meet the natural nutritional needs of these animals and also provide a series of health and behavioral benefits when raised in captivity[3]. Pecking and disease are common problems among poultry raised in close-quarter, industrial style-conditions, and the inclusion of insect protein into their feed could be a cost-effective method to mitigate these factors. When instances of pecking break out among poultry, the addition of live insect larvae to their diets can substantially reduce pecking damage by accommodating natural behaviors[3]. Insects have also been shown to increase immune responses in broiler chickens[14]. The inclusion of farmed insects into poultry diets could considerably reduce costs and increase animal welfare while also meeting nutritional needs. Studies regarding the incorporation of yellow mealworms and BSF into poultry feed, with up to 100% replacement of conventional protein meals, have found that growth rate and protein conversion ratios are largely comparable to conventional feed[3].

2.3.3 Aquaculture

Fishmeal accounts for the main feed used within aqua- and mariculture systems, with more than 90% of all fishmeal produced is used for aquaculture[11]. Approximately 20 million tons of fish are caught every year expressly to fulfill this purpose, most of them food-grade fish fit for direct human consumption[15]. As aquaculture is one of the fastest growing food production industries worldwide, and most capture fisheries have been at their harvest limits since the year 2000, there has been substantial investment into developing sustainable alternatives to fishmeal that deliver similar nutrient content.

In the meantime, many fish producers have fallen back on using plant-based aquafeed, which, as stated previously, presents a number of sustainability challenges. Moreover, there are several challenges regarding the nutritional content of vegetable-based feeds, as they are generally less digestible and less palatable to fish[16,17]. Insects, on the other hand, are part of the natural diet of most types of farmed freshwater fish, and studies show improved feed to conversion ratios and growth performance with partial replacement of plant-based meals by insect aquafeeds[4]. While the comparison of insect meal to fishmeal has so far been seen to be less profound, studies show overall that it is a nutritionally suitable, much more sustainable alternative to conventional fish-based aquafeed, especially when the nutritional content of the insects used are closely managed through rearing practices[4].

2.4 Current production of insects for feed

Developing and recently-industrialized nations are at the vanguard of researching cost-effective commercial insect husbandry schemes. China in particular already has a large insect farming infrastructure, where use of commercially reared silkworms, houseflies, Chinese wax scale, and yellow mealworms are already common in pet and animal feed[17]. Thailand is the world's leading producer of crickets for consumption by humans and animals. While there are large scale BSF producers in the USA and Australia, partnerships in Asia and Africa have invested heavily into the rearing of BSF and other insects locally for smallholders and members of rural populations[11]. Initiatives in Ghana led by the Swiss Programme for Global Issues for Development to transform municipal solid waste into animal feed and fertilizer via insects, particularly BSF, have provided promising potential solutions to problems regarding public hygiene and closing local nutritional gaps.

As seen in Ghana, insect husbandry for animal production additionally provides exciting potential for the advancement of sustainable economic and resource-use models. The model of circular economy aims to reduce societal food waste and recycle nutrients back into food production systems[6]. Insects can provide a highly efficient means of bioconversion of low-quality food and animal waste into high-quality protein and fertilizer in the form of insect frass (manure). Circular economy models are especially appropriate for developing countries such as Myanmar, where resources are more limited. Insects can provide crucial public health and nutrient recycling services while also providing a much-needed product for other sectors in the economy, such as animal feed. There are currently a multitude of regulatory hurdles regarding the production of insects for use in animal feed within the European Union, as insects are considered 'farmed animals,' and thus have strict conditions over what they can be fed before being passed on to livestock[6]. However, Myanmar does not have to follow that approach (See Chapter 6).

2.4.1 Safety and regulation

As with any novel feed, risks to animal and human safety should be considered when developing the manufacture of insect-based animal feeds. Insect diets have direct effects on the build-up of toxins within their tissues, and insects have been known to exhibit bioaccumulation of pesticides and heavy metals[4]. The likelihood of these risks should be considered and then appropriate measures put in place within the farming operations and the sources they use for obtaining substrates. In practice, the risk of potential insect toxicity from bioaccumulation is actually higher when insects have been harvested from the wild, rather than farmed[6].

Several experimental trials were conducted by a European consortium (with partners in China and Ghana) between 2015 and 2016 regarding the safety of animal feed made from commercially reared insects. These trials concluded that under properly managed production conditions, there are no noted safety concerns for fish, chicken, or pork reared on insect-based feed, and that the nutritional profile of the finished product fell well within EU regulatory limits[13]

2.5 Species of interest

Currently, only a few species of insect have been identified as being commercially viable for use in feed. Most research only considers feeds made of one single species, though studies suggest that investment into individualized formulations of insect meals to meet species-specific nutritional needs may further refine the process of converting insect biomass into animal protein to maximize input efficiency, feed-to-conversion ratios, and overall industry sustainability[5]. However, the BSF and yellow mealworm larvae [YML] are considered the most promising candidates for production of single-species feed. Though crickets, locust, and grasshoppers have also proven to be effective aquaculture feeds[4], BSF and YML have the best track records in terms of broad-range nutritional quality and large-scale rearing.

2.5.1 Black Soldier Fly

Most contemporary research into the use of insects in animal production has focused on BSF cultivation. This interest is due to the effectiveness of BSF in converting organic by-products and underutilized side-streams into biomass with high protein content[18]. BSF has a high rate of reproduction resulting in high daily biomass output, is suitable for production both industrial and lower-intensity rearing facilities, is not a known pest, and there has been evidence to suggest that animals fed BSF meal have improved immune response and gut health[6,19]. It also has been demonstrated that BSF meal can suitably replace fishmeal (up to 50%) in diets for several fish species[4,20]. Several peer-reviewed studies found that when compared to traditional feed, the use of meal made from commercially reared BSF either improved or did not significantly alter the final body weight or rate of gain for several livestock species[5].

2.5.2 Yellow Mealworm Larvae

Feeds made from YML, a common grain pest, have also proved to have significant improvements in the rearing of high-demand aquaculture species over conventional aquafeed, particularly of tilapia and African catfish, which both demonstrated mixed results when fed BSF meal[4]. According to the Food and Agriculture Organization of the United Nations [FAO], tilapia and catfishes combined comprise almost ten percent of the world's total economic aquaculture value[21], and they both comprise a substantial fraction of Myanmar's aquaculture. Yellow mealworms have also been shown to be nutritionally suitable feed for poultry, in some cases improving overall animal health when compared to those raised on soybean-based feed meals[22,23].

2.6 Considerations for Myanmar

Feeds produced from BSF and YML would prove highly appropriate for the Myanmar aquaculture sector. The most common aquaculture species in Myanmar comprise the rohu and common carp, tilapia, and striped catfish, along with the giant river prawn and the giant tiger prawn. As stated previously, tilapia and catfishes have been shown to respond favorably to YML feed in particular. BSF feed has been shown to be comparable to fishmeal in most species of carp[4], and both BSF and YML encouraged both higher growth rates and survivorship in prawns, especially when compared to plant-based diets[24].

While it may occasionally be available from local small-scale producers, access to commercially raised insect-based aquafeed is currently limited in Myanmar[9]. The lack of cost-effective alternatives to fishmeal will cause further reliance on plant and crop-based feeds, which are proven to be less nutritious than insect-based feeds. This would also create demand to grow crops for the purpose of making feed—a particularly precarious prospect in that region, as the deleterious effects associated with the expansion of monocrop agriculture in Myanmar can already be witnessed through the ecological impacts of the growing oil palm industry[25], calling for more sustainable alternatives than conventional crop-based feed.

Myanmar is the ninth largest producer of aquaculture in the world, and current projections predict that the industry will continue to grow in the coming decade. As worldwide tastes shift more toward Western-style diets rich in meat and fish[26], innovations regarding sustainability and efficiency in animal production are paramount to meet growing demand. With a population of nearly eight billion people and counting, food security is one of the most pressing issues facing our world today. According to a 2020 FAO report[27], hunger has continued to rise in the past decade. Meeting the nutritional demands for a growing world population will only put increasing pressure on our already finite resources.

In order to maximize efficiency and sustainability in production, ameliorate poverty, and reduce nutritional gaps, there is a substantial niche for alternative high-quality protein feed in Myanmar aquaculture. Insect farming is highly supported in literature to be cost effective and efficient methods of transforming low quality, inexpensive inputs into protein-rich biomass sustainably. Most notably, as evidenced in Ghana and in several projects in the EU, farming operations for both these insects can scale effectively[6], allowing investors to initiate pilot projects without the risk associated with industrial-scale overhead.

Endnotes

1. GMI (2016). Edible Insects Market Size, Share – Global Industry Report 2023. Global market insights industry reports, food, nutrition and animal feed. In).

2. Aquafeed. (2019). Interview with Kevin Fitsimmons. Aquafeed: Advances in Processing & Formulation, 11(3), 6–8.

3. Leek, A. (2016). Insect Bioconversion Products in poultry feed (Issue July).

4. Henry, M., Gasco, L., Piccolo, G., & Fountoulaki, E. (2015). Review on the use of insects in the diet of farmed fish: Past and future. Animal Feed Science and Technology, 203(1), 1–22. https://doi.org/10.1016/j.anifeedsci.2015.03.001

5. Gasco, L., Biancarosa, I., & Liland, N. S. (2020). From waste to feed: A review of recent knowledge on insects as producers of protein and fat for animal feeds. Current Opinion in Green and Sustainable Chemistry, 23, 67–79. https://doi.org/10.1016/j.cogsc.2020.03.003

6. Ojha, S., Bußler, S., & Schlüter, O. K. (2020). Food waste valorisation and circular economy concepts in insect production and processing. Waste Management, 118, 600–609. https://doi.org/10.1016/j.wasman.2020.09.010

7. Devendra, C., & Sevilla, C. C. (2002). Availability and use of feed resources in crop – animal systems in Asia. 71, 59–73.

8. Sone, P., & Aung, Y. H. (2012). Antimicrobial use in livestock production.

9. Spectrum. (2018). Overview of the Aquaculture Feed Sector in Myanmar and Potential For Insect Based Protein Inputs.

10. Cassidy, E. S., West, P. C., Gerber, J. S., & Foley, J. A. (2013). Redefining agricultural yields: From tonnes to people nourished per hectare. Environmental Research Letters, 8(3). https://doi.org/10.1088/1748-9326/8/3/034015

11. Stamer, A. (2015). Insect proteins — a new source for animal feed. EMBO Reports, 16(6), 676–680. https://doi.org/10.15252/embr.201540528

12. Oonincx, D. G. A. B., & Boer, I. J. M. De. (2012). Environmental Impact of the Production of Mealworms as a Protein Source for Humans – A Life Cycle Assessment. 7(12), 1–5. https://doi.org/10.1371/journal.pone.0051145

13. Charlton, A. J. (2016). Insect Protein – International Quality and Safety findings. Insect Protein - Feed for the Future. http://www.proteinsect.eu/fileadmin/user_upload/press/final-conf/Insect_Protein_-_International_Quality_and_Safety_Findings.pdf

14. Biasato, I., Gasco, L., Marco, M. De, Renna, M., Rotolo, L., Dabbou, S., Capucchio, M. T., Biasibetti, E., Tarantola, M., Bianchi, C., Cavallarin, L., Gai, F., Pozzo, L., Dezzutto, D., Bergagna, S., & Schiavone, A. (2017). Effects of yellow mealworm larvae (Tenebrio molitor) inclusion in diets for female broiler chickens: implications for animal health and gut histology. Animal Feed Science and Technology, 234(August 2016), 253–263. https://doi.org/10.1016/j.anifeedsci.2017.09.014

15. Cashion, T., Le Manach, F., Zeller, D., & Pauly, D. (2017). Most fish destined for fishmeal production are food- - grade fish. Fish and Fisheries, 18, 837–844. https://doi.org/10.1111/faf.12209

16. Merrifield, D. L., & Olsen, R. E. (2014). Dietary Effect of Soybean (Glycine max) Products on Gut Histology and Microbiota of Fish. Hany El-Shemy, IntechOpen. https://doi.org/10.5772/20101

17. Papatryphon, E., & Soares, J. H. (2001). Optimizing the levels of feeding stimulants for use in high-fish meal and plant feedstuff-based diets for striped bass , Morone saxatilis.

18. Yen, A. L. (2015). Insects as food and feed in the Asia Pacific region : current perspectives and future directions. Journal of Insects as Food and Feed, 1(1), 33–55. https://doi.org/10.3920/JIFF2014.0017

19. Sheppard, D. C., Larry, G., Thompson, S. A., & Savage, S. (1995). A value added manure management system using the black soldier fly. Bioresource Technology, 50(1994), 275–279.

20. Tomberlin, J. K., Huis, A. Van, Benbow, M. E., Jordan, H., Astuti, D. A., Azzollini, D., Banks, I., & Bava, V. (2015). Protecting the environment through insect farming as a means to produce protein for use as livestock , poultry , and aquaculture feed. 1(1), 307–309. https://doi.org/10.3920/JIFF2015.0098

21. Bondari, K., & Sheppard, D. C. (1987). Soldier fly, Hermetia illucens L., larvae as feed for channel catfish, Ictalurus punctatus (Rafinesque), and blue tilapia, Oreochromis aureus (Steindachner). Aquaculture Research, 18(3). https://doi.org/10.1111/j.1365-2109.1987.tb00141.x

22. Junning, C., Zhou, X., Xue, Y., Lucentea, D., & Laganaa, C. (2019). Top 10 species groups in global aquaculture 2017. Food and Agriculture Organization of the United Nations, June, 7. http://www.fao.org/3/ca5224en/ca5224en.pdf

23. Bovera, F., Piccolo, G., Gasco, L., Marono, S., Loponte, R., Vassalotti, G., Mastellone, V., Lombardi, P., Attia, Y. A., & Nizza, A. (2015). Yellow mealworm larvae (Tenebrio molitor, L.) as a possible alternative to soybean meal in broiler diets. British Poultry Science, 56(5), 569–575. https://doi.org/10.1080/00071668.2015.1080815

24. Mastoraki, M., Vlahos, N., Patsea, E., Chatzifotis, S., Mente, E., & Antonopoulou, E. (2020). The effect of insect meal as a feed ingredient on survival, growth, and metabolic and antioxidant response of juvenile prawn Palaemon adspersus (Rathke, 1837). Aquaculture Research, 51(9). https://doi.org/10.1111/are.14692

25. Nicholas, K., & Fanzo, J. (2018). Palm Oil in Myanmar : A Spatiotemporal Analysis of the Effects of Industrial Farming on Biodiversity Loss. Ldl, 210–222.

26. Ranganathan, J., Vennard, D., Waite, R., Dumas, P., Lipinski, B., Searchinger, T. I. M., & Authors, G. M. (2016). Shifting Diets for a Sustainable Food Future Janet. Proceedings of the International Joint Conference on Neural Networks, April, IV–537--IV–542.

27. FAO. (2020). Food security and nutrition around the world in 2020. In The State of Food Security and Nutrition in the World 2020

Chapter 3 – Insects as food - nutrition and risks

3.1 Introduction

This chapter explores the nutritional value of edible insects with particular reference to those available in Myanmar. It also highlights certain risks that need to be managed.

Much of the content of this chapter is based on a recent review of edible insects by Imathiu[1].

3.2 Nutritional value of edible insects

The specific nutritional quality of an insect depends on their species, stage of development, diet, method of rearing and sex. However, in general, research has found that edible insects are highly nutritious and can be reared in ways that have relatively very low environmental impacts. For this reason, they could contribute to dietary diversification of the world in hopes to ensure the reduction of hunger and malnutrition[1].

Insects in general provide a higher quality source of suitable **protein** for humans than plant sources. Insects have a relatively high nitrogen conversion factor of 6.25, a metric that is used to estimate the total protein in insects[2]. They can be seen as an alternative to processed meats, as these have been linked to many diseases, including cancer. Experts posit that increased consumption among the human population could reduce the prevalence of these sorts of health issues[1].

Insects are also important sources of energy, fats, and minerals[1]. The **fat** in insects is polyunsaturated, making insect products a potential way to provide healthier fats to lower cholesterol in the human diet compared to other meats with monounsaturated fats, like beef and pork. There is a higher amount of fats in insects when they are in their larvae form -palmitic and oleic acids[1]. These fats could be used to create oil, as they are liquid at room temperature. This means that they could be used in cooking, as they contain healthy fats such as polyunsaturated fats and essential fatty acids[2].

Insects can also be good sources of many **minerals** such as phosphorus, manganese, calcium, copper, selenium, zinc, iron, and a variety of vitamins (riboflavin, biotin, pantothenic acid), which support the normal functioning of processes within the body[1].

Finally, their high **chitin** content (10%), makes them a good source of fibre, which can reduce the pathogenic microorganisms sometimes growing in the human gut while also promoting life of useful gut bacteria[1].

3.3 Risks to be controlled associated with eating insects

As opposed to harvesting from the wild, the farming of insects can actually reduce the risks associated with eating insects if they are confined and their diets controlled[1].

Generally, insect farming, processing and labelling practices need to take account of the following risks (some of which are dependent on the type of insects being farmed):

- Farming insects from larvae avoids the risks of consumers eating **pesticide** residues, which may be present on wild insects[1] – assuming the farmers manage their herds carefully.
- Careful management can prevent transmission of **parasitic food-borne diseases**. Cockroaches can transmit parasites like *Entamoeba histolytica*, *Giardia lamblia*, and *Toxoplasma spp.* to humans[1]. The Reduviidae insect family (a large diverse family of the order Hemiptera) can carry the trypanosomiasis parasite and transmit it to humans. The WHO found that around 7 million people are infected with this worldwide[3].
- Guidance and training are needed for farmers to know what to feed farmed insects, so as not give them any substrate containing **pathogenic or food spoilage mould**. This would produce mycotoxins in the product, especially aflatoxins, which are carcinogenic and can cause stunted growth[1].
- Mealworms, superworms, greater wax moths, and crickets all contain a high gram-positive **bacteria** content, which can be harmful to human health and also cause the insects to spoil. This risk can be easily reduced by further processing, such as boiling, then roasting, or storage in a fridge[3].
- Farming domesticated insects can also reduce the risk of insects being carriers of **pathogenic microbes** e.g. Escherichia, Staphylococcus and Bacillus through hygiene practices being put in place to reduce microbiological hazards[1].
- BSF and yellow mealworm larvae have potential for use as food, but they may contain traces of non-essential **heavy metals** like arsenic and cadmium. These can have negative effects in the human body if levels are too high. They are also present in mulberry silkworm, scarab beetle, house cricket and Bombay locust[1]. However, the risks associated with this is relatively low, as most heavy metals are impossible to avoid ingesting or inhaling in everyday life. It could be reduced further through less exposure of these specific insects potentially mixing with other insects. Experts are unsure on the safe levels of these but for arsenic it may be 100 parts per billion[4].
- Long-horned beetle, grasshoppers, termites, mealy bugs, and silkworm pupae all contain **antinutrients,** which inhibit the digestion and utilisation of essential nutrients in the body, e.g. tannin, oxalate, phytates[1]. A study done on cassava processing showed that processing methods can reduce these antinutrients in food products, such as oven drying and fermentation especially for phytates[5].
- When distributing and selling insects as food to consumers, there also needs to be an awareness of the potential **allergen** risk factor. People with existing seafood allergies must be wary of eating insects due to them being closely related to crustaceans[1]. This can be managed easily though labelling of products and also potentially through processing of insects with methods like fermentation and hydrolysis[3].

3.4 Edible insect species in Myanmar - farming and nutrition

According to Ruth Devadoss[6], a number of types of insects are currently eaten in Myanmar. Table 3.1 sets out what we have found about whether they can be farmed (see categories of insect farming levels in Chapter 4 and nutritional and other factors).

Table 3.1. Specific nutritional benefits and risks associated with insects currently eaten in Myanmar (Source where not specified: Imathiu 2020)

Type of insect	Can they be farmed for eating?	Nutritional quality	Risks	Processing options
Crickets	Very widely farmed both in SE Asia and in NL and Canada at small, medium and large scale, with different levels of technology.	- contain ACE inhibitory activity which can regulate blood pressure as ACE usually raises blood pressure[3]. - 61% protein, 13% fat, significant levels of magnesium and folic acid, esp. good chitin[1]. - 19-22g/100g protein content[1]. - Excellent source of iron, calcium, copper, magnesium, manganese, zinc[3].	- protein digestibility and minerals may decrease upon processing. - Contain a high gram-positive bacteria content.	- There are many ways of processing and selling crickets – whole fresh, dried, powdered, etc. -Can be incorporated into wheat pasta to further process and enhance nutritional quality[7].
Grasshoppers	Creating natural breeding environments or industrial scale, high tech.	- contain ACE inhibitory activity which can regulate blood pressure as ACE usually raises blood pressure[3]. - 61% protein, 13% fat, significant levels of magnesium and folic acid, esp. good chitin[1].	- Cause of allergens. - may contain antinutrients which inhibit the digestion and utilisation of nutrients in the body.	- Widely consumed in Mexico and USA whole.

		- Excellent source of iron, calcium, copper, magnesium, manganese, zinc[4].		
Palm weevil larvae	These are farmed in Thailand – creating a natural breeding environment.	-3 3% fat, high levels of folic acid[1].		- Drying method in farming has a significant effect on the functional properties of these[8]. - practices in Thailand (See Section C.2)
Giant water beetles	Only harvested from the wild	- 33% fat, high levels of folic acid[1].		
Stink bugs	May not be possible to farm these.	- In China, the biological characteristics, medicinal and health care value of the stink bug have been investigated[9].	- may contain antinutrients which inhibit the digestion and utilisation of nutrients in the body.	- Can be boiled, fried and roasted[10]. - Adults are one of the common traditional Chinese medicinal insects, which can be used in combination with other traditional Chinese medicines to treat various diseases[11,12].
Honey bugs	May not be possible to farm these.		- may contain antinutrients which inhibit the digestion and utilisation of nutrients in the body.	
Cicadas	Some farmers have created natural breeding environments for these.		- incidences of allergic reactions after consuming silkworm pupae and cicadas have been reported in China[13].	- Often fried and roasted.

Other Beetles	**Mealworms** are the larval form of the **mealworm beetle**, Tenebrio molitor, a species of **darkling beetle**. All scales and technology levels of farming.	- 33% fat, high levels of folic acid.		- Both dried and live mealworms are sold throughout China, and exported. - Some large-scale farms in Shandong and Xinjiang are also equipped with microwave drying equipment. The larvae can be cleaned, dried and packaged in the same location. - Larvae are also used to process insect oil, protein powder, chitin and other products. - Some companies have also tried to use the mealworm to treat waste in a rural circular economy model, including kitchen waste and vegetable and fruit peels.
Weaver, and other, Ants	Relocating plus insect management.	-contain ACE inhibitory activity which can regulate blood pressure as ACE usually raises blood pressure[3].	- Weaver ants can contain parasites Dicrocoelium dendriticum that can be transmitted to humans[1].	- direct consumption or processed as dry, powder, liquor and other product[10].

Table 3.2 Other insect species that might be suitable for farming in Myanmar. (Source: Feng *et al.* 2019)

Type of insect	**How widely farmed for eating**	**Nutritional quality**	**Risks**	**Processing options**
Bees	- Very widely farmed in different ways – hives, etc. - Honeybees have been reared artificially throughout	- Bee larvae, pupae and adults are high in nutrient and protein content, low in fat, have reasonable amino		- In this industry, the main products are honey, bee pollen, royal jelly, propolis, and beeswax.

	history, and the farming technology is well-developed.	acid composition, and contain various vitamins and mineral elements.		- The bees are deep-fried, boiled in soup and added to cold salad, etc.
Silkworm pupae	-most common insect farmed in China[1]. - Many Chinese provinces have silkworm culture industries.	-50% protein, 30% lipids[2].	- Incidences of allergic reactions after consuming silkworm pupae and cicadas have been reported in China[13].	- Due to their high protein content and a variety of medicinal and healthcare properties, silkworm and tussah are processed into (health) foods in addition to being directly consumed.
Cockroaches	-fully domesticated and reared completely in captivity in China.			
Oriental migratory locust	- Farming techniques for these insects are well-developed. - Several species of locusts are common edible insects in all parts of China. *L. migratoria manilensis*, called oriental migratory locust, is more popular in recent years due to its large body, good taste and developed farming techniques.	- Both nymphs and adults are edible, and possess a high protein and low fat content[11,10].		- The bodies of the locust are crispy after frying and baking, and are often used as a dish with liquor and barbecue. - The female adults with eggs are palatable and suitable for eating by humans, and the male adults with bright colours are often used as feed for ornamental birds and other artificially-farmed animals.

Wasps	- Only partially raised in captivity in China. There are quite a number of wasp breeding companies. - Due to the popularity and high economic value of wasps, a number of small farming enterprises and family-sized farms have emerged in southern China. The main farming species are *V. velutina* and *V. mandarinia.*			-The larvae and pupae are usually cooked by frying, grilling, boiling, or fried with chicken eggs.
Bamboo caterpillar	- The bamboo worm in China is distributed mainly in Yunnan, living in more than 10 types of bamboo. - Mainly harvested from the wild. - Relocating plus insect management.			- Matured larvae are usually collected. - rich in nutrients and is considered to taste good[14]. - In addition to being eaten in the distribution area in southern Yunnan, the bamboo worm is sold to other areas after being frozen or fried and packaged.
Diving beetles	-The underdeveloped method of artificial farming involves collecting larvae from the wild followed by rearing in aquaculture ponds covered	- Cybister japonicus Sharp, which is rich in nutrients, especially protein, is the most common edible species[15].		- They are used in soup or are deep-fried.

	with isolation nets until the adults emerge and are harvested.			
Longhorn beetles	-Various attempts have been made to farm these but the farming scale is small and undeveloped.	- The larvae are rich in nutrients and possess medicinal health value, and are expensive.		
Dragonfly	-Only partially raised in captivity in China			
Sand-crawling insects	-The necessary technologies are underdeveloped in China but there are various attempts underway.			- The larvae of the 'sand-crawling insect' are found under rocks by the unpolluted streams. The body of the larvae is large and easy to catch, and are cooked by frying, stewing and boiling.
Bean hawkmoths	-The necessary technologies are underdeveloped in China but there is small scale rearing.			-Can be cooked in a variety of ways.

Endnotes

1. Imathiu, S. (2020) Benefits and food safety concerns associated with consumption of edible insects, NFS Journal, 18 (November 2019), pp. 1–11.

2. Jantzen da Silva Lucas, A., Menegon de Oliveira, L., da Rocha, M., & Prentice, C. (2020). Edible insects: An alternative of nutritional, functional and bioactive compounds. Food Chemistry, 311(November 2019), 126022. https://doi.org/10.1016/j.foodchem.2019.126022

3. de Castro, R. J. S., Ohara, A., Aguilar, J. G. dos S., & Domingues, M. A. F. (2018). Nutritional, functional and biological properties of insect proteins: Processes for obtaining, consumption and future challenges. Trends in Food Science and Technology, 76(April), 82–89. https://doi.org/10.1016/j.tifs.2018.04.006

4. Chodosh, S. (2018), 'Freaking out about heavy metals in your food? Heres what you should know', Popular Science, Available at: https://www.popsci.com/heavy-metals-baby-food/

5. Montagnac, J.A., et al. (2009) 'Processing techniques to reduce toxicity and antinutrients of cassava for use as a staple food', Comprehensive Reviews in Food Science and Food Safety, 8(1), pp. 17-27.

6. Devadross, R. (2019) Edible Insects Myanmar [Infographic]. [Online] [online]. Available from: https://venngage.net/p/107566/edible-insects-myanmar (Accessed 10 December 2020).

7. Gravel, A., & Doyen, A. (2020). The use of edible insect proteins in food: Challenges and issues related to their functional properties. Innovative Food Science and Emerging Technologies, 59(December 2019), 102272. https://doi.org/10.1016/j.ifset.2019.102272

8. Guo, Y.H. and Zhang, Q.L. (2015). Advances in the study on the biology, development and utilization of Aspongopus chinensis Dallas. Lishizhen Medicine and Materia Medica Research, pp. 692-693.

9. Feng, Y., Zhao, M., Ding, W.F. and Chen, X.M. (2019), Overview of edible insect resources and common species utilisation in China. Journal of Insects as Food and Feed, 1(1), pp. 1-13.

10. Li, L. and Li, X.F., (2010). Analysis of nutritional components of Aspongopus chinensis in Guizhou. Chinese Bulletin of Entomology, 47, pp. 748-751.

11. Zhang, G.W., Sun, S.L., Tang, J., Ling, W.H. and Zhong, Y.L. (2011). Analysis of the nutritional composition in Locusta migratoria manilensis. Acta Nutrimenta Sinica, 33, pp. 90-91. https://doi.org/10.13325/j.cnki.acta.nutr.sin.2011.01.002

12. Liu, M., Li, P.C., Liu, C., Song, C.M. and Ma, H.B. (2017). Determination and analysis of three species of Orthoptera edible composit nutrition. The Food Industry, 38, pp. 286-288.

13. Meticulous Research. (2019). Edible Insects Market - Global Opportunity Analysis and Industry Forecast (2019-2030). https://www.meticulousresearch.com/product/edible-insects-market-forecast/

14. Feng, Y. and Chen, X.M. (2000). The nutritional elements analysis of bamboo insect and review on its development and utilization value. Forest Research, 13, pp. 188-191. https://doi.org/10.13275/j.cnki.lykxyj.2000.02.013

15. Cong, J.M. (2007). Nutritional value appraisal of predacidiving beetle. Food Research and Development, 28, pp. 118-120. https://doi.org/10.3969/j.issn.1005-6521.2007.09.037

Chapter 4 – The diverse nature of insect farming

4.1 Introduction

This section describes the range of different ways in which insects can be "farmed" in order to produce protein and other byproducts. In practice, the nature of the techniques will be very different for different types of insects and different markets.

4.2 Different levels of artificiality/technology

There are a number of different levels of "farming" along a continuum from the most natural to the most artificial and industrial. We have classified them as shown in Table 4.1.

Table 4.1. Farming methods and characteristics. (Sources: Varied including interview with Feng, Feng *et al.* 2019, and Hanboonsong *et al.* 2013)

Category	Characteristics	Examples
Relocating plus insect management	The insects live and breed entirely naturally but within a designated "farm" and with some simple interventions or management methods to improve productivity.	**Weaver Ants** - Ant nests found in the wild are smashed and relocated to nearby land. The ants in the nests migrate out and re-establish multiple nests in the trees there. They live in colonies on tree branches and farmers facilitate breeding from these. They usually do this on mango trees, and enable the colonies to grow by: - providing a continuous supply of water. - constructing simple overhead ant highways made from rope that link trees, which protect them from ground-based predators and enabling them to forage using less energy. **Bamboo caterpillars**, In Thailand they control mating by using a nylon net cage that covers the bamboo shot, but simply releasing moths into a bamboo plot can be just as effective and is easier. In China, farming methods primarily involve artificial promotion of propagation. This method combines nurturing the host bamboo plants in areas suitable for the growth of bamboo worms and allowing worms to develop into adults in the bamboo cavity to improve their mating and spawning rate[1].
Create natural breeding environment	A breeding or growth environment from nature is set up on the "farm."	**Cicadas** - placing collected tree branches with eggs in cool ventilated rooms while maintaining a specific humidity in September. In March of the next year, the eggs in tree branches are placed in an incubator and hatched in conditions with temperature of 26-30 °C and relative humidity of 80%. After the nymphs emerge, the branches are buried in the roots of a host

		tree, such as poplar. The nymphs can grow for 3 years until they are harvested before adult emergence[2]. **Palm weevil** farming can take place within palm trunks or stems where sections are cut and then drilled with holes where the larvae will develop. Locating these conveniently makes their care (watering and breeding) and harvesting easier.
Man-made breeding environment - fully manual operation	Some man-made containers or facilities are set up to provide the conditions that the insects are used to, enabling production to be concentrated.	**Ant** nests can be harvested from the wild and moved to man-made indoor rearing ponds. The ants feed on other insects or animal meat and vegetable and fruit peels, and that are then sold or processed after the ant population has propagated and expanded in the nest. **Palm weevil** farming where they are bred in plastic containers filled with ground palm stalk and pig feed. **Bee** hives. **Wasps** can have greenhouse cultivation. Some farmers use one room like a factory. Bring light and air in the winter. In summer they can get food from the wild. Can be the basis for a profitable business as they are very popular. Need to be specialists to know how to avoid getting stung. **Cricket** farming in Thailand utilizes man-made containers for breeding. These consist of concrete cylinder or block pens, plywood boxes or plastic drawers. In addition, they will contain bedding and cardboard egg cartons with bowls containing husk/sand mixtures for egg laying. There will also be separate breeding tanks where eggs are incubated and hatched. This level of farming can be at different scales - from the crickets being kept under the house, to the use of separate farms or nursery pens.
Man-made environment with some automation.	Certain elements involved with insect production and related quality costs (feeding, watering, handling, harvesting, cleaning systems) are improved by adding technology.	
Man-made unnatural environment	Deliberately creating unnatural growing conditions to enable	Hargol Foodtech has found it can farm grasshoppers through manipulating temperature, humidity, light, ventilation, which shortened the incubation time for

	more intensive production.	eggs and increased the number of life cycles per year[3].
Fully industrial with extensive automation	An industrial set-up with the maximum of automation and monitoring of the herd carried out by other devices.	

Berggren *et al.*[3] highlight that these different options are suited to different contexts and for production for different markets. Further, as the farming is more sophisticated, it allows for more control over quality, protection from disease, etc..

While it can appear like a continuum, in practice, the jump to include automation makes a substantial difference to the costs of setting up and running and these costs can only be recovered, and a business made viable, if the benefits from manual costs being reduced can be fully realised - and this requires a large scale of operation. Thus, a recent report looking at how much return is achieved from different ways of making use of abattoir waste[7] found that farming BSF was very promising with either small scale or large scale operations delivering the best results. Small scale but mechanised is not cost-effective (Table 4.2).

Table 4.2. Table listing economics of different organismal rearing systems (Source: Hanboonsong *et al.* 2013)

BSF farming Scenario	**Cap ex $AUS**	**Op Ex $AUS pa**	**IRR**	**Profit pa**
Whole live larvae - manual at 104 tpa substrate	0.48m	0.33m	1.8 yrs	0.584m
Rendered larvae - mechanised at 20 ktpa RMP substrate	3.4m	1.3m	11 yrs	0.318m
Rendered larvae - mechanised at 160 ktpa feedlot + RMP substrate	12.3m	5.78m	3 yrs	5.79m

There are various systems that can be used as insect farming is scaled up. For instance, in Kenya, they have developed two options for medium sized cricket farming: Bucket-rearing, in which crickets are housed in 80L or 100L buckets with holes for air flow, and pen-rearing, where enclosures resemble small cattle dips. Bucket-rearing allows for more control over environmental conditions, but the scale of it makes it slightly more suitable for medium-sized farming operations[4]. Pens allow for rearing on a larger scale, but are more susceptible to variable environmental conditions[4]. Table 4.3 illustrates the pros and cons of each method.

Table 4.3. Pros and cons of main cricket rearing systems (Source: Orinda *et al.* 2017)

Bucket system - for small scale	**Pen system - for larger scale**
Advantages: · Medium carrying capacity(up to 2.5kg per bucket per cycle) · Lower capital requirement · Easy to disassemble (cleaning, disinfection, harvesting) · Lower risk of disease outbreak causing loss of whole colony · Retains warmth · Easy to transfer crickets in buckets	Advantages: · Carrying capacity up to 10kg per cycle in a 1.5m by 1.5m by 0.5m pen · Crickets have reduced contact with faeces · Efficient utilisation of space · Better able to protect from predators
Disadvantages: · Need a supply of affordable plastic buckets · Limited life of plastic buckets · Risk of overheating · Crickets have increased contact with faeces · Humidity in wet season can cause losses in smaller crickets (low temp. in buckets) · Not cost effective over 30 buckets · Difficult to maintain cleanliness	Disadvantages: · High initial cost of building materials · Running costs higher · Higher risk to whole colony if disease or pest outbreak · Limited to a set number of pens, depending on the space available. · More effort to clean and disinfect

4.3 Insect Mass Production Technologies

The book *Insects as Sustainable Food Ingredients* has a useful chapter by Cortes Ortiz *et al.*[8] that covers the range of considerations when setting up insect farming operations. Most of the following is extracted from that.

In practice, a complex system needs to be put in place that combines the production of eggs, pupae and larvae, in order to create an on-going flow of product. See Figure 4.1 for an example of this - in a BSF farm.

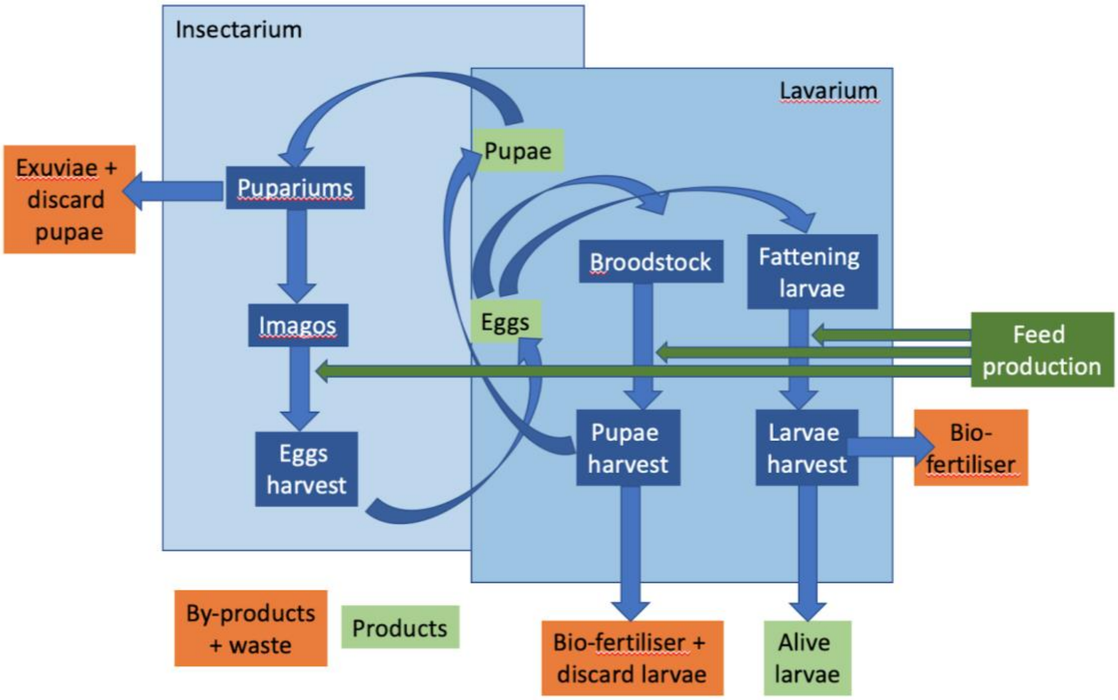

Figure 4.1. The full BSF production system. (Source: Caruso *et al.*2014)

Production of BSF has to be carried out in two, closely coordinated but physically separated, sections:

- Production of adults and eggs - the role of the insectarium
- Grow-out of larvae and production of pupae - the role of the larvarium.

If these are not physically separated, adult females would be strongly attracted by the production substrates which would affect how they lay their eggs, which makes production management more challenging.

Part of the pupae "crop" are transferred into the puparium inside the insectarium so as to periodically renew the broodstock. Within the insectarium eggs are produced and collected to also be transferred to the larvarium for a new cycle of production of larvae and of pupae.

4.3.1 What to feed the insects

Most insect species being farmed for food or feed around the world are omnivores, often scavengers in their natural environment. As a result, they can consume food from a variety of origins. While it is possible to farm insects on varied and inconsistent diets, the productivity of farmed insects can be improved by providing a correctly balanced diet. There is also growing evidence that the diet of the insects has a very significant impact on the quality of the protein that is produced[9].

Fruit and vegetable waste can be used for insect farming. However, productivity will be improved by including additional (high) value additives in their substrates. To understand the nutritional aspects for insects in animal feeding read 'State-of-the-art on use of insects as animal feed' by Makkar et al. (2014).

As well as ensuring correct nutrient content, it is important to bear in mind how insects feed. Insects can be classified according to their feeding adaptations and different forms of substrate will need to be used for different varieties of insect.

4.3.2 Rearing conditions

When establishing an insect farming operation, as we have shown, there are many different levels of intervention and separation from the insects from their natural state/context. Different levels of mechanization, automation, etc. bring benefits in terms of reducing labour and increasing potential yields but they are only justified when the operation reaches a certain scale. Also, there needs to be sufficient capital available and confidence that there is a market for the ultimate product. As with other forms of livestock farming, different insects require different conditions to thrive.

The first consideration is whether the insect species/stage can travel beyond just a 2-dimensional bottom of a flat surface, or not. There are different ways of achieving the maximum density of insects so that production can be optimized with limited space, but it is important not to create a level that brings problems. See Table 4.4.

Table 4.4. considerations when planning the space for insect farming. (Source: Makkar et al. 2014)

Characteristic **of insects**	Space considerations	Risks over attempting to over-produce.
Insects can crawl vertically, jump, or fly	Cardboard dividers, egg crate material, or a more permanent lattice of some material or another can create a 3D crawling space to enable larger density of insects	
Insects that can only move around a flat surface – true of most larvae	Trays with insects should be close to feed/substrate.	Need to allow passage of air and avoid over-heating. Some insects will only consume feed to a certain depth so exceeding this will lead to wasted feed.
Either	Rearing boxes can be held in multilevel shelves, which are filled with as many rearing boxes as possible	Need to arrange boxes so that they can be moved around – eg. Using a trolley.

Maintaining the correct temperature for the insects to thrive is critical. If it gets too hot, or too cold, they will either start to slow down their growth or be prone to disease, etc. Thus, there needs to be a suitable climate control system.

Handling of the feed is another aspect that needs careful planning. Broadly speaking, feed can be divided into perishable and dry:

- **Perishable feed** (esp with high water content): Only collect when needed, maybe once or twice a week to reduce feed spoilage.
- **Dry feed** (eg. Spent grain, flour): Avoid providing too much into the rearing/feeding area at any one time as it can become contaminated over time.

Cleaning or rinsing can be required as part of production. This depends on whether the insects naturally migrate away from their feed as they reach a key stage – this is one of the particular benefits of farming Black Soldier Flies as the larvae naturally seek a higher location away from their feed/frass to pupate, greatly facilitating harvesting. Where necessary, this requires the ability to transfer insects between containers. In all cases, the farm must have the facility to give the containers a high pressure clean before re-use. This will help reduce the risks of disease passing between herds.

The farm should also have a facility for handling the frass as this can be sold on as a valuable byproduct. If the aim is to produce a biofertiliser, the process is:

1. Separate the frass from live insects and feed residue
2. Add suitable proportion of a carbon rich feedstock such as sawdust or straw
3. Moisten it and adjust the pH to be around 7.5
4. Pile it up and turn it every 48 h until the temperature of the pile starts to decrease
5. Let it rest until the pile does not heat up anymore.
6. Prepare for shipment using a packaging flour machine with identification

Endnotes

1. Guo, Y.J., 2009. The experiment of artificial culture bamboo insect in wild bamboo forest. Modern Agricultural Sciences 16: 103-106.

2. Zhao, R.Y. and Duan, Y. (2012). Cicada cultivation and utilization. The Jindun Publishing House, Beijing, China, 129 pp.

3. Cosgrove, E. (2017, July 14). Commercial Grasshopper Farmer Hargol Foodtech Raises $600k Seed Round . Ag Funder News. https://agfundernews.com/grasshopper-farmer-hargol-foodtech-raises-600k-seed-round.html

4. Feng 2019

5. Hanboonsong, Y., Jamjanya, T. & Durst, P. B. (2013) Six-legged livestock: edible insect farming, collection and marketing in Thailand. Bangkok: Food and Agriculture Organization of the United Nations. Available at: www.fao.org/contact-us/licencerequest (Accessed: 7 December 2020).

6. Berggren, Jansson, A., & Low, M. (2018). Using current systems to inform rearing facility design in the insect-as-food industry. Journal of Insects as Food and Feed, 4(3), 167–170. https://doi.org/10.3920/JIFF2017.0076

7. All Energy Party Ltd. (2017). Abattoir Waste to Revenue. Meat and Livestock Australia Ltd. (October).

8. Cortes Ortiz, J.A., Ruiz, A.T., Morales-Ramos, J.A., Thomas, M., Rojas, M.G., Tomberlin, J.K., Yi, L., Han, R., Giroud, L. and Jullien, R.L. (2016). Insect mass production technologies. In: Dossey, A.T., Morales-Ramos, J.A. and Guadalupe Rojas, M. (eds.) Insects as sustainable food ingredients: production, processing and foodapplications. Elsevier, London, UK, pp. 153-201.

9. Ojha, S., Bußler, S. & Schlüter, O.K. (2020) Food waste valorisation and circular economy concepts in insect production and processing. Waste Management. 118600–609.

10. Dortmans B.M.A., Diener S., Verstappen B.M., & Zurbrügg C. (2017). Black Soldier Fly Biowaste Processing - A Step-by-Step Guide. Eawag: Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland.

11. Caruso, D., Devic, E., Subamia, I.W., Talamond, P. & Baras, E. (eds.) (2014) Technical Handbook of Domestication and Production of Diptera Black Soldier Fly (BSF) Hermetia illucens, Stratiomyidae. 1st. PT Penerbit IPB Press.

12. Makkar, H.P.S., Tran, G., Heuzé, V. & Ankers, P. (2014) State-of-the-art on use of insects as animal feed. Animal Feed Science and Technology. 1971–33.

Links for further reading:

State-of-the-art on use of insects as animal feed by Makkar *et al.* - https://www.researchgate.net/publication/264287361_State-of-the-art_on_use_of_insects_as_animal_feed

Chapter 5 – Insects as food and feed-Production processes

5.1 Introduction

This chapter provides a brief introduction to the different processes that can be required to convert live insects into saleable products/commodities.

5.2 Dispatching (killing)

Dispatching of insects is firstly done to harvest them and initially preserve them.

Freezing is the most efficient and humane way to do this as insects are cold-blooded and poikilothermic so their metabolisms will slowly stop in the cold and they will die in their sleep with no harm caused. They must be frozen as quickly as possible to prevent any microbial growth[1].

5.3 Decontamination

Removing contaminants potentially containing harmful chemicals or microorganisms from the insects is the next important step as this makes them safe for human or livestock consumption. This is mostly done by thermal (heat) or radiation (In a microwave) processes[2].

5.4 Drying

Solid insects are dried to prepare them for the comminution stage. The most common methods are[3]:

- freeze-drying - frozen and then dried by sublimation of the crystallized water;
- being cooked in the oven (to roast them);
- fluidised bed-drying or microwave so they can be ground and sieved to produce a fine powder;
- spray drying; this process involves a product that is prepared and propelled into the air as a spray using a high pressure spray nozzle or by spinning equipment, it is circulated in warm dry air until the water is removed and it drops[1].

5.5 Defatting

This is the process of removing fat from the material to increase the protein content of insect products, and enable insect oil to be separated out as a distinct product[3]. It is done either by mechanically pressing or aqueous and solvent based methods[2].

5.6 Comminution (grinding/milling)

For most products, a fine particle size dry powder will be the ideal insect-based ingredient format. Insect powders have a number of benefits[1]:

- Powders have the longest shelf life;

- Powders can be blended with many other ingredients effectively,
- A powder can also have the mildest flavor and aroma, and
- Powders tend to be ideal for most food equipment as they can be poured into, flowed through, and overall, utilized easily.

This is normally done by grinding or milling of the dry insects.

One of the problems experienced during grinding of larvae is browning from iron content, caused either by enzymatic or non-enzymatic factors. In a study looking at the extent of this in relation to different insects, the colouring of the larvae was strongest in BSF, followed by the yellow mealworm, then lesser mealworm. This problem can be reduced by lowering the pH with sodium bisulphite[2].

5.7 Insects as feed production techniques

When the aim is to provide insects as feed for livestock or pets, there are different options for what the product can be:

- Insects are sold **alive** as feed, for example a company called Kreca sells 95% of their insects alive for pet food and fish breeding[4];
- Whole but dried or frozen form for lizard, snake and other exotic pet food[1];
- As a meal -- eg. Magmeal by Agriprotein. Sold to livestock feed companies that incorporate it in different levels to feed formulations for a range of target livestock categories and development stages.

Endnotes

1. Dossey, A.T., Tatum, J.T., McGill, W.L. (2016) ‘Modern insect-based food industry: current status, insect processing technology, and recommendations moving forward’, *Insects as Sustainable Food Ingredients,* pp.113-152.

2. Huis, A.V. (2020) ‘Insects as food and feed, a new emerging agricultural sector: a review’, *Journal of Insects as Food and Feed,* 6(1), pp.27-44.

3. Gravel, A., Doyen, A. (2020) ‘The use of edible insect proteins in food: Challenges and issues related to their functional properties’, *Innovative Food Science and Emerging Technologies,* 59.

4. Erens, J., et al (2012) ‘Large scale insect rearing in relation to animal welfare’, *Wageningen UR.*

Links for further reading:

Agriprotien - https://www.agriprotein.com/our-products/

Chapter 6 – Ensuring quality and managing risks relating to the production and use of insect protein

6.1 Introduction

This chapter focuses on different approaches that have been used to protect consumers and ensure quality of insect protein that enters the human food chain. At one extreme, the European Union has the most wide-ranging and comprehensive Regulatory framework for minimising the risk of insect protein as either food or feed to consumers. No other region in the world has such an approach. Further, there are a range of resources and sources of guidance regarding training/consultancy in insect farming and production processes and techniques. Finally, as has been noted in the chapter on Associations (See Chapter 7), there are many groups that have formed between peers in the sector to support the sharing of knowledge of effective practices and experience

6.2 European Regulatory approach

Europe pays the greatest amount of regulatory attention to insects. While this has put farmed insects on a more robust footing as acceptable food and feed, it has resulted in some very restrictive requirements on farming practices.

6.2.1 Insects as livestock feed

There is a very good and up to date position paper[1] on the legal position of farmed insect material in Europe published by the IPIFF. It explains that, in 2015, the European Food Safety Authority published a risk profile opinion[2] evaluating the 'safety of insects as food and feed.' This focused on a number of potential risks that could arise from feeding insect protein to livestock. This informed the development of a very restrictive and cautious set of regulations as a first step in introducing farmed insects as a source of protein for livestock. The history of this includes Europe's agriculture being devastated by bovine spongiform encephalopathy. This disease was passed between cows through the practice of recycling bovine carcasses for meat and bone meal protein, and then feeding it to other cattle[3]. This experience resulted in extreme caution regarding what is fed to livestock in order to mitigate the risk of contaminants being passed up the food chain. For this reason, European legislation is very restrictive as the Commission (and all the Member States that all need to agree) demands a very high standard of proof that no possible risks to consumers can arise. Thus, only a limited range of substrates can be used to feed the farmed insects and they have to be reared and processed in conditions that have a very high level of biosecurity This brings considerable challenges in harnessing the full potential of farmed insects and rules out many approaches that may well not present significant risk, but where the safety has simply not been proven.

Regulation (EU) 2017/893 introduces a specific section for insects and insect products that allowed producers to feed insect protein to aquaculture animals. The Regulation requires that insects be processed in establishments that are specifically approved for that purpose so that potential microbiological risks associated with such products can be managed effectively. Furthermore, such approval is conditional on the fulfilment of a specific processing method, as described in the EU 'animal by-products legislation' – i.e. in Regulation 142/2011. The authorisation is limited to seven insect species: BSF, house fly, yellow mealworm, lesser mealworm, house cricket, banded cricket and field cricket. This list reflects the state of evidence regarding the safety of feeding protein from them to livestock.

The position paper argues that the Regulations currently allow insect farming to take place but that further relaxation of restrictions would be beneficial. They summarise the position and recommendations in a useful diagram – Figure 6.1.

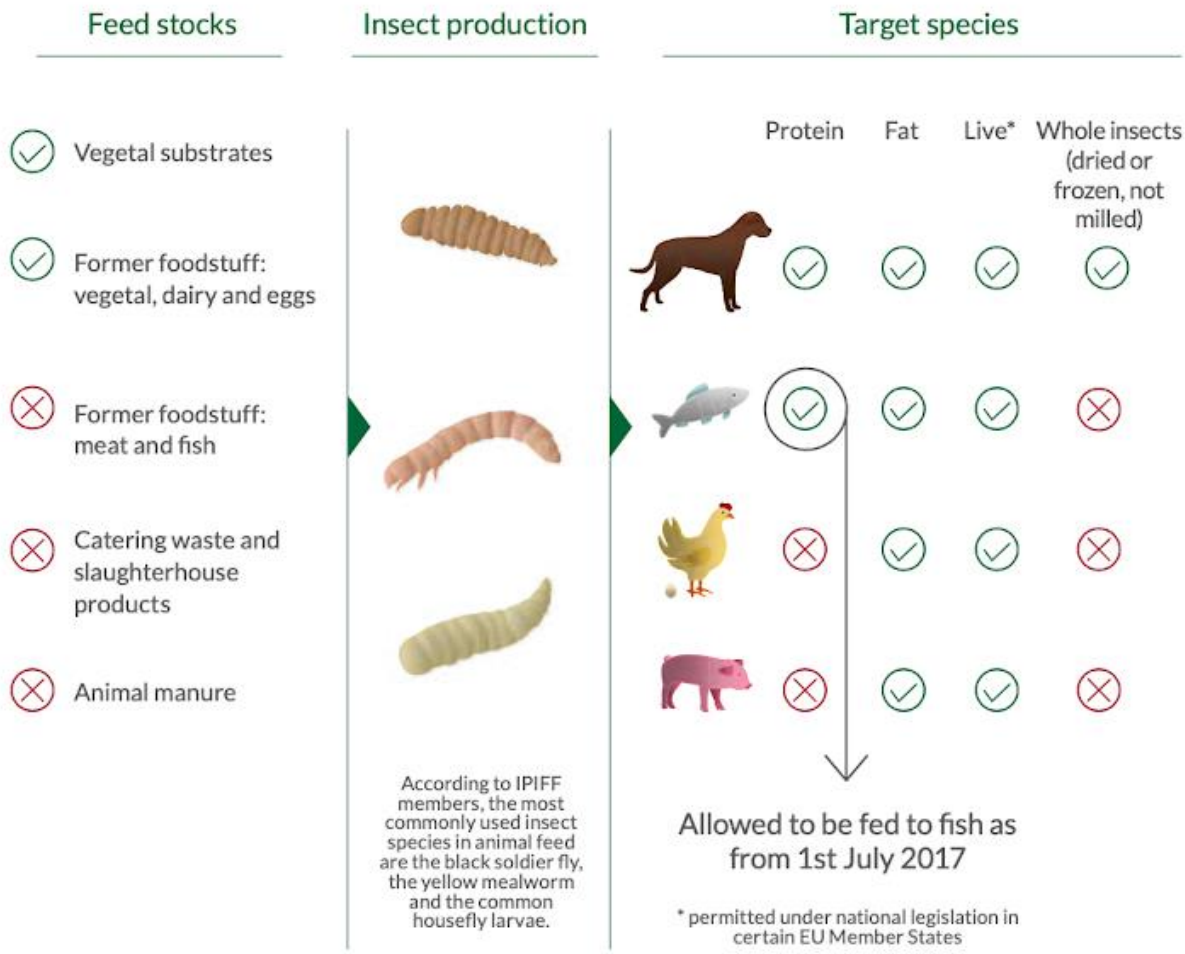

Figure 6.1. Summary of EU Regulations regarding insects fed to animals (Source: IPIFF 2020)

The UK is in the process of leaving the European Union and is exploring ways in which adopting a different Regulatory regime could bring benefits. There is a considerable debate underway regarding how the UK could relax regulations around insects farmed for livestock feed and there is a consultation underway to develop a Roadmap for how the sector could grow and what regulatory changes would make the greatest difference. This could provide a useful opportunity for Myanmar to learn from others.

6.2.2 Insects as Food - European Novel Food Regulations as described by IPIFF

As with the position on farmed insects as livestock feed, the European Commission has taken a very cautious approach toward allowing insects to enter the market within human food products. Their position, again, is that they assume the material to be unsafe unless/until there is convincing evidence to the contrary.

The Novel Food Regulation (new Regulations are (EU) 2015/2283) applies to certain categories of foods that were not used for human consumption to a significant degree within the EU before 15 May 1997, or resulting from production processes or practices not commonly used before that date (i.e. 'novel foods').

These Regulations did not previously recognise insects within the definition of Novel Foods but the new Regulations have introduced a centralised authorisation procedure. Under Regulation (EU) 2015/2283, whole insects and their preparations are considered as novel food and must thus be authorised under the new EU novel food system with the view to be lawfully marketed within the EU.

There are broadly two routes to authorisation but each involve an applicant submitting a portfolio of evidence to demonstrate the safety of the food ingredient for which they are seeking approval. The two routes are:

- a 'fast track route' to lawfully place novel foods on the EU market for which a history of consumption can be demonstrated in a non-EU country. This requires that documentary evidence be submitted of the history of consumption. It is important to note, however, that where the proposed production or consumption of insect material differs from that historically, there needs to be evidence that these differences do not introduce new risks for the consumer. Thus, if the history is primarily of insects harvested from the wild, then a proposal to sell farmed insects needs to involve a risk assessment of farming methods and evidence of safety. Similarly, if the intention is to provide insect material in a new form, then this also needs to be proven as safe.
- The standard route to approval involves a complete dossier setting out laboratory and other testing evidence plus details of farming practices, etc. and safeguards plus details of how the insect material will be consumed and by which consumer groups - showing that all these arrangements are safe, no toxins or other contaminants could become concentrated and result in products falling outside of European safety standards, etc. Gathering this evidence is a very substantial undertaking and requires a body with considerable financial resources to carry it out.

The list of applications that have been submitted for insects to be approved is here.

Anticipating the first novel food authorisations, IPIFF developed an up-to-date labelling guidance document with the view to support food business operators in prior to placing on the market their insect-based food products. This is both to reassure consumers and to alert them to the allergenicity considerations given that there is (limited) evidence that those allergic to shellfish may also be allergic to insect protein, given the similarity in protein type.

6.2.3 Importing insect material into the European Union

The EU has put in place a list of just three countries from which insect materials can be imported (Annex IIIa of Regulation (EU) 2019/1981): Canada, Switzerland and South Korea. According to the position statement from the EU, these countries were included as they provided sufficient guarantees to be authorised for entry into the European market. We understand that Thailand is seeking to be accepted as an importer, on the same basis.

6.3 Regulations in other regions

The European approach to protecting the consumer from risky food products is in contrast to the USA where the responsibility for establishing the safety of food products falls on the company creating the products, with the risk of litigation creating the incentive to effectively manage these risks. Also, in China, insects and insect material can be sold in "wet markets" with no regulatory controls (although there was a brief period, following the COVID-19 outbreak when all creatures taken from the wild or farmed in the wild could not be sold—this has been relaxed given that insects do not carry diseases that can be passed to humans), though to sell them in supermarkets/food shops the requirement is simply for the farming methods and production to follow standard health and safety and hygiene standards.

Across North America there are no specific regulations for insect farming. Manufacturers are simply required to comply with generic quality standards and hazard management procedures.

In Asia, there is very little regulation of insect farming for food or feed, and generally no insect-specific requirements. The only exceptions, according to Meticulous Research[5] are:

- Thailand is working on the creation of a first set of insect breeding guidelines and Good Agricultural Practices guidelines for the breeding of insects.
- In China, only silkworm pupae are explicitly included in 2014 in the list of foods allowed by the Ministry of Health.
- South Korea`s government has been working since 2011 on legalizing farming of crickets, mealworms, and larvae.
- The Food Standards Australia & New Zealand (FSANZ) Advisory Committee on Novel Foods (ACNF) assessed three species which includes *Zophobas morio* (super mealworm*),* *Achaeta domestica* (house crickets), and *Tenebrio molitor (*mealworm beetle) and categorised them as non-traditional novel foods in Australia and New Zealand.

In China, thirteen kinds of insects and insect products have been evaluated according to Procedures for Toxicological Assessment of Food in China; while there is limited data on these items, research shows they are safe[6]. There have recently been investigations into the risks associated with consumption of protein from insects commonly eaten in China in order to inform the development of safety evaluation and risk mitigation measures[7]. These focuses on species including silkworm, tussah, yellow mealworm and their insect products. A review carried out in 2018 brings together existing research on this[8].

6.4 Guidance

There are a growing number of online resources available for those entering the insect farming/insect protein sector. The Woven Network has assembled those we have come across for the benefit of our members. These include:

- A bug's life – Large-scale insect rearing in relation to animal welfare (Jesse Erens et al., Wageningen University, 2012)
- The Black Soldier Fly How-to-Guide ENST 698-Environmental Capstone Spring 2013
- Technical handbook of domestication and production of diptera Black Soldier Fly (BSF) Hermetia illucens, Stratiomyidae (Caruso et al., IRD Editions, 2014)
- IPIFF Insect Food Product Labelling Guidance
- BioBoost Report on Insect Breeding (Coudron et al., BioBoost, 2019)
- Black soldier fly biowaste processing – A step-by-step guide (Swiss Federal Institute of Aquatic Science & Technology, 2017)
- IPIFF Draft Guidance on good Hygiene in Farming
- Code of Good practice: Insect Production, Processing and Use in Animal Feeding, Portugal

Endnotes

1. IPIFF. (2020). The insect sector milestones towards sustainable food supply chains.

2. EFSA Scientific Committee. (2015). Risk profile related to production and consumption of insects as food and feed. EFSA Journal, 13(10), 4257. https://doi.org/10.2903/j.efsa.2015.4257

3. CNN Editorial Research. (2020, July 1). Mad Cow Disease Fast Facts. CNN. https://edition.cnn.com/2013/07/02/health/mad-cow-disease-fast-facts/index.html

4. IPIFF. (2019). The european insect sector today: challenges, opportunities and regulatory landscape IPIFF vision paper on the future of the insect sector towards 2030

5. Meticulous Research. (2019). Edible Insects Market - Global Opportunity Analysis and Industry Forecast (2019-2030). https://www.meticulousresearch.com/product/edible-insects-market-forecast/

6. Feng, Y., Chen, X.M. & Zhao, M. (2016). Edible insects of China. Science Press, Beijing, China

7. Zhao, M., Feng, Y., He, Z., Ma, T., Wang, C. Sun, L., & Wang, J. (2018). Research progress on insect edible safety in my country. China Sericulture, 39(2): 35-41.

8. Gao, Y., Wang, D., Xu, M.L., Shi, S. Sen & Xiong, J.F. (2018) Toxicological characteristics of edible insects in China: A historical review. Food and Chemical Toxicology. 119.

Links for further reading:

Summary of applications for farmed insects submitted to the EU - https://ec.europa.eu/food/safety/novel_food/authorisations/summary-applications-and-notifications_en

IPIFF labeling guidance document - https://ipiff.org/wp-content/uploads/2019/09/FIC-doc.pdf

EU position statement on farmed insects - https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32019R1981

Insect farming resources assembled by Woven - https://woven-network.co.uk/resources/#resources_reports

Chapter 7 – Insect Farming Associations around the world

7.1 Introduction

This chapter explores the different ways in which those involved in farming insects and related sectors can be associated for mutual benefit.

7.2 Different ways associations can provide support

There are quite a number of associations or membership bodies for those involved in exploiting insect protein for food or feed in business or academia. These take many different forms but are generally seen to be very valuable to their members in different ways and for supporting the growth of the sector.

The ways associations can support the sector include:

- Supporting networking and sharing of information and experiences. At an early stage when the sector is young and farmers are not competing in a challenging market, there is a general openness to sharing information quite openly and supporting the growth of the whole community. However, as individual companies secure private investment and start to grow and become more competitive they can become more cautious about how much to share, in order to develop competitive advantage in the market. Specific initiatives include:
    - Simply having a newsletter for members or for anyone interested can support promotion of developments and new products or services.
    - Establishing a website with resources and acting as a repository of information can be another way to support those seeking to set up or grow.
    - Holding events where people can listen to speakers and network to build relationships for both peer-to-peer and between suppliers and customers.
- Creating a collective voice for the sector. As the sector becomes established, there will be common concerns or developments that will affect the businesses, along with opportunities for seeking resources or support. This will be much easier if there is an established body that can represent the sector and pool ideas or perspectives, which will then take that information to relevant authorities. In practice, different parties will not all agree on what is needed but gathering views and these differences can still be much more efficient than going out to them all individually. Specific ways this can work include:
    - Lobbying for Government regulations or policies to change, or responding collectively to Government consultations

- Seeking support from research/innovation investment agencies - demonstrating that the sector is of sufficient size to warrant this and making the case for the specific areas of knowledge that need to be investigated
- Pooling resources between organisations to enable projects to go forward that any one on its own would not be able to fund - this can also be a vehicle for securing public funding if there is means of matching private and public investment.
- Promoting the safety and benefits of eating insects or feeding insect material to livestock.

7.3 Examples of different associations that exist around the world

Table 7.1 shows a range of examples of associations and their particular characteristics. Statements reflect the knowledge and perspective of the authors and are not necessarily all objective.

Table 7.1 List of Insect Farming Associations

Association	**Geographical coverage**	**Characteristics**
Woven Network	UK based but with international membership.	"To connect, inform and promote all those keen on enabling insects to become part of the human food chain and on developing them as a sustainable alternative source of protein and nutrition. To identify key barriers and opportunities for addressing challenges facing this emerging sector and leading campaigns and programmes to address these. To galvanise wider action and involvement of specialists to open up resources for the benefit of the sector." Set up by enthusiasts. Very low membership fee so it has limited capacity as run by volunteers. Membership can be individual, student or organisation - with different fee levels. Newsletter mailing list has over 500 recipients. Due to low fee, members are mixture of companies, farmers, academics, students and other interested individuals. Holding annual conferences with other UK partners. Website with resources for members and monthly newsletter. Running Webinars since global pandemic. Often asked to represent the sector or speak at conferences, etc. Did attempt to find a way to pool funds to enable Novel Food applications to be prepared.
Insect Biomass Conversion Task & Finish Group (IBTFG)	UK	"This is one of a number of Task & Finish Groups set up under the UK Government Agricultural Productivity Working Group (APWG) to tackle priority issues that address transforming UK agri-food productivity.

		The APWG acted under the direction of the Food and Drink Sector Council (FDSC) whose remit is to recommend how the UK can improve the productivity and sustainability for the entire farm to fork food chain, covering farming, manufacturing, retail, hospitality and logistics and to respond on behalf of the UK Agri-Food sector to the UK's Industrial Strategy published by BEIS in January 2018. The Insect Biomass Task & Finish Group represents key stakeholders across the Insect Biomass value chain and are committed to collaborating in order to deliver insect production at scale in the UK. "
International Platform for Insects as Food and Feed (IPIFF)	Brussels based - mainly European companies or those with an interest in Europe.	"IPIFF is an EU non-profit organisation which represents the interests of the insect production sector towards EU policy makers, European stakeholders and citizens. Composed of 71 members, IPIFF promotes the use of insects for human consumption and insect-derived products as a top tier source of nutrients for animal feed. Registered in the EU transparency register, IPIFF is a member of various 'EU institutional consultative platforms' established by EU public authorities."
Other European national associations	Portugal: Portugal Insect Belgium: Belgian Insect Industry Federation (BIIF) Finland: Finland Insect Production Association Sweden: Insektsforetagen France: FFPIDI Netherlands: Venik Spain: Aproinsecta Denmark: Danish Insect Network (DIN)	These vary considerably in form and constitution. Most have been set up by businesses within these countries that want to mutually support one another. Membership can be less than ten, depending on the country. The first one to be established was Venik, in Netherlands, where the largest number of insect farming operations exists.
North American	USA and Canada	"The North American Coalition for Insect Agriculture (NACIA) began in 2016 when around fifty stakeholders in

Coalition for Insect Agriculture (NACIA)		the insects for food and feed industry met at the Eating Insects Detroit Conference. Acting for educators, researchers and entrepreneurs in the growing "BugAg," movement. They seek to represent a wide diversity of types of insect farming, recognising the farmed insects can be a source of many different economically valuable materials." It has a low fee and relies on donations to make it sustainable.
National Innovation Alliance of Resource Insect Industry	China	In order to promote the development of the insect industry, the State Forestry and Grassland Bureau approved the establishment of this organisation. Includes industry and academia to support the growth of all industries that create products from farmed insects. The committee running this comprise a mixture of industrial insect material production companies and leading academics. It is chaired by a leading academic and the Chinese Academy of Forestry.
National Innovation Alliance of Galla Sub-Industry	China	This is a sub-group within the NIARI focused on industrial farming and processing of gallnuts. This is funded by the Chinese national body responsible for forestry as it contributes to economic activity within forested areas.
Various Chinese associations and groups	Provincial or local	There are many loose associations of insect farmers. These can be just to discuss farming technology and share information. There are different social media groups for sharing information - WeChat, QQ, etc. Some have closer relationships by clubbing together to sell insects to a common company and benefit from training and support, including eggs from that company. The company then buys fresh insects from the farmers and processes to create products to sell into the market - dried, etc. By being a member of this and following the company guidance the farmers get a higher price.
Asian Insect Food and Feed Association (AFFIA)		"The Asian Food and Feed Insect Association- AFFIA- aims at bringing industry and research stakeholders from the insects' sector in a collaborative movement towards the development of entomoculture, entomophagy and their related activities." This association largely represents larger players in the ASEAN region, often those with international origins. Given that there are estimated to be over 20,000 small scale insect farms in Thailand, it is unlikely that AFFIA

		would be able to represent this community.
Black Soldier Fly Farming Facebook Group.	International group.	With over 9,000 members, this group is used extensively by its members to share information and updates on anything relating to BSF farming. Members are generally small scale farmers.
Carolina Black Soldier Fly Farming Facebook Group.	Originally for farmers in North and South Carolina, USA but membership is not restricted so is very international.	Nearly 5,000 members, this group is used extensively by its members to share information and updates on anything relating to BSF farming. Members are generally small scale farmers.
Entomophagy and Edible Insects Facebook Group.	International group.	1,400 members who are a mixture of chefs, insect food companies and enthusiasts, sharing new ideas, recipes, etc.

Links for further reading:

Woven Network - https://woven-network.co.uk/

Insect Biomass Conversion Task & Finish Group - https://www.fera.co.uk/media/wysiwyg/Final_Insect_Biomass_TF_Paper_Mar19.pdf

International Platform for Insects as Food and Feed - https://ipiff.org/

Portugal Insect - https://en.portugalinsect.pt/

Belgian Insect Industry Federation - https://www.biif.org/

Insects Foretagen - http://www.insektsforetagen.se/

FFPIDI - https://www.insectescomestibles.fr/blog/ffpidi-federation-entomophagie/

Venik - http://venik.nl/site/wp-content/uploads/2012/10/140508-flyer-website-Venik-english-def.pdf

Apro Insecta - https://www.aproinsecta.org/

Danish Insect Network - https://en.inbiom.dk/danish-insect-network

North American Coalition for Insect Agriculture - https://nacia.org/

Asian Insect Food and Feed Association - https://affia.org/

Black Soldier Fly Farming Facebook Group - https://www.facebook.com/groups/BSFFarming/

Carolina Black Soldier Fly Farming Facebook Group - https://www.facebook.com/groups/287724761391404/

Entomophagy and Edible Insects Facebook Group - https://www.facebook.com/groups/723449954417747/

Chapter 8 – Case Studies

C.1 China

C.1.1 About the country

China is a huge country with a great variety of climatic and topographic zones as well as a population with diverse cultural traditions. It also has a particularly striking combination of extremely well developed technological capability and industry sectors and rural areas that continue to live much as they have for centuries.

Finally, Southern provinces of China share a lot of characteristics with Myanmar and other Southeast Asian countries.

C.1.2 Overview of the insect farming sector

China has a long history of using insects as food and as medicine - with evidence of this dating back over 2,000 years. In more recent times, this has now extended into the cultivation of insects for sources of input to agricultural and industrial production.

This diversity means that this short section will only provide a few highlights of the situation in China based on the author's network and experience.

C.1.3 Points of interest

C.1.3.1 Insects as food

China has many ethnic groups and living in different regions, which have distinguished eating habits . This diversity results in a great variety of insect varieties available to them, traditions and preferences in relation to eating insects. One can buy fresh insects, frozen, canned and dried insects in markets (Table C.1.1 provides some recent figures on their cost). The majority of edible insects are still primarily collected from nature. Given that harvesting from the wild has limitations and can lead to degradation of ecosystems, there are plenty of efforts to farm insects. Generally, the farming of insects for human consumption is on a small scale with undeveloped technologies (see Chapter 5).

Table C.1.1. Prices of edible insects available for purchase. (Source: Feng *et al.* 2019)

Name	**Fresh or dry weight**	**Yuan RMB / kg**	**MMK / kg**
Silkworm	fresh	25	5.090
Bamboo caterpillar	fresh	60 - 150	12.200 - 30.500
Bean hawkmoth	fresh	220 - 560	44.740 - 113.870
Mealworm	fresh	16 - 40	3.250 - 8.140
Diving beetle	fresh	180 - 560	36.600 - 113.870
Longhorn beetle	fresh	7.000	142.340
Bee	fresh	30 - 100	6.100 - 20.340

Wasp	fresh, with hive	100 - 400	20.340 - 81.400
Black ant	dry	160 - 260	32.540 - 52.870
Locust	fresh	40 - 120	8.140 - 24.400
Chinese cicada	fresh	130 - 140	26.440 - 30.300
Stink bug	fresh	300 - 500	61.000 - 101.670
Stink bug	dry	1.000 - 2.000	203.400 - 406.670
Dragonfly	fresh	80 - 180	16.270 - 36.600

We will not attempt to describe all the edible insect varieties that exist across China. Prof Feng at the Yunnan-based Resource Insects Research Institute has spent over 20 years investigating the variety of edible insects that exist in China and their nutritional properties and farming challenges. She has documented 324 species of edible insects in China and has collected nutritional data on 174 species. She published a book on Edible Insects in China in 2016 - only available in Chinese (Feng, Y., Chen, X.M. and Zhao, M., 2016. Edible insects of China. Science Press, Beijing, China.). With her colleagues, she has also published a recent review of edible insects in China in 2019[1].

We have drawn on this in Chapter 5 on the nutritional value of insects, to indicate which varieties are farmed in China and what is known about their nutritional qualities.

At present, there are no regulations specific to insect farming. Thus:

- Insect farming companies are only subject to the standard registration requirements for any agricultural business. Otherwise, farming can be done by families.
- So long as they only sell to “wet markets” there is no further expectation regarding quality standards, etc..
- There are also some insects available for sale on the Internet
- If insect materials are to be sold in supermarkets, the farmers must undergo standard training in farm management, risk management, hygiene, etc. Most do not choose to do this.
- As a result of the concern of wild creatures passing on diseases to humans in the context of wet markets, the Chinese Government introduced a blanket ban on the sale of anything from the wild but this has since been relaxed to exclude the sale of insects as insects cannot be carriers of diseases that affect humans.

C.1.3.2 Insects for animal/pet/livestock feed

There is a very substantial amount of industrial scale insect farming with companies targeting both the domestic and export markets.

- Thus, mealworms are extensively exported from China for use in pet food, fishing, livestock farming sectors around the world.
- There is growing interest in BSF farming with many different approaches being explored. Many of these focus on this as a means of turning organic waste into a valuable commodity, including some that offer the opportunity for households to

host small scale BSF growing kits, feeding them, on household waste and providing the resulting larvae back to the company.

- Large-scale housefly production system using chicken or pig manure as substrate is established in China to provide fresh maggots or maggot powder for feeding chickens and shrimps[2].

C.1.3.3 Insects for industrial processes

There is a sizeable industry in China producing biochemicals and some of these draw on farmed insects. The author has contacts in the gallic acid production sector. Gallic acid is a substance that has many uses with 97% of global production (8,500 tonnes/year) in China - Hubei province. Gallnut, produced by the gallnuts aphid parasitize on the Rhus chinensis Mill and Rhus potaninii Maxim trees. Rhus chinensis, the Chinese sumac, or nutgall tree, is a plant species in the genus Rhus. Figure C.1.2 shows the process of gallnut cultivation.

Figure C.1.2 - The process of cultivation for gallnuts. The photos show, from left to right, starting top left: the aphids, the moss that provides the bed for aphid growth, collecting aphids, locating the aphids in bags on the trees, the growing gallnut and mature gallnuts. (www.ccbiotech.com.cn)

Galls produced on these are a source of gallotannins. These soluble plant tannins have been used for centuries in traditional Chinese herbal medicine. It is currently widely recognised for its antioxidant properties and is widely used in food, feed, beverages and pharmaceuticals.

Endnotes

1. Feng, Y., Zhao, M., Ding, W.F. and Chen, X.M. (2019), Overview of edible insect resources and common species utilisation in China. Journal of Insects as Food and Feed, 1(1), pp. 1-13.

2. Zhu, F.X., Yao, Y.L., Wang, S.J., Du, R.G., Wang, W.P., Chen, X.Y., Hong, C.L., Qi, B., Xue, Z.Y. & Yang, H.Q. (2015) Housefly maggot-treated composting as sustainable option for pig manure management. Waste Management. 35.

C.2 Thailand

C.2.1 About the country

Thailand is a small country that borders with Myanmar and with which there is an extensive trade of insects - mainly into Thailand, we believe. Laos PDR, Myanmar, and Vietnam share common forest and watershed resources and people living in these countries have similar preferences regarding insect foods[1]. The study confirmed that 44 species of insects are eaten in northeastern Thailand alone.

Thailand has many similarities and yet has developed insect farming in a way that has not happened in Myanmar. The extent of insect eating may be partly explained by the conditions that make farming generally more challenging. Meticulous Research[2] suggests that consuming insects is greatest in the Northeast part of Thailand which is the poorest part and where crops/livestock are very hard to grow.

C.2.2 Overview of the insect farming sector

Thailand is the country with the most substantial insect farming sector, given its size, and this has been extensively studied. The book, "Six-legged livestock: edible insect farming, collecting and marketing in Thailand"[3], is a useful source of information about the scale and nature of the sector, being based on an extensive survey that was carried out at the time[1].

According to the book, the only insects farmed are crickets and palm weevil larvae:

- Cricket farming has gone on for 20 years, so is a relatively recent development given that eating insects has a much longer history. They estimate that there are around 20,000 cricket farms, which use much the same techniques as were used at the start but there has been considerable consolidation of the sector with the result that most farms are medium or large scale enterprises and there are community cooperatives of farmers for mutual support. Significantly, given the scale of insect farming operation, a large quantity of chicken feed is used to feed them - ie. they cannot be sustained on organic waste material alone.
- Palm weevil larvae farming is heavily dependent on the availability of the very particular food sources needed, such as sago palm trees and lu phru trees.
- Weaver ant colonies can be maintained within a farm and can be used for breeding to establish new colonies.
- Other insects are eaten in Thailand and Myanmar, but with no farming methods developed - bamboo caterpillars and grasshoppers are the most popular. Care is being taken to ensure that the harvesting is sustainable.

Insect farming businesses include some very large companies (Eco Insect Farming, Bugsolutely, Thailand Unique, Next Food, Sahakhun Bug Farm Ltd, and Global Bugs - Meticulous Research) that share production with local farms. In addition, most farms are still local farms from small to large scale. The Thai Government has encouraged the local farmers to join as a group such as community enterprises or cooperatives, by offering loans with low interest rates or grants for product development and marketing available to these. The government also encourages and supports insect farmers to do GAP (Good

Agricultural (insect Farming) Practice) to ensure food safety and farmers can register as a GAP farm.

According to a recent global market study of the edible insect market[2], the Thailand edible insects market has an annual average production of 7,500 tons/year, was valued at $94.6 million in 2018 and they project it to grow at a CAGR of 22.8% to reach $263.6 million by 2023.

C.2.3 Points of interest

Study of a cricket farm

Recent detailed analysis of a medium sized cricket farm[4] sheds valuable light on the production levels being achieved and the necessary inputs.

The paper presented a life cycle assessment performed on an existing production system of field cricket and house cricket in north-eastern Thailand. The report studied a medium-sized cricket farm with the following:

- 2,720 m^2 with 80 pens,
- Around 8 cycles a year - 40-50 day life cycle of the crickets
- Requiring 76.2 tonnes of insect feed (very similar to broiler feed containing fish meal, soybean meal, grain maize, palm oil, calcium carbonate and salt)
- 20.4 tonnes of pumpkins were added to the feed at the end of the crickets' life cycle to improve the colour of the cricket material
- Producing 36.7 tonnes of fresh insect material - Feed conversion ratio = 2.50
- Producing 26.5 tonnes of frass

The feed-biofertiliser conversion ratio differed by insect variety studied:

- Field cricket ratio was 38% (100 kg of feed generated 38kg of frass)
- House cricket ratio was 62%

They also analysed the Nitrogen, Phosphorus and Potassium content of the frass -Table C.2.1.

Table C.2.1 - quantity of minerals in farmed crickets.

Mineral	Gryllus bimaculatus	Acheta domesticus
Nitrogen	2.58%	2.27%
Phosphorus	1.55%	2.02%
Potassium	1.78%	2.26%
Calcium	38%	38%

Endnotes

1. Yhoung-Aree, J. & Viwatpanich, K. 2005. Edible insects in the Laos PDR, Myanmar, Thailand, and Vietnam. In M.G. Paoletti, ed. Ecological implications of minilivestock, pp. 415–440. New Hampshire, Science Publishers

2. Meticulous Research. (2019). Edible Insects Market - Global Opportunity Analysis and Industry Forecast (2019-2030). https://www.meticulousresearch.com/product/edible-insects-market-forecast/

3. Hanboonsong, Y., Jamjanya, T. & Durst, P. B. (2013) Six-legged livestock: edible insect farming, collection and marketing in Thailand. Bangkok: Food and Agriculture Organization of the United Nations. Available at: www.fao.org/contact-us/licencerequest (Accessed: 7 December 2020).

4. Halloran, A., Hanboonsong, Y., Roos, N. & Bruun, S. (2017) Life cycle assessment of cricket farming in north-eastern Thailand. Journal of Cleaner Production. 15683–94.

C.3 Ghana

C.3.1 About the country

Ghana is a sub-Saharan West African country situated on the Gulf of Guinea. Encompassing a land area equivalent to roughly half that of Myanmar, it has a population of approximately 31 million people. This figure is expected to double within the next century—an alarming prospect, as experts fear this will only exacerbate existing public health issues within the nation. Poverty and unemployment are already rampant in Ghana, resulting in an increasing lack of food security and proper sanitation for many people, especially in rural areas. Child malnutrition is of particular concern, with only 13% of infants aged 6 – 23 months meeting their minimum required nutritional intake[1], despite the large amount of food waste that occurs in Ghana's current agricultural system[2]. These issues are thought to mainly be a result of the overall demographic shift away from agriculture to service industries due to the limited opportunities provided by traditional rural occupations, which are inclusive of agriculture[3]. However, this movement of people into urban and peri-urban areas only contributes to the country's problems regarding sanitation and food security.

Resultantly, the creation of new industries for forms of sustainable agriculture in rural and semi-rural areas has been identified as one of the most promising ways to reduce poverty and unemployment, while also increasing food security for this growing nation.

C.3.2 Overview of the Insect farming sector

Ghana has been the focus of research into the viability of edible insect production systems in recent years. Results of various studies have shown that insect farming can potentially reduce nutritional gaps and bolster overall public health in Ghana by creating self-sustaining, circular economies that reduce poverty through community-based farming efforts. The success of these schemes is reflected in largely positive stakeholder attitudes in Ghana toward the production of edible insects for human use.

Insect husbandry, particularly farming of the palm weevil and BSF, has the potential to create jobs, recycle waste, and provide novel sources of highly nutritious protein for both animal feed and for direct consumption by humans, along with other potential benefits. The creation of a burgeoning Ghanaian insect husbandry industry has proven to be an effective method by which to begin to tackle the nation's issues regarding unemployment, malnutrition, and lack of sanitation.

The main lesson that can be learned from Ghana is that insect farming can be highly profitable in places where insect consumption is already common, and in developing countries where industry solutions can meet public health and agricultural needs.

C.3.3 Points of interest

Palm Weevil Farming

Insects are part of a traditional diet for many Ghanaian ethnic groups, particularly the palm weevil, which is consumed worldwide, including in South Asia[4]. The palm weevil is a highly nutritious insect, providing several essential macro and micro nutrients that are important for human health, particularly for children[5]. It is traditionally semi-domestically cultivated as a byproduct of palm wine production, as palm trees that are felled after tapping become infested by the insect. Palm weevil consumption has been reduced in recent years due to the overall reduction of profitability regarding palm wine, though it is still highly regarded as a delicacy among its traditional consumers, often even preferred over other forms of protein such as chicken[6]. Very little risk is associated with palm weevil consumption[5].

Created to meet demand among traditional consumers, palm weevil farming has become a lucrative industry in southern Ghana. Palm weevils can be farmed on the micro-scale, with single households able to grow a weevil crop with limited land and resources[7]. It has also proved profitable enough to be farmed on the semi-industrial scale, with one company in Ghana, AnePaare Farms, already in the business[8]. Since relatively little capital is needed to enter the business—possible zoning restrictions from landlords are considered to be a higher barrier of entry to the industry than lack of funds or training[6]—Ghanaian palm weevil farmers have been able to repay loans and earn a profit from palm weevil products within their first year of production[7].

Palm weevil farming has reduced poverty and improved living conditions in southern Ghana. It provides employment to women and other underemployed groups in Ghana, such as pensioners and those with a lack of formal education[7], and even improves waste streams, as changing the production substrate from traditional palm pith to brewery waste actually improves the nutritional content of the weevil. This also has an effect of improving the environmental impact of the industry by reducing the need to harvest palm trees[5].

BSF Farming

Several enterprises for the farming of BSF larvae have been established in Ghana in recent years, particularly Western-funded projects such as the work done by Swiss Programme for Global Issues for Development and the UK's ENTOPrise. Most investment has been focused on refining the effective conversion of food and other biowastes into frass for fertilizer, which can ensure higher food security through increased agricultural yields[9]. This also has the potential to improve sanitation in large urban areas like Accra, where people are eager to reduce the amount of open refuse in the streets[2]. Ghanaian farmers tend to prefer organic fertilizers over non-organic, and are receptive of fertilizers produced from BSF frass[10]. The BSF larvae themselves are converted into animal feed, which are readily purchased and used by Ghanaian farmers when available[10]. It is expected that the BSF farming industry will grow in conjunction with the Ghanaian aquaculture industry, as farmed fish are both a ready consumer of BSF feeds and a potential source of high quality substrate through their waste[11].

Considerations and Stakeholder Attitudes

Stakeholder attitudes toward the expansion of the insect farming industry are overwhelmingly positive. Many people in Ghana see insects as a way to meet nutritional needs, provide a source of income, increase other agricultural yields, and improve waste streams[2,10,11]. Farmers in particular are highly receptive to the use of insects for feed and fertilizer[10]. However, some reticence regarding incorporation of insects into diets has been recorded among certain subsets of the population, particularly where eating insects isn't traditional[6]. Despite this, barring aversion due to religious reasons, many people who are otherwise skeptical about insect consumption say that they would consider entomophagy if it was endorsed by health workers or the government or if insects were processed as otherwise unrecognizable food additives[6], the latter of which would provide another opportunity for industry growth.

Endnotes

1. Ghana Statistical Service Accra. (2015). Ghana Demographic and Health Survey 2014. www.DHSprogram.com.

2. Popoff, M. (2016). Stakeholder's Attitudes Towards the Use of Insect-Derived Materials in Animal Feeds and Bio-fertilizers (Issue 1).

3. Plecher, H. (2018, May 14). Ghana - Statistics & Facts. Statista. https://www.statista.com/topics/3029/ghana/

4. Anankware, J. P., Fening, K., & Obeng-Ofori, D. (2015). Insects as food and feed: A Review. International Journal of Agricultural Research and Review, 3(1), 143–151. https://www.researchgate.net/publication/270815558

5. Parker, M. E., Zobrist, S., Lutterodt, H. E., Asiedu, C. R., Donahue, C., Edick, C., Mansen, K., Pelto, G., Milani, P., Soor, S., Laar, A., & Engmann, C. M. (2020). Evaluating the nutritional content of an insect-fortified food for the child complementary diet in Ghana. BMC Nutrition, 6(1), 1–11. https://doi.org/10.1186/s40795-020-0331-6

6. Laar, A., Kotoh, A., Parker, M., Milani, P., Tawiah, C., Soor, S., Anankware, J. P., Kalra, N., Manu, G., Tandoh, A., Zobrist, S., Engmann, C., & Pelto, G. (2017). An Exploration of Edible Palm Weevil Larvae (Akokono) as a Source of Nutrition and Livelihood: Perspectives From Ghanaian Stakeholders. Food and Nutrition Bulletin, 38(4), 455–467. https://doi.org/10.1177/0379572117723396

7. N Commander, T., Anankware, J. P., Royal, O. O., & Obeng-Ofori, D. (2019). Econometrics of Domestication of the African Palm Weevil (Rhynchophorus phoenicis F.) Production as Small-Scale Business in Ghana. In Edible Insects. https://doi.org/10.5772/intechopen.90259

8. Debrah, S. K., Kyerematen, R., & Afreh-Nuamah, K. (2019). African palm weevil, Rhynchophorous phoenicis Fabricius (Coleoptera: Curculionidae): An alternative mini livestock in Southern Ghana. In International Journal of Novel Research in Life Sciences (Vol. 6). https://www.unicef.org/

9. Quilliam, R. S., Nuku-Adeku, C., Maquart, P., Little, D., Newton, R., & Murray, F. (2020). Integrating insect frass biofertilisers into sustainable peri-urban agro-food systems. Journal of Insects as Food and Feed, 6(3), 315–322. https://doi.org/10.3920/jiff2019.0049

10. Popoff, M. (2016). Smallholder Farmers Attitudes Towards Insect-Based Feed and Bio-Fertilizers (Issue 2).

11. Popoff, M. (2016). Transforming Waste Streams Into Animal Feed And Bio-Fertilizers: Identifying Waste-Handlers and Quantifying Waste (Issue 3)

C.4 United Kingdom

C.4.1 About the country

The UK has a highly developed economy set in a group of densely populated small islands off the coast of Northern Europe. Scotland, the northernmost of the four nations that make up the UK, has a very extensive aquaculture sector. Salmon is Scotland's largest food export and the worldwide retail value of Scottish farmed salmon is over £1 billion[1]. The Scottish fish farming sector pays the highest feed costs among the top 4 salmon farming nations, consuming an estimated 238kt of feed annually[2]. Soy makes up around 10% of salmon feeds with the result that Scotland imports a great deal of Soy from Latin America[3].

Potentially significantly, the UK is about to leave the European Union at the beginning of 2021 and this will enable the Government to develop legislation independent of the European Commission. As a result, there is considerable interest in areas where some relaxation of Regulations could be beneficial.

Aside from that, agriculture and oil extraction, Scotland is looking to diversify its economy and has established Zero Waste Scotland to identify and support new business opportunities that make use of biproducts from existing industry or agriculture. They have carried out a series of studies into the potential for insect farming to become established to provide more locally produced feed for the fish farming and create jobs and economic value domestically and are actively promoting the potential role locally farmed insects could have in the economy.

C.4.2 Overview of the insect farming sector

The UK currently has only 12 insect farms aimed at food or livestock feed (Figure C.4.1) but there are a range of businesses that are developing based around the sector. The largest sub-sector are companies working on insect farming technology.

C.4.3 Points of interest

The Government and its Innovation Agency, InnovateUK has been increasingly supportive of the sector in recent years and has funded a number of research and technology development projects and companies. According to Gateway to Research, UK research and innovation funding supported 11 projects with "insect protein" in the title or abstract - building the strength in UK insect farming technology. The largest programme was the EU funded and UK-led ProteINSECT programme.

The UK Government's Food and Drink Sector Council has established a number of expert/stakeholder groups to investigate the potential of a range of selected areas that have significant potential for increasing productivity of UK agriculture. One of these was focused on Insect Biomass Conversion. As well as some leading insect farming companies and research institutions, the group includes Zero Waste Scotland, British Poultry Council, Tesco, McDonalds, National Farmers Union, and some feed companies.

In 2020, the World Wildlife Fund and Tescos have jointly sponsored the development of a roadmap to test the feasibility of and identify how to scale up production of insect farming for livestock feed in the UK and we have been invited to comment on a recent draft.

Figure C.4.1: The Woven Network's Entomap. Source: Woven Network.

The edible insects sector is less substantial due to the lack of familiar insect-based food products, the relatively high cost of products that do contain insects and their limited availability in the UK. There has also been a long-running tension between this sector and the TV series: I'm a Celebrity Get me Out of Here. This involves contestants being faced with a number of extreme challenges and eating insects is usually part of this, reinforcing the public perception that eating insects is abnormal and unpleasant. One company secured the license to sell insect products carrying this branding but, again, it focused on the "yuck factor" and the idea that eating insects is a "Dare".

The Woven Network has been a vocal spokesperson for the sector, giving talks, arranging demonstrations and presenting to the UK Parliament, Chatham House and in Brussels. We have kept in touch with the evolving sector over the years and there are some notable successes developing and promoting insects within mainstream food products and dishes.

Endnotes

1. Glencross, B. (2016) 'A Vision for Avian Proteins in Salmon Feeds in Scotland', in 70th Meeting of the Advisory Committee on Animal Feedingstuffs. [Online]. 2016 University of Stirling.

2. Riera, A. & Lenaghan, M. (2017) Black Soldier Fly – A Circular Economy Solution for Scotland. (1).

3. Newton, R. (n.d.) The global protein gap: Food, feed, and what it means for Scotland.

Links for further reading:

Zero Waste Scotland - https://www.zerowastescotland.org.uk

ZWS Press Release - https://www.zerowastescotland.org.uk/press-release/scots-invited-get-buzz-insect-farming-introductory-events-zero-waste-scotland

Gateway to Research - https://gtr.ukri.org

ProteINSECT Programme - http://www.proteinsect.eu

FERA Insect Biomass Conversion Task & Finish Group FAQ - https://www.fera.co.uk/media/wysiwyg/our-science/FAQs_on_Insect_Biomass_Conversion.pdf

Youtube video illustrating “yuck” factor of eating insects (Available only in the UK) - https://www.youtube.com/watch?v=UExs6ILnkx4

Example of product branding - https://www.amazon.co.uk/Tobar-Tucker-Trial-Challenge-Packets/dp/B074N2VQD3

C.5 Kenya

C.5.1 About the country

Like Myanmar, Kenya is a nation in transition. Situated in Sub-Saharan east Africa, Kenya's economy is rapidly advancing in the wake of political reforms enacted within the last decade. It is largely dominated by agriculture, with livestock production accounting for nearly 12% of its GDP[1], though its aquaculture sector is somewhat underdeveloped, accounting for only 0.5% of GDP[2]. Even so, Kenya is a net exporter of fish, particularly Nile perch, and there has been substantial development of its freshwater aquaculture sector since 2000—a figure that is only expected to rise as the government continues to try and promote the development of the industry.

Like many other parts of the developing world, policymakers in Kenya are turning toward the development of new sustainable agricultural methods and industries as a method of job creation and ensuring food security. Climate change is forecasted to hit Sub-Saharan Africa especially hard, which risks disruption to Kenya's incredibly important agricultural sector and has incentivized researchers to explore more resilient methods of food production.

C.5.2 *Overview of the insect farming sector*

As a result of these concerns about sustainability, Kenyans have taken up insect farming for food and feed with considerable enthusiasm. This phenomenon is bolstered by the fact that insects are a part of many traditional diets among many different Kenyan ethnic groups, and many experts believe that the nutrition provided by insects could be a good way to bridge gaps in food security among the rural Kenyan populace[3]. Currently, there are seventeen main insect species that have been recorded as commonly consumed in Kenya for food and feed[3]:

- Desert locust
- Longhorn grasshopper
- Grasshopper
- Field Cricket
- House Cricket
- Termite
- Honey Bee
- Black Ant
- Cabbage Tree Emperor Moth
- BSF

A pilot study by INSFEED demonstrated the viability of a insect-based feed market in Kenya in 2014, but the actual recent establishment of the insect farming sector in Kenya is largely in part to research and outreach implemented by Copenhagen-based GREEiNSECT, a research consortium that is made up of academics and industry professionals from both Europe and Kenya. As of 2020, the world's first standards for commercial insect production for food, ingredients, and feed are currently being drafted in Kenya. House cricket, field cricket, and BSF currently comprise the main species for commercial insect rearing for food and feed in Kenya[4]. Crickets are widely eaten by people for protein, while BSF is almost exclusively raised for animal feed as an alternative to soy-based feed and fishmeal.

C.5.3 *Points of Interest*

Cricket Farming

Species of crickets that are currently being reared on the commercial scale in Kenya comprise the common house cricket and the field cricket. While the field cricket is larger in size and faster growing, house cricket rearing has proved to be slightly more economical on medium-to-large scales due to the fact that house crickets tend to be more resilient and adaptable to changes in environmental conditions and rearing on different types of substrates[4].

BSF Farming

BSF rearing is of particular interest in Kenya due to its ability to act as a feed for the poultry and growing aquaculture industries. Of the species that were piloted for large scale rearing in Kenya, BSF proved to be the most economical and the most profitable after economic analysis[5]. BSF feed is able to replace conventional feed in poultry up to 100%, providing a substantial reduction in price regarding protein conversion ratios[5]. This was found to be particularly agreeable to households that are headed largely by women, as they are more likely to buy market animal feed than mixing their own. BSF as a more economical source of animal feed could then prove to be a tool for women's empowerment in the region. Nairobi-based Insectipro has created a successful business turning municipal organic waste into BSF protein for feed. They have trained over 2000 farmers in Kenya, and as of September 2020, product demand has outstripped its capacity to produce with its current drying equipment[6]. There is also interest in using BSF chitin produced by Insectipro, a byproduct of the rear ing process, for pharmaceutical use.

Endnotes

1. Kenya Markets Trust. (2020). *Our Focus on Livestock*. https://www.kenyamarkets.org/our-focus-on-livestock/

2. Food and Agriculture Organization of the United Nations. (2015, February). *Fishery and Aquaculture Country Profiles - The Republic of Kenya*. FAO. http://www.fao.org/fishery/facp/KEN/en

3. Münke-svendsen, C., Ekesi, S., Kinyuru, J., Ayieko, M., Makkar, H., Halloran, A., & Roos, N. (2016). *Technical brief # 1: Insects as food and feed in Kenya – past , current and future perspectives*.

4. Orinda, M., Magara, H., Ayieko, M., Nyakeri, E., Munke-Svendsen, C., Halloran, A., & Roos, N. (2017). *Technical brief #2: Insect production systems for food and feed in Kenya*. http://greeinsect.ku.dk/news/greeinsect-technical-brief-2 farming/GREEiNSECT_Technical_Brief__2_Farming_Systems.pdf

5. Komi, F., & Nakimbugwe, D. (2017). *Integrating insects in poultry and fish feed in Kenya and Uganda*.

6. Reuters. (2020, September 23). Kenya harnesses fly larvae's appetite to process food waste. *New York Post*. https://nypost.com/2020/09/23/kenya-harnesses-fly-larvaes-appetite-to-process-food-waste/

Links for further reading:

INSFEED - http://www.icipe.org/research/plant-health/insect-food-and-feed/projects/insfeed-insect-feed-poultry-and-fish-production

GREEiNSECT - https://greeinsect.ku.dk/

Kenyan Draft Standards for Farmed Insect Production - https://www.kebs.org/images/standards/public_review_standards/2020/June/DKS_2921_Code_of_Practice_PR.pdf

Insectipro - https://www.insectipro.com/

Chapter 9 – Conclusion and Recommendations

There are a great many reasons why a country such as Myanmar should develop an insect farming sector. Many other countries have seen the potential to grow viable businesses, support local and global livestock farming through provision of high quality feed, reduce the carbon footprint associated with alternatives sources of protein and open up new, highly nutritious sources of protein for all.

Based on our studies and observations from around the world, we believe that, with the right support and regulations, Myanmar could develop a thriving insect farming sector that should contribute substantially to the health and economic well-being of your population while also reducing the risks of damage to your ecosystem from excessive harvesting of wild insects.

Recommendations

We offer the following recommendations regarding the development of insect farming in Myanmar based on the information outlined in this report. Based on current knowledge, it can be concluded that insects have the potential to be a sustainable, highly nutritious source of protein for both human and animal consumption. Industry entry is often highly accessible, requiring relatively little initial investment of capital when compared to other agricultural industries. Insects also provide a method with which to reduce waste and efficiently recycle nutrients back into food production while also promoting public health, making insect husbandry highly suitable for developing countries such as Myanmar.

Overall recommendation for going forward:

Based on our observations of other countries developing insect farming sectors, we see the following as the key areas for consideration:

- Is there scope for farmed insects to bring benefits for livestock feed?
- Is there scope for farmed insects to bring benefits for human consumption?
- Which insect species are the best suited to either/both of these?
- What are the main challenges that will need to be overcome to establish viable insect farming operations within the context?
- What are the main risks that should be managed?
- What mix of peer-to-peer networks/training/briefing/inspection/regulations are most likely to be appropriate?
- What sources of wider expertise and learning could be sought from outside of the country?

As such, we conclude that there is great potential for building an insect farming sector for both human food and animal feed in Myanmar as a part of its sustainable development strategy. We recommend that careful consideration is given to the above questions in planning the way forward.

Considering this, we present the following recommendations regarding insect farming in Myanmar, if development should so occur:

1) BSF and yellow mealworm should form the basis of an insect animal feed industry. Given available information, these species would prove to be the most effective species to farm on a large scale, as they have both proven to be effective in the rearing of terrestrial livestock and many important aquaculture species produced in Myanmar’s ever growing aquaculture sector.

BSF has proven to be effective in the rearing of aquaculture fish with partial replacement of conventional feed, providing high quality protein that encourages the growth of more nutritional fish protein at higher rates. Yellow mealworm could prove particularly useful in both the small-scale and industrial rearing of poultry, as mealworms have proven to be beneficial to both animal health and growth rate. Insect rearing industries in both Kenya and Ghana could prove to be useful examples for the development of a sector in Myanmar, especially on smaller scales.

2) Crickets, grasshoppers, and palm weevil have the potential to be good fits for the Myanmar food market. Crickets and grasshoppers have proven to have high farming potential, and there is reason to believe that there would be an active consumer base among the Myanmar populace. China and Thailand in particular provide ready examples of how these insects can be farmed at scale. Palm weevil, which is indigenous to the area, could also prove to be a ready source of sustainable protein for human consumption for Myanmar, as it is already consumed intermittently among various ethnic groups in Southeast Asia. It is regularly consumed in Ghana, where it is also native, and rearing of the insect has spawned a successful cottage industry there.

3) To head off possible issues regarding environmental regulations and reduce the risk of introducing potentially invasive species, there should be a particular focus on rearing insects that are native or indigenous to the region. Crickets, grasshoppers, and palm weevil are native to the region. While BSF is a cosmopolitan insect with a presence in the region, yellow mealworm is not native to Myanmar. However, there are many resources regarding guidance for setting up farming systems for both of these insects, as they are already widely farmed; this makes it easy to reduce the risk of accidental invasion. The fact that there is existing guidance for these systems will provide a good foundation for managing inputs and effectively regulating the industry to produce a safe and quality product.

4) As for general industry development, we recommend that potential investors contact existing industrial-scale producers and gauge their willingness to explore Myanmar as a potential new market. However, before this process begins in earnest, we recommend initial investment into pilot products in order to be able to predict the possible idiosyncrasies inherent in the Myanmar production climate. These would include investigation into waste streams, logistics, and local storage solutions.

5) Further research into different farming methods may be needed for some insects, along with the development of general standards for employee training, quality control, and product inspection. This could be achieved through the development of networks and associations of different stakeholders in the insect farming industry, in order to learn together and support one another as the industry grows. The Chinese insect farming industry could provide a wealth of information for further development in Myanmar.

6) The creation of an industry “roadmap” based off of further investigation from such sources and the research presented in this report would prove exceedingly useful in laying out the possible development of the Myanmar industry, and provide ready information for potential investors.

And finally…

We strongly applaud the work Spectrum has already done to gather evidence of the situation regarding insect consumption and farming practices and to work with a wide range of stakeholders to build a consensus around a way forward.

You are on a journey towards an exciting future and learning from evidence and practice around the world will be critical to enabling you to accelerate this and build on others' experience and research.

We hope to be able to continue to play a role in this and wish you well.