Chapter

The Potential of Insect Farming to Increase Food Security

Flora Dickie, Monami Miyamoto and C. Matilda (Tilly) Collins

Abstract

Insect protein production through 'mini-livestock farming' has enormous potential to reduce the level of undernutrition in critical areas across the world. Sustainable insect farming could contribute substantially to increased food security, most especially in areas susceptible to environmental stochasticity. Entomophagy has long been acknowledged as an underutilised strategy to address issues of food security. This chapter reviews and provides a synthesis of the literature surrounding the potential of insect farming to alleviate food security while promoting food sovereignty and integrating social acceptability. These are immediate and current problems of food security and nutrition that must be solved to meet the UNDP Sustainable Development Goals.

Keywords: climate change, sustainability, entomophagy, insectivory, acceptance

1. Introduction

Entomophagy is prevalent in many regions, and ~1500–2000 species of insects and other invertebrates are consumed by 3000 ethnic groups across 113 countries in Asia, Australia and Central and South America [1]. Africa, where more than 500 species are consumed daily, is a hotspot of edible insect biodiversity [2, 3]. In Thailand, entomophagy has spread to the south from the north-east as people migrate towards city centres. It has become so popular that >150 species are sold in the markets of Bangkok [4]. The most common edible insects are moths, cicadas, beetles, mealworms, flies, grasshoppers and ants [5]. Although human insectivory is an ancient practice and 80% of the world's population consumes insects, it is relatively uncommon in contemporary Western culture. In many regions that have traditionally eaten insects, the practice is declining due to globalisation, and their consumption has decreased over the last decade as agriculture and living standards change, and the availability of wild-caught insects has decreased [6–8].

This chapter reviews and provides an accessible synthesis of the literature surrounding the potential of insects to alleviate food security while promoting food sovereignty and integrating social acceptability. These are immediate and current problems of food security and nutrition that must be solved to meet the Sustainable Development Goals [3, 9].

2. Food insecurity

Food insecurity is created when food is unavailable, unaffordable, unevenly distributed or unsafe to eat. Inefficiencies in the current food production system generate inconsistencies between the demand and supply of food resources, which is exacerbated by the diminution of pastures and increasing demand for food. Thirty percent of land is already used for agriculture, but 70% of this is used for macro-livestock production, an industry which consumes 77 million tonnes of plant protein only to produce 58 million tonnes of animal protein per year. This animal protein is not evenly distributed across the globe, as the average person in a 'developed' country consumes 40 g more protein a day than the average person in a 'developing' country [10]. The demand for affordable and sustainable protein is high, while animal protein is becoming more expensive and less accessible in some regions, especially in Africa [11].

To ensure food access and to alleviate poverty, there is a particular need for investment into Africa's agricultural potential as this continent will soon account for 50% of the world's population growth. Currently, Africa has 25% of all undernourished people worldwide, and the income gap between rural and urban areas drives rapid urbanisation; this is decreasing the agricultural workforce [12, 13]. With substantial food insecurity and rising food prices, one in six people dies from malnutrition and hunger, and more than 1 billion people are undernourished, triggering 1/3 of the child disease burden [10, 14]. Effects are worse in the populations that already have high rates of malnutrition, such as Zambia, where chronic undernutrition is 45% and causes 52% of deaths in the population under the age of 5. Over 800 million people are thought to have a food energy deficit average of >80 kcal/day/person [3, 15].

The prospect of global food shortage grows as the world's population is estimated to increase to 9 billion by 2050. The conventional meat production system will not be able to respond sufficiently to the increase in demand. *Per capita*, meat consumption is expected to increase by 9% in high-income countries by 2030, and the increase in world crop prices will increase the price of meat by 18–21% [16]. Systems with a low carbon footprint must be promoted according to the economic and cultural restraints of the region by modifying animal feed from soy meal to locally sourced feed [17]. Any expansion of agricultural land must be mitigated to reduce losses in natural ecosystems. Therefore, our increasing population will need to be fed from the same area of land available now [18].

Climate change is also a growing threat to global food security as this is reducing the area of land available to agriculture [10], and future cereal yields are predicted to decrease, especially in low-latitude areas. The poorest countries will suffer the worst consequences of climate change, which will increase both malnutrition and poverty. To prevent future undernutrition and to decrease current levels, food access and socioeconomic conditions must improve globally [14]. With this climate change-driven prediction of reduced agricultural yields in most countries given current crop practices and varieties, it is therefore necessary to increase the diversity and sustainability of crop supply so that food insecurity is not exacerbated [15].

3. Nutritional potential of edible insects

In general, insects have a higher quality of nutrition than macro-livestock in terms of protein, lipids, carbohydrates and vitamins [10]. Insects have high crude protein levels of 40–75%, contain all essential amino acids, are rich in fatty acids and have a high proportion of dietary fibre, and it has been further suggested that there are health benefits from eating chitin through enhancement of gut flora and antibiotic properties, though it is not known how insect fibre specifically affects human health [19].

In a study of the calorific value of 94 insect species, 50% were higher than soybeans, 87% higher than maize, 63% higher than beef and 70% higher than fish [10]. The composition of omega-3 and omega-6 fatty acids in mealworms is comparable to that of fish, and other insects with ideal fatty acid ratios are house crickets, short-tailed crickets, Bombay locusts and scarab beetles [20]. Some insect species have micronutrients not found in some conventional animal proteins, such as riboflavin in termites and high concentrations of thiamine in silk moth larvae (224.7% daily human requirement) and palm weevils (201.3%) compared to chicken (5.4%). Mealworms have a higher content of protein (all essential amino acids), calcium, vitamin C, thiamine, vitamin A and riboflavin per kg than beef. Although the nutritional content of many insects is well-described in the literature, there is a variation depending on diet, sex, life stage, origin and environmental factors, and the realised nutritional content also depends on preparation and cooking [21–23].

Insect consumption has the potential to reduce hunger on a global scale as they are nutrient dense as well as calorie dense. A calorie deficit of 1500 kcal/day could be addressed by rearing 1 kg/day of crickets in 10 m^2 while also providing the recommended daily amount of lysine, methionine, cysteine, tryptophan, zinc and vitamin B_{12}. Not only do insects provide calories and nutrients, but they are also cost-effective, easily grown and can be environmentally sustainable when incorporated into a circular production system using organic side streams.

4. The rise of insect farming

Until the end of the twentieth century, the most common way to collect insects worldwide was by wild harvest (circa 90%), and the tradition of collecting and eating insects from the wild is seen in many cultures. Though seasonality limits consistent availability, traditional regulation patterns can mitigate this and maintain locally sustainable sources [24, 25]. Wild catch is declining in many areas with many factors contributing to this including land conversion, overexploitation and urbanisation [7]. With insects acknowledged to be key to the delivery of many ecosystem services, their conservation in natural ecosystems is now paramount [26, 27]. In response, the farming of edible insects is now rising from being only a minor component of the market and should be promoted to improve quality and supply as well as to limit the environmental impacts of wild harvesting [11, 28].

No matter the scale of insect farming, the economic benefits boost food security in terms of availability and accessibility and at the same time improve dietary quality and contribute to both gender equity and livelihoods. At the community scale, more than 20,000 small farmers in Thailand profitably produce crickets; in Laos, the majority of insect vendors are illiterate females who may earn c$5/day; in Uganda and Kenya, the Flying Food Project supports expansion of small-scale farms into local and greater value chain markets [20, 29, 30]. By integrating mini-livestock farming into current agricultural systems, the access to edible insects could be improved and simultaneously provide co-benefits such as female employment and a high-grade compost contribution to the enhancement of soil fertility [28]. Harvesting insects as a by-product of another industry also has substantial potential but needs more widespread implementation and cultural assimilation. For example, domesticated silkworms for the textile industry can be eaten in the

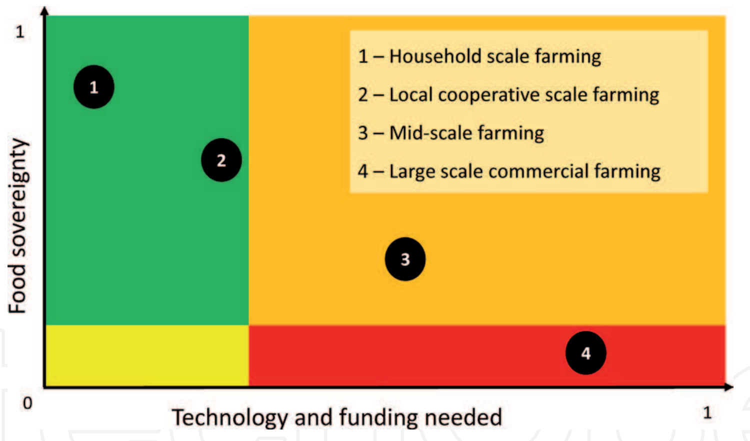

Figure 1.
Trade-offs in the scale of production needed to maximise food sovereignty relative to the technology and initial funding needed. X axis: 0 = none needed, 1 = high setup costs needed. Y axis: 0 = no food sovereignty, 1 = complete food sovereignty.

pupa stage, and palm weevils reared on felled palm trees could be moved into more formal production [15]. Insect farming is now moving into western markets and developing technologically refined production systems. The French company Ynsect has raised $175 M for expansion, and the USA edible insect market is predicted to increase by 43% in the coming 5 years [31, 32]. There are different costs and benefits at all scales (**Figure 1**), though all may have an important place in future food security.

5. The environmental advantage of insect farming

In general, insects have a lower consumption of energy and resources than conventional animal livestock. Insects are poikilothermic, so they expend less energy, are more efficient in transforming phytomass into zoomass and have higher fecundity and growth rates and a higher rate of matter assimilation. On average, an insect only needs 2 g of food per gramme of weight gained, whereas a cow needs 8 g of food. Not only is the efficiency of insect production higher because of the feed conversion ratio (**Table 1**) but also because the edible portion of insects is higher as crickets can be eaten whole, but we only eat 40% of a cow, 58% of a chicken and 55% of a pig [8, 10, 33].

Edible insects are an environmentally attractive alternative to conventional livestock because they require less feed and water; they produce lower levels of greenhouse gases and can be raised in small spaces. Worldwide, livestock contributes to 18% of greenhouse gas emissions, which, in light of global warming and climate change, favours the less resource-intensive insect production which emits fewer greenhouse gases by a factor of 100 [3, 28].

Insects can be a renewable food source in the future as many edible species can consume agricultural and food waste or culinary by-products, but there remain important research gaps in understanding the effects of variable feedstocks as most case studies use high-grade feed [10, 15, 28]. Such organic side streams could be used to reduce the environmental impact of insect farming while simultaneously creating a novel, circular waste-processing income. Throughout the world, 1/3 of all food is wasted, and household food waste is 70% of the post-farm total. If food waste was its own country, it would be the third largest emitter of greenhouse gases after the USA and China [30]. Food waste is expected to increase in the future

	Cricket	Poultry	Pork	Beef
Feed conversion ratio (kg feed: kg live weight)	1.7	2.5	5	10
Edible portion (%)	80	55	55	40
Feed (kg: kg edible weight)	2.1	4.5	9.1	25

Table 1.
Efficiencies of production of conventional meat and crickets [17].

with a continually growing and increasingly urbanised global population adopting 'modern' lifestyles.

It is challenging and wasteful to commercialise traditional composting of multiple waste streams on a large scale, but waste can be fed directly to insects to convert low-value biomass into higher-value insect mass. By valorising waste as feed, it may mitigate the impact of the food industry. Some fly (Diptera) species are known to be able to convert agricultural manure into body mass and reduce the waste dry matter by 58%. For food waste the conversion is as high as 95% leaving the remainder as a high-grade soil improver [30, 33].

6. Acceptability of eating insects as animal protein

The feasibility of promoting edible insect farming as sustainable protein depends on social acceptance, as the benefits cannot be realised if people do not choose to eat insects. The understanding of current perceptions, which often depend on class, location, gender and age, is essential to any market development. In some locations, newly urbanised citizens view insects as pests or as poor person's food [7]. Although in this particular case, acceptance does depend on the insect itself, as there is an inferiority complex associated with wild harvesting of insects. In the Western world, insects are largely unfamiliar and mostly viewed as holiday novelty or 'yuk'; thus, awareness of local taboos, cultural preferences and the population's exposure to insects as food are crucial for the successful promotion of insect farming for food [3, 15, 34].

In many urban and developed populations, a central issue is food neophobia, but after taking the first step in trying an insect, continued exposure correlates with increased acceptance. Processed insect products such as cookies, snack bars or powders further normalise the protein source [34, 35]. Conventional meat has a special status in society, both culturally and structurally in meals, so a sustainable culinary culture must be promoted in order to associate insect protein with pleasurable food [17].

There are also risk considerations with the dissemination of novel foods and novel production pathways. Possible effects of prolonged insect consumption are nutrient malabsorption, growth alteration, allergy risk and contamination, and more research is needed into the digestion and absorption of insects in the human body [36]. Intensive insect farming runs risks of microbial infestation, parasites and pesticides. Preventative approaches, such as probiotics, transgenerational immune priming or heat treatment, and measured responses such as those advocated by Integrated Crop Management (ICM) will develop with the industry [20, 37]. There are other limitations in the lack of protocols in storage and decontamination, and although international regulation is underway, these ancient foods are currently classified the EU as novel foods [38].

7. Conclusion

The issue of food security is multi-faceted, and each country's solution will be different. Tackling food security requires responses that are both innovative and culturally appropriate. Farming insect livestock has the potential to alleviate food insecurity while promoting food sovereignty, especially if it is integrated with social acceptability in mind. Engagement of all stakeholders on the production and consumption sides and continued support for and from them will be vital for the success of its implementation. Commercial farming is growing across Europe and the North American continent, though a question yet to be answered at a wider scale is how edible insect farming can be increased and deployed in a way that benefits all parties, including especially the most vulnerable. We have overviewed the field and hope that this synthesis of much important work along with the exemplar production model of **Figure 2** can provide encouragement and compact information to those seeking to evaluate the future of farmed insect production.

There is currently too little research available on the integration of insect farming with existing agricultural systems, and future solutions require the coordination of international, national and legal frameworks. With this in place, the future food revolution will be more able to directly benefit the poor and be environmentally sustainable [39].

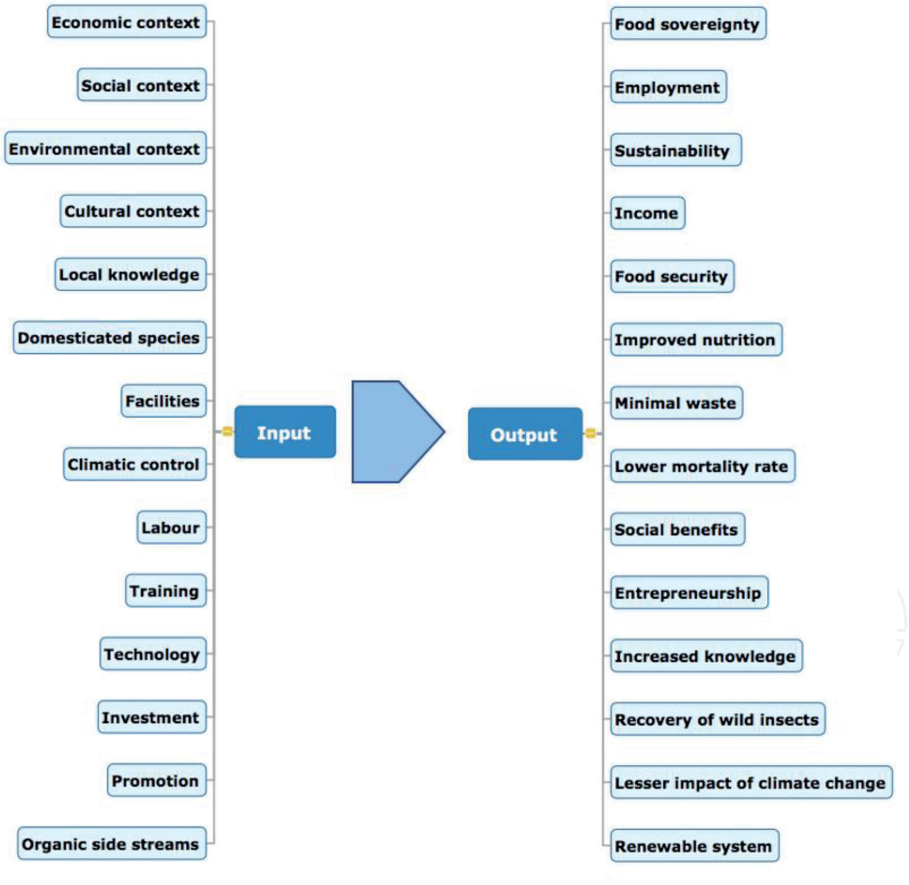

Figure 2.
Idealised schematic of the inputs and outputs of a sustainable production model for insect farming.

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Conflict of interest

The authors declare no conflict of interest.

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