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Insects for sustainable animal feed: inclusive business models involving smallholder farmers

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Global population growth, an increasing demand for animal products and scarcity of conventional feed ingredients drive the search for alternative protein sources for animal feed. Extensive research indicates that insects provide good opportunities as a sustainable, high quality and low-cost component of animal feed. Here, we discuss how insect farming can promote inclusive business for smallholder farmers in the agribusiness value chain. Inclusive business models involving insects as ingredients in feed may contribute to solving socio-economic and environmental problems in developing countries, aligning with the United Nations' Sustainable Development Goals. With low initial capital investments, smallholder insect farmers have good opportunities to increase productivity, improve their livelihood and contribute to food security and a circular economy.

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Introduction

While smallholder farmers are responsible for the basis of global food production [1••], those in low income communities do not necessarily benefit by gaining access to commercial value chains. Integrating smallholder farmers in a circular economy and thus making them stakeholders in the agribusiness value chain can help to improve their quality of life in a sustainable way. Developing this through inclusive business (IB) models [2,3••] will empower smallholder farmers, and promote their financial viability as well as environmental sustainability.

In the developing world, particularly in Africa where most of the human population increase is expected to occur, economic growth and changing dietary patterns will account for a 70% increase in the demand for livestock products by 2050 [4,5]. Feed costs represent 60–70% of total costs of livestock production [6]. Important protein sources in feed are soybean meal whose use competes with food production, and fishmeal whose availability is increasingly limited because of marine overexploitation [7,8]. Costs of these feed ingredients rapidly increase, especially affecting resource-poor farmers. The search for sustainable alternatives has led to a growing interest in insects as feed component [6].

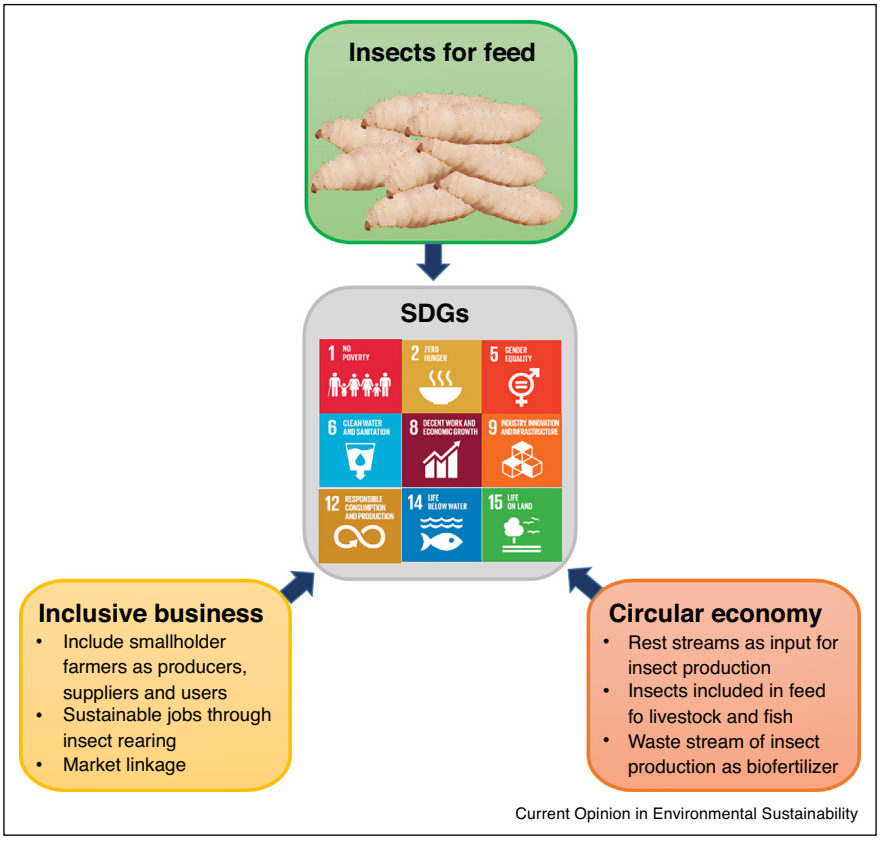
Insects contain high levels of protein and their production has a small ecological footprint [9]. Among the insect species that are mass reared, the black soldier fly (BSF) *Hermetia illucens*, house fly (HF) *Musca domestica* and yellow mealworm *Tenebrio molitor* have received considerable attention because they can feed on different substrates including organic waste streams [10,11]. The ability of these insects to convert organic waste into high-quality nutrients has rapidly opened innovative economic prospects. These include insect-based protein as an alternative to fishmeal or soybean meal for pig [12], poultry [13••] and fish [14] feeds. BSF and HF larvae are currently reared exclusively as feed ingredients [6,15].

This review focusses on how the value of insects as feed component can contribute to improving livelihood of smallholder farmers through IB models and reshaping food systems into efficient, climate resilient and nutrition-driven elements of a circular economy. In doing so, we will emphasise how and why IB models in this area align with the Sustainable Development Goals (SDGs) (Figure 1).

Insects as feed

Recent studies indicate that insect meal can be an excellent replacement of fishmeal or soybean meal in animal feed [6,12,13••,14,15]. Insects are rich sources of macronutrients and micronutrients [9,16]. BSF larvae, for example, contain high levels of protein (37–63%) and fat (20–40%) that have well-balanced amino acid and fatty acid profiles, respectively [17,18]. Insects are good sources of minerals, such as

Figure 1



Sustainable production of insects, their use in animal feed, contribution to a circular economy and applying inclusive business models involving smallholder farmers contribute to achieving the Sustainable Development Goals (SDGs) 1, 2, 5, 6, 8, 9, 12, 14 and 15.

calcium, iron, potassium, magnesium, phosphorus and zinc as well as vitamins including niacin, vitamin B12, thiamine and riboflavin [19,20].

When BSF larval meal replaced soybean and fishmeal in proportions of 10–56%, broiler quails and chickens had satisfactory taste, aroma and nutritional composition of the meat, confirming that BSF larval meal is suitable for inclusion in poultry diets [13••,21]. Insects have also been implemented as fish feed: nursing Nile tilapia fingerlings with different levels of fishmeal replacement by BSF meal resulted in similar growth performance and feed conversion [22]. Piglets fed diets with 5–10% levels of BSF larval meal exhibited satisfactory growth performance, with minimal effects on blood profiles [12]. Also, at higher inclusion levels, performance similar to the use of conventional feed has been recorded [23]. Overall, research indicates that BSF larval meal is a suitable component of animal feed [12,13••,14,15].

Organic waste reduction and environmental sanitation

The production of insects as feed has interesting characteristics. Insects can efficiently convert low-grade organic substrates into high-quality protein [6]. BSF and HF larvae can be reared on organic waste, which would otherwise end up in dumpsites, causing environmental pollution. BSF (Box 1) is most commonly utilised. For instance, in one day, BSF larvae can reduce 30 metric tons of food waste to *ca.* 10 metric tons (waste reduction 66%), while producing 930 kg of dry biomass [24•]. Waste reduction of 51–80% by BSF larvae was recorded on pig, chicken and kitchen waste [25].

Fly larvae can also be used in environmental sanitation programs to improve human health conditions. In Africa, private companies currently convert human waste from slums into organic fertilizer and fly larvae [26•]. These initiatives help to sanitise the environment for poor communities.

In conclusion, the production of fly larvae as feed component provides high quality feed ingredients while contributing to a circular economy.

Environmental sustainability

Implementing insects in nutrient cycling for feed production is innovative and currently receives ample

Box 1 Black soldier fly (*Hermetia illucens*)

The BSF is present in tropical and subtropical regions of the world [27]. Larvae can develop on several waste streams including vegetable and fruit waste, animal manure and human excrements resulting in significant waste reduction and high nutritional quality insect biomass [10,11,19,25]. Larvae reach highest biomass after *ca.* two weeks under optimal diet and temperature conditions [10,11]. Content of individual amino acids as percentage of crude protein is high (1.3–12.8%), which is comparable with fishmeal (2.1–13.1%) and soybean meal (1.3–20.7%) [28]. BSF is not considered a pest and is not known as a vector of diseases. Adult BSF are not attracted to human habitats and do not constitute a nuisance. These characteristics make BSF an attractive insect species for animal feed.

attention [29••]. The production of one metric ton of HF larval meal to replace 0.5 metric ton of fishmeal and 0.5 metric ton of soybean meal, for example, resulted in reduced land use and increased energy use [30•]. Similar data were reported for mealworm meal production [31]. Land use is globally under pressure and, thus, production of insects for feed alleviates this. The higher energy consumption was mainly needed to maintain optimal temperatures for larval production [30•]. Thus, exploiting environments that match optimal temperatures, such as in tropical regions, may reduce energy use.

Insects convert their feed more efficiently than pigs and cattle [32,33•,34,35•], which contributes to their importance for valorising organic waste streams [11]. Sustainability of insect production is highest if the insects are fed with organic resources that are currently not suitable as feed for livestock. Current protein sources in feed are soybean meal and fishmeal whose use is under pressure because of environmental aspects [26•]. Therefore, rearing BSF as feed may mitigate environmental impact of feed production [35•].

Inclusive business

For small-scale farmers, the most important costs of livestock production are represented by the costs of feed which amount up to 70% of all costs and this is especially due to the costs of protein components. Soybean meal and particularly fishmeal prices are rapidly increasing [26•]. As a consequence, farmers in low-income and middle-income countries are in need of alternatives that are both effective and affordable.

A survey among smallholder poultry farmers in four counties in Kenya showed that they are aware of the opportunities of insects as feed component (Figure 2). Female farmers appear to be more informed of the opportunities than male farmers. However, these farmers usually depend on external sources for feed, including national and international feed companies (Figure 2). This makes them economically dependent on imported feeds that are commonly based on fishmeal and soybean meal. Yet, fly larvae may be produced locally by smallholder farmers providing opportunities to become feed suppliers in addition to or instead of being feed buyers. They may rear fly larvae as feed component either to be included in feeds that they formulate themselves or to sell to feed millers [36]. This will provide farmers with opportunities to actively engage in the emerging insect agribusiness value chain [37•]. Becoming less dependent on international feed producers and simultaneously gaining income from producing fly larvae as feed component contributes to improving livelihood and food security of smallholder farmers [37•].

Economical aspects

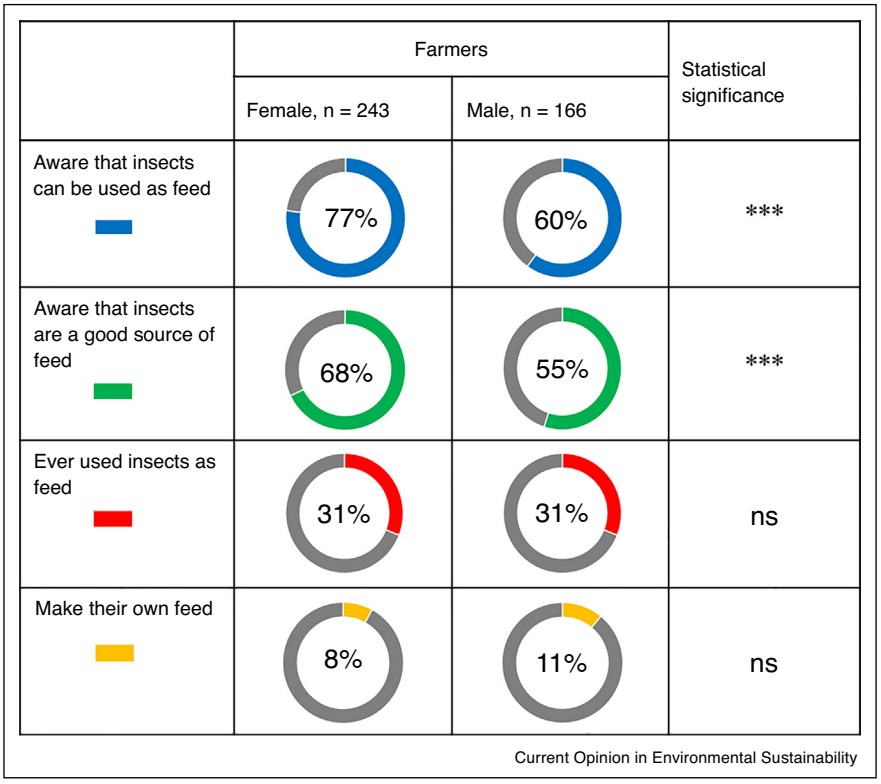
The economics of adopting insects as feed ingredient include the production of the insects as well as incorporating them in feed for livestock. The production costs of fly larvae involve investments in infrastructure such as space and containers. These costs are minor [38]. Additional costs involve resources such as water, electricity and feed substrates for the fly larvae, and labour [38]. Comparing break-even sales prices of feeds that include HF or BSF meal as protein source with prices of conventional feeds in West Africa indicates that insect meals are competitive to feeds based on fishmeal as protein source [38]. Costs of protein ingredients for chicken feed in Kenya are 1.20 and 0.85 US $/kg for fishmeal and BSF meal respectively [13••]. Dietary replacement of soybean and fish meal by BSF meal in broiler feed resulted in an improved feed conversion rate leading to higher yield with less feed input. In combination with lower costs for BSF meal than for fishmeal and soybean meal, this resulted in a 25% higher return on investment when using BSF meal [13••].

The production of fly larvae is based on waste streams as input. Many of these waste streams are currently not valorised and end up in landfills. This leads to environmental damage in terms of, for example, contribution to global warming and limiting of resource recovery [39]. However, the increasing importance of waste streams as input in the production of a valuable feed component may result in an increase in costs of this resource of insect production. Reducing labour costs will be important to limit the production costs of BSF and HF for feed [38]. Moreover, an additional benefit of producing insects for feed is that the rest stream remaining after harvesting the fly larvae can be valorised as fertilizer, thus providing an additional financial benefit [38,40]. In conclusion, producing HF or BSF as feed component is competitive with the use of fishmeal and although the price of substrates is likely to rise, other benefits of fly production are likely to outweigh this.

Insect farming in the context of a circular economy

Insect farming by smallholder farmers can increase local supply of insects as animal feed in an integrated livestock-fish farming system. Farmers may use on-farm waste streams such as crop leftovers as input for BSF production and add the

Figure 2



Farmers' perception and use of insects as feed for poultry in Kenya. The blue, green, red and yellow colours represent farmers' responses. Asterisks indicate significant differences between male and female farmers (z-test): ***: $P < 0.001$, ns: not significant.

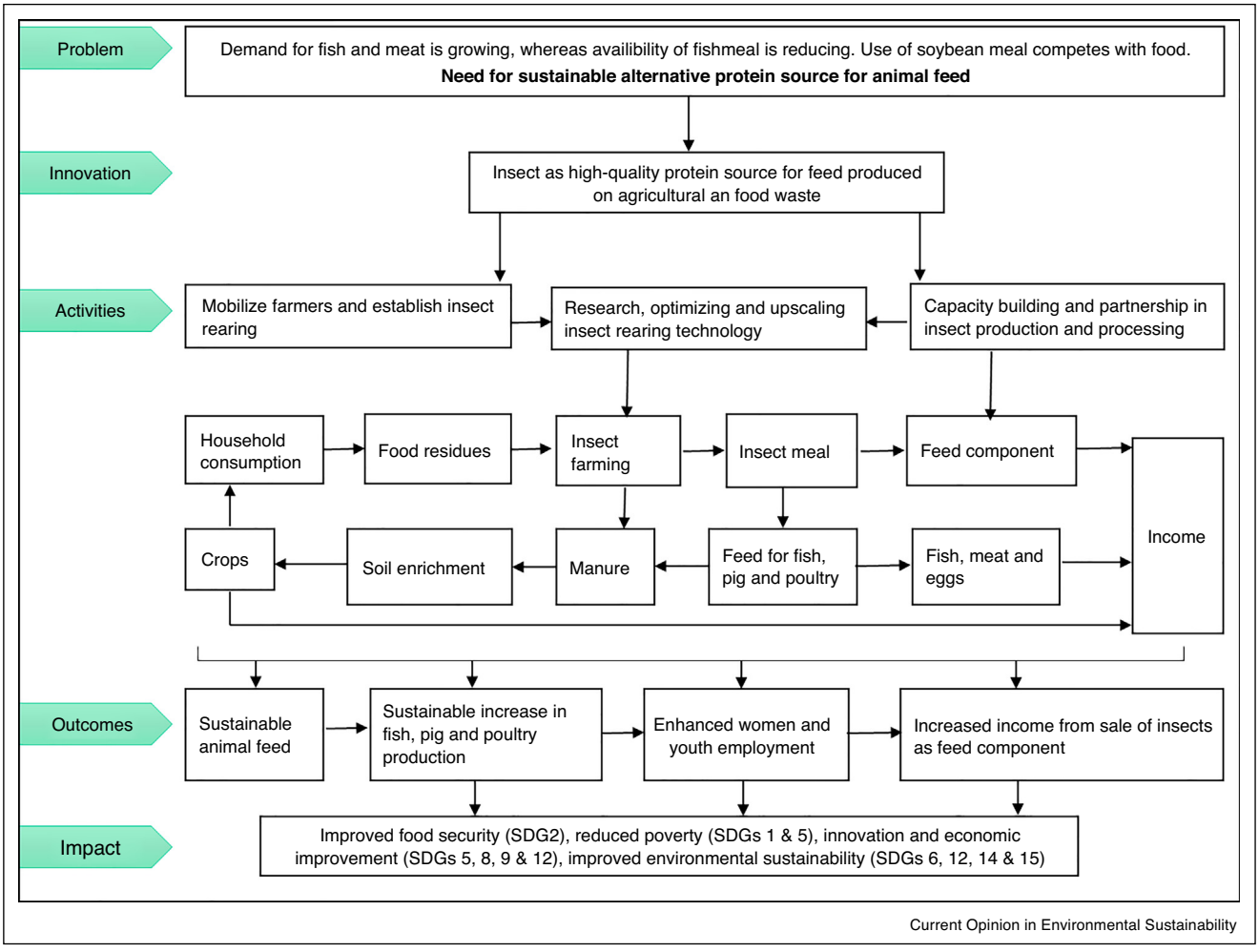
resulting fly larvae to the feed for their livestock. This results in a circular approach that closes the nutrient cycles on farm (Figure 3). With limited space, resource-poor farmers who engage in insect farming may increase their productivity while contributing to waste management [37•]. Smallholders can start up innovative businesses with limited inputs to generate insect meal for animal feed and the waste stream of insect production can be used as organic fertilizer for crop production [29••]. Sales from resulting animal products (fish, meat and eggs, insect meal) and crop yields can supplement household income or provide food. Insects can thus effectively close nutrient cycles (Figure 3), avoiding food wasting because waste becomes a resource. One key aspect to consider in closing the loop is the legislative constraints of using insect meal as (ingredient of) livestock feed [41]. Inclusion of insect meal in livestock and fish diets is currently allowed in Kenya and Uganda [26•] and under development in the EU (http://ipiff.org/insects-eu-legislation/). Thus, this promising model is now in the process of being accepted by regulators as well.

Sustainable development goals

IB models enable individuals, households, entrepreneurs, micro-sized, small-sized, and medium-sized enterprises to secure access to affordable goods and services relevant to sustainable livelihoods and engaging in value chains in beneficial and sustainable ways [3••,42•,43,44•]. Inclusive business models are sustainable business solutions that expand access to goods, services, and livelihood opportunities for low-income communities in commercially viable ways [45]. Insect production by smallholder farmers may both disconnect them from expensive external inputs such as fishmeal-based feed as well as connect them to local economies by selling the insects to local livestock farmers as well as feed millers (Figure 3).

In January 2016, the United Nations officially adopted the SDGs and called for a universal action to end all forms of poverty, fight inequalities and tackle climate change within a package of 17 SDGs. Specific for this call is the inclusion of poor, middle-income and high-income people. However, efforts towards achieving the SDGs are felt differently among low-income and high-income people, men and women, developed and developing countries [43]. Implementing innovative and sustainable food production strategies such as insect farming for animal feed involving smallholder farmers may contribute substantially to several of the SDGs, which are interconnected (Figure 1) [1••,26•,46•].

Figure 3



Insect farming for feed in the context of a circular economy can generate income and create employment: innovation, activities, outcome and impact.

Access to and control over natural resources globally impact how rural people secure decent livelihoods, escape hunger, participate in decision making and overcome social and economic exclusion [47]. With minimal inputs, resource-poor people can set up small insect farms to produce for themselves or the local market (Figure 3) hence reducing poverty (SDG 1) and hunger (SDG 2) [29••].

Water scarcity, poor water quality and inadequate sanitation negatively impact food production and livelihoods, thus worsening malnutrition. In South Africa, preliminary trials show that BSF larvae can be effectively used in urine diversion dehydrating toilets to manage human faeces, while conserving water to alleviate sanitation problems faced mainly by the rural poor (SDG 6) [48]. Commercial insect farming is becoming a new sector for economic growth and employment opportunities (SDG 8). Inclusive insect farming may promote sustainable industrialisation, increase employment and local technology development in low-income communities (SDG 9) as well as improve gender equality (SDG 5). Insect bio-conversion can ensure sustainable use and reduction of food waste (SDG 12). Increased insect production as feed may provide a sustainable alternative to fishmeal, thus reducing effects on biodiversity due to overfishing and conversion of forests to agricultural land (SDGs 14 and 15).

In conclusion, IB models align with the SDGs by strengthening stakeholder engagement in agricultural value chains, while mitigating the effects of food production on the environment.

Future prospects

Changes in feed systems are dependent on several potential drivers, including technological, environmental,

political, economic, cultural and demographic drivers [49]. Technological drivers are clearly present for insects as feed [6,12,13••,14]. Fly larvae have great prospects for animal feed and waste management [6]. Environmental drivers include the valorisation of waste streams as well as mitigation of biodiversity loss and climate change [6,26•]. Producing insect meal requires limited land and water. Insects can sustainably close nutrient cycles while providing animal proteins and useful by-products, creating employment, increasing local productivity and connecting smallholder farmers to the agribusiness value chain. As long as the fly larvae can be reared on substrates that are a true waste stream, the production of fly larvae as feed will not interfere with food production and will provide a sustainable alternative for fishmeal. Future research should focus on the suitability of a diversity of waste streams that effectively support the growth of the fly larvae while not competing with other use. The remaining drivers, including political, economic, cultural and demographic drivers, are institutional and require a multi-stakeholder involvement [49]. The production of fly larvae for on-farm and local use may make smallholder farmers less dependent on feed millers that provide feed based on expensive and unsustainable fishmeal or soybean meal. For smallholder farmers to be able to effectively connect to the agribusiness value chain and supply fly larvae to national feed millers, it is important that they can supply sufficient volume. To do so, farmers likely need to organise in cooperatives. This will not only improve supply volume but can also empower them within the value chain. The novel production of insects as feed ingredient by smallholder farmers aligns with various SDGs: smallholder farmers can benefit from new markets while generating meaningful profits and increasing economic resilience in low-income communities. Developing the institutional drivers will be vital for successfully implementing the use of insects for feed via inclusive business models.

Conflict of interest statement

Nothing declared.

Acknowledgement

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