Feasibility study: Black soldier fly production for animal feed in Ethiopia

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RAISE-FS Working paper #009

WAGENINGEN UNIVERSITY & RESEARCH

TRAIDE FOUNDATION

RAISE-FS Resilient Agriculture for Inclusive and Sustainable Ethiopian Food Systems

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Summary of document
Black soldier fly rearing is an innovative biotechnology that has the potential to tackle, in a sustainable manner, challenges related to organic waste management, proteins and lipids sourcing for animal feed, and access to fertiliser. Ethiopia appears to possess a suitable environment for the adoption of this technology and the development of an industry. Logistical, legal and cultural aspects will play important roles if this promising sector is to be successful.

Keywords: Black soldier fly, animal feed, organic waste management, organic fertiliser, circular economy

This manual can be downloaded for free at https://edepot.wur.nl/637480

Contents

Abbreviations and acronyms

BSF	black soldier fly
BSFL	black soldier fly larvae
FCR	feed conversion ratio
GDP	Gross Domestic Product
GWP	Global Warming Potential
HORECA	hotel, restaurant and catering
ICIPE	International Centre of Insect Physiology and Ecology
RAISE-FS	Resilient Agriculture for Inclusive and Sustainable Ethiopian Food Systems
SME	small and medium-sized enterprise
SWC	solid waste collection
TAM	total addressable market

Summary

Effective organic waste management, affordable animal feed and fertiliser are three major challenges that permeate across rural and urban Ethiopia. The rearing of black solder fly (BSF, Hermetia illumes), a tropical insect and biotechnology, has been demonstrated, across the globe, to have the potential to tackle some or all of these challenges in a sustainable manner.

This feasibility study assesses the opportunities and challenges, at various scales, for the onset of this innovative industry in the country. It introduces the biotechnology, evaluates the different waste streams within different contexts (urban, rural, industrial), assesses the demand-driving factors for alternative ingredients for animal feed, presents two business cases to illustrate the potential of a BSF farm, and then elicits challenges to overcome and recommendations to undertake for smooth technology adoption and steady sector growth over the coming decade.

The increase in both the human population and migration into urban areas of Ethiopia have led to an increase in waste production. On average, 60% of the waste in an around urban areas is organic, yet it is often mixed with other waste types, making it challenging to be used as is for BSF rearing. Yet with adequate separation policies and practices, BSF could play a crucial role in reducing the total biomass generated and thus alleviate the pressure on landfill and municipalities whilst making urban areas more attractive.

Agro-processing and agricultural waste appear to be more promising for the rearing of BSF. Hotspots of potential project locations have been identified where there are ideal climatic conditions for BSF and value chain stakeholders are concentrated. Waste streams in rural areas are already well reused by farmers, thus developing projects that generate more than 0.5 tons/month of dry larvae is challenging. A medium-scale BSF farm, close to an urban area or on the premises of an agro-processing company, has been shown to be logistically and financially viable. Yet, the need for a thorough understanding of the project supply chain is crucial. Indeed, the quantity and quality of substrates (the waste streams) fed to the larvae play a critical role in the operational and financial success of the BSF farm.

The demand for animal-sourced food has been increasing over the past decade, and so has the price of animal feed ingredients, particularly protein sources. The need for competitive alternative sources of protein for animal feed, and thus BSF, has been estimated and confirmed from recent market data and key personal communications. Similarly, the need for affordable fertiliser has been also estimated and confirmed. Interviews with key stakeholders on the issue of integrating BSF products into their operations have elicited encouraging responses. Yet, it has also been recognised that cultural acceptance may be challenging, particularly without a legal framework, demonstration sites, and adequate communication and marketing strategies.

Follow-up studies on waste streams local to the project and customer segmentation could bring significant insight to ensure the success of any project implementation. Efforts to establish a legal framework need to be pursued, and early awareness-raising of public and private regional stakeholders should be undertaken. Research and capacity building also need to be undertaken to provide local expertise and encourage the onset of BSF farms.

1 Introduction

1.1 Context

With the increase in human population, growing migration into urban areas, and the rising number of middle-income households, most cities in emerging economies are facing numerous challenges. Three of these major challenges are:

1. The inadequate handling of the increasing waste generated in and around urban areas due to weak infrastructure.
2. The lack of substantial provision of animal protein to the population due to the high and volatile production costs of inputs, leading to high and unaffordable consumer prices.
3. The increasing cost of fertilisers due to infrastructural and geopolitical shifts.

This triple burden is also likely to be taking place across Ethiopia, in both urban and rural areas. Black soldier fly (BSF) biotechnology has the potential to tackle all of the above-mentioned challenges in a sustainable manner.

1.2 Purpose of this study

The potential of insect use by humans has been explored in several countries in East Africa. Insects have been used for many purposes: pest control, feed alternative, food alternative, cosmetics and waste management, with varying success. Different species have been introduced and tested at various scales. Black soldier fly larvae (BSFL) as a source of animal protein has gained strong interest over the past decade because of its biological characteristics, resilience to different environments, and relevance to tackle pressing challenges such as food security and environmental preservation. The Ethiopian livestock sector is facing various barrier regarding nutrition , including feed shortages, poor-quality feed, and fluctuating feed prices, all of which have a negative impact on the performance of the sector. To alleviate these bottlenecks, alternative and local feed ingredients, particularly sources of protein such as BSFL, could play a strong role in the future.

This feasibility study was conducted to identify the opportunities and challenges of BSF farming in Ethiopia. The specific objectives were to:

- conduct a suitability analysis of the climatic and sociocultural contexts in targeted locations for BSF farming
- assess the commercial viability of small-, medium- and large-scale BSF farms in specific locations
- put forward recommendations to facilitate the onset of the new sector in key areas across Ethiopia.

1.3 Approach

The scope of the assignment was to study the feasibility of BSF production in Ethiopia, with a focus on the role BSF products could play in alleviating feed supply problems of small-, medium- and large-scale poultry farms. Apart from assessing the technical feasibility, the study also investigated current and required factors to enable and stimulate insect production in the country. This report was drafted based on:

1. literature and secondary resources
2. interviews with key resource personnel in Ethiopia.

This work is the result of a collaborative effort between TRAIDE and Wageningen University & Research. The organisations have combined resources and research results in this report to increase its quality as well as its outreach.

1.4 Acknowledgements

The authors would like to thank the different stakeholders interviewed who provided valuable, concrete and up-to-date information and data, making this research more accurate and thus more informative to whomever would like to undertake the production of BSF in Ethiopia. These stakeholders are Alema Koudijs (Marlies Van Horssen), Sunvado (Joost Heij), ChicoMeat (Jaco Hendriksen), ICIPE (Tadele Tefera), Hawassa University researchers and students, and two commercial poultry farmers.

2 Black soldier fly

2.1 Life cycle of the BSF

BSFL stand out as a source of animal feed. In the wild, BSFL naturally feed on decomposing organic matter and the flies reproduce next to it. The natural habitats of BSF are tropical areas with high temperatures and high relative humidity. The insect thrives best at a temperature of 27ºC (~1ºC) and a relative humidity of 70% (~5%). Under these climatic conditions, the performance of the insect is at its maximum, with the development rate, feeding capacity and protein content of the insects being optimal. In ideal conditions, it takes about 11 days for the insect to develop from its egg stage to its prepupal stage (see Figure 1), while the larvae can reduce up to 55–76% of the total waste biomass as larval feed. Additionally, an adult larva (prepupa) is composed of ~38% dry matter (DM), itself made of proteins (~40% of DM), lipids (~25 of DM), minerals (~20% of DM) and fibre (~10% of DM).

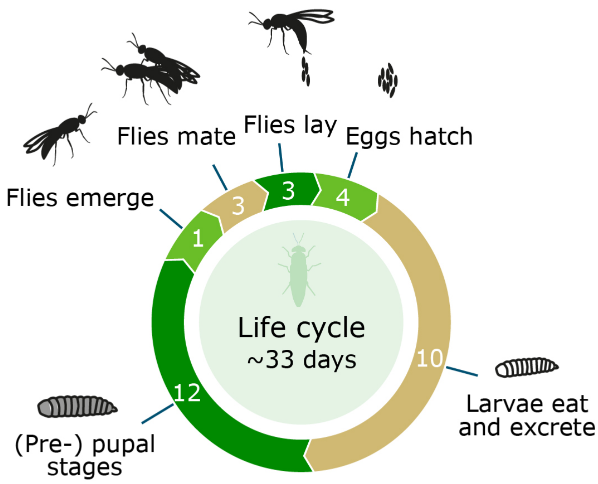

Figure 1: Life cycle of the BSF

2.2 BSFL as a source of feed

BSFL as an animal feed ingredient has many advantages, particularly in comparison to soya bean production. The major environmental advantages of BSF farming compared to its alternatives (soya bean and other protein sources for livestock feed production) are as follows: (1) less land and water is required (57 and 10 times less, respectively); (2) greenhouse gas emissions are lower (1.7 times lower); (3) insects can transform low-value organic by-products into high-quality food or feed (2 tons of CO_2 per ton of waste converted). BSFL are a significantly more efficient and more sustainable protein source than soya (see Table 1). BSFL are also efficient bio-converters that can be mass-reared on low input resources.

Table 1: Environmental impacts of soya and BSFL

Protein source	BSFL	Soya vs BSFL (times more)
Land (m^2/kg of protein)	0.06	57× more
Water (m^3/kg of protein)	0.2	10× more
GWP (kg CO_2-eq)	2.9	1.7× more

Sources: Authors' calculation using Willaarts et al., 2011, Bosch et al., 2019, WatchMyWaste.com.au, Greenhouse Gas Calculator, EPA

Soya beans are seasonal products, both locally and internationally, which inevitably leads to price variations and logistical costs. Soya quantity and quality partially depend on weather conditions of the previous year, and geopolitical factors which greatly affect their availability, quality and price. In contrast, BSF can be produced all year round in tropical climates and in climate-controlled environments. They can be produced near agro-processing and industrial zones to facilitate logistics. The water, energy and land required for production are much lower compared to soya bean production. If the substrate and climate are maintained relatively constant, the quality of the product also remains constant. These factors make BSFL a relevant and sustainable alternative to other protein sources (e.g. soya bean, fishmeal, cotton/ rape/sunflower seeds, distillers' grain) for the livestock feed sector in Ethiopia. Moreover, the additional high-value nutrients, such as lipids and chitin, and by-products such as the organic fertiliser/soil enhancer derived from the larvae frass (insect excreta and substrate leftover, which can be post-processed) bring additional income streams to the business and increase financial resilience (see Figure 2).

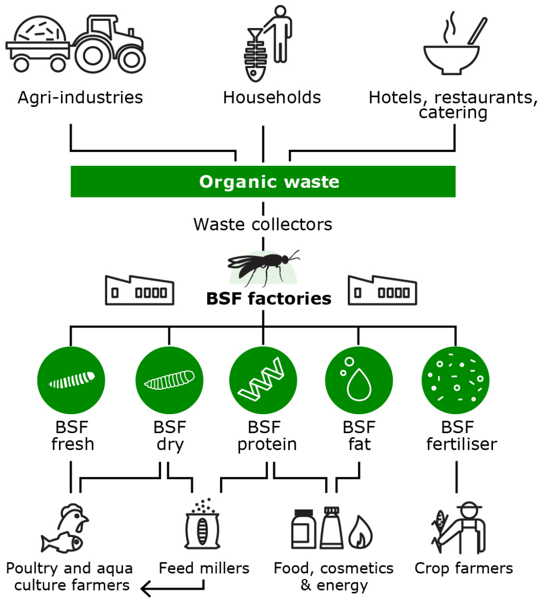

Figure 2: Sample production model for a medium or large-scale BSF farm

3 Waste streams

BSFL naturally feed on decomposing organic matter, which can be geared towards waste management or protein and other product provisions. In all cases, crucial for the success of BSF rearing is to have a clear qualitative and quantitative understanding of the various organic waste streams available. The substrate is one of the most important factors in BSF production. The availability, quality and cost of the substrate can highly influence BSF production costs and product quality. This section describes waste production, management and profile in the vicinity of different urban areas. It also presents specific contexts in which BSF could be used as a biotechnology to reduce organic waste.

3.1 Different types of waste

BSFL feed on almost any decomposing organic matter. Many substrates have been explored as potential feed sources for the insect. Agro-processing waste/by-products (e.g. brewery waste, coffee leftovers, rice kernels, various fruit and vegetable pulp and peel, chicken feed, livestock manure, human faeces, slaughterhouse leftovers, food leftovers from institutions and the hotel, restaurant and catering (HORECA) industry, fruit and vegetables in markets that are not fit for sale) are some of the substrates that have been tested, solely or mixed, as feed for BSFL. Different substrates and rearing conditions can lead to significant differences in performance in terms of, inter alia, bio-conversion and protein, lipid and frass profiles. It is important, therefore, to have a good understanding of the waste streams available, and their quantities and qualities, to be able to develop mixes that can maximise production.

3.1.1 Urban waste

Two major factors drive the growth of organic waste in Ethiopia: rapid population increase and economic growth. In 2007, the population was nearly 74 million (Ethiopian Statistical Services, 2007); the current population is more than 100 million – the second largest in Africa next to Nigeria, and by 2025 projected to be more than 125 million. The growing population and economy have encouraged many people to migrate to cities. Many of these cities, for instance, Addis Ababa, Mekelle, Adama, Bahir Dar and Hawassa, have had to sprawl out and accommodate urban infrastructure, often with little urban planning. Because of urban and economic growth, cities have faced the increasing challenge of solid waste management. The rise in total residents, waste per capita produced and total waste, along with inadequate infrastructure, have resulted in tremendous pollution, all leading to social, economic and environmental costs.

The country has opted for strong private sector involvement in the management of solid waste, particularly solid waste collection (SWC). The Environmental Protection Agency (EPA) indicates the fundamental principles for the byelaws that each city must establish. The byelaws have the following principles:

a. cities are responsible for ensuring that all waste generated within their jurisdiction is collected, transported, treated, disposed or recycled
b. such collection, transportation, treatment, disposal or recycling must take account of the stipulated waste management hierarchy.

The main objectives of the byelaws are to ensure that waste is avoided, or at least minimised, reused, recycled, recovered and disposed of in an environmentally sound manner. Even though the principles are written in the byelaws, they are not always properly implemented by cleaning administration departments and cleaning administration agencies.

It is the responsibility of the cleaning administration departments and agencies of each city to promote and facilitate the development of the private sector to manage waste disposal. Consequently, different cities have adopted different schemes and frameworks to organise the collection of waste, which inevitably leads to differences in structural operation, challenges and efficiencies. Table 2 provides an overview of these different schemes and their attributes.

Table 2: Waste management analysis of five major cities in Ethiopia

Cities	Addis Ababa	Mekelle	Adama	Bahir Dar	Hawassa
Private companies	20	4	6	5	5
SMEs	~500	?	~30	~30	~30
Contractual scheme	Service contract	Service contract	Licensing contract	Service contract	Service contract
Contract duration (years)	1	5	*	1	1
Contract renewal	Not guaranteed & open bidding	Not guaranteed & open bidding	Not guaranteed & open bidding	Not guaranteed & open bidding	Not guaranteed & open bidding
Payment scheme to company	Rate/m³ ≈ trucks to landfill	Rate/m³ ≈ trucks to landfill	Direct contact with resident	Monthly lump sum	Rate/m³ ≈ trucks to landfill
Resident financial contribution	Tax – Pro rata of water consumption to city	Tax – Pro rata of water consumption to city	Monthly fee to company	Tax – Pro rata of water consumption to city	Tax – Pro rata of water consumption to city
Company revenues	US$2.22/m³	US$1.27/m³	US$0.66–US$1.9/ household /month	~US$15,000	US$1.18/m³
SME revenues	US$71/month	-	US0.66–US$1.9/ household/month	US$71/month	US$71/month
Allocation of collection zones	No	Yes	No	Yes	Yes
Pay within 45 working days	Yes (60% of companies)	No	-	No	No
Laws enforcement by local government	No (≈80% of companies)	No	No	No	No

Sources: Authors' calculations using Cheru (2016), Mohammed and Dijk (2017), Gelan (2021), Xie and Mito (2021) and Teshome (2021)

Despite recent efforts from national and local governments in adopting new strategies and supporting the involvement of the private sector in SWC, the systems are far from efficient, which results in strong social, environmental and economic costs, often borne directly or indirectly by residents, businesses and municipalities. The reasons for the misfunctioning of the systems are multiple. The low service rate paid to collectors, delays in payments, lack of long-term contracts with collectors, lack of well-defined targets for collectors, and the lack of clear demarcations between the waste collector's operational zones – creating overlaps or 'forgotten' areas. These limitations do not create an attractive environment for small and medium-sized enterprises (SMEs) or private companies to invest in hardware that will improve their services to the best of their ability, or even pursue their activities in the long run.

The solid waste generated by urban areas is differentiated in terms of sources and composition across cities. Table 3 provides an overview of some of these differences. The waste composition also varies between household income groups.

Table 3: Waste production and composition in five major cities in Ethiopia (2010 and 2022)

Cities	Addis Ababa	Mekelle	Adama	Bahir Dar	Hawassa
Population 2010	2,900,000	261,000	260,000	170,000	200,000
Waste generated, 2010 (tons/day)	1,132	78	59	99	46
Waste per capita, 2010 (kg/cap)	0.39	0.30	0.23	0.58	0.23
Population, 2022	4,800,000	432,000	430,345	281,379	331,034
Waste generated, 2022 (tons/day)	3,200	222	168	281	131
Waste per capita, 2022 (kg/cap)	0.67	0.51	0.39	1.00	0.39
Waste generated, 2030 (tons/day)	8,300	575	435	730	339
Share of waste collected	70%	82%	48%	58%	44%
Share of organic waste	65%	-	58%	87%	-
Share of paper, plastic, glass, and metal recycled	13.50%	-	35.00%	6.00%	-
Share of other waste	21.50%	-	7.00%	7.00%	-

Sources: Authors' calculations using Cheru (2016), Mohammed and Dijk (2017), Gelan (2021), Xie and Mito (2021) and Teshome (2021)

It is clear from Table 3 that the increase in population correlates with the rise in waste generated. Also, the waste generated per capita is projected to increase due to an expected rise in income. The average collection rate across the five cities is 60%. This means that 40% of the daily waste is not collected and remains in the streets or disposed at the outskirts of the cities without any regulation. On average, 70% of waste is organic, which compares with other cities such as Kampala, Nairobi and Kigali (Xie and Mito, 2021). It is important to note, however, that the share of organic waste as well as recyclables varies greatly across cities.

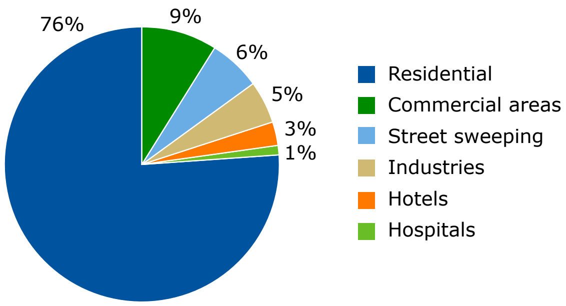

Figure 3: Share of municipal solid wastes by source in Addis Ababa
Source: Addis Ababa Solid Waste Management Agency (2019) in Xie and Mito (2021)

It is also clear that waste generation is forecast to increase in the coming decade, and that, given the lack of infrastructure and effective schemes in place in many urban areas, cities and their residents will increasingly face the challenges created by poor waste management.

The quality, also referred to as 'purity', of the waste depends on the sources. The purity level indicates the level at which different waste types (organic, plastic, hazardous) are mixed into bundled waste streams. The scope of this study did not allow a precise determination of waste purity level, and this would require further research. It can be said, however, that waste separation, although part of the prerogative of the EPA, is not well advocated by municipalities and not yet implemented by residents or businesses. Consequently, much of the solid waste is a mix of organic, plastic, paper, and other non-recyclable waste (when not individually dumped on the street). Waste collected directly from HORECA and other industries tends to be purer in its composition and less mixed, as it is often already separated at the production source. These waste streams are usually available in larger quantities at more consistent time intervals, making them the most suitable to use when starting the production of BSF.

It is clear that waste management – particularly organic waste management – is not efficient and effective in large cities in Ethiopia. Given the total cost of €80/ton (€36 direct costs and €34 indirect costs) that waste generates in Addis, the total addressable market (TAM) was estimated by assuming that 25% of that cost could be redirected to a BSF waste processing facility. At a rate of €20/ton, the TAM has been calculated for the five major cities for 2022 and 2030 (see Table 4).

Table 4: Macro-level market analysis

Cities	Addis Ababa	Mekelle	Adama	Bahir Dar	Hawassa	Total
Organic waste collected (tons/year), 2022	531,804	46,370	17,044	51,599	14,674	**661,491**
Organic waste collected (tons/year), 2030	1,379,367	120,273	44,209	133,835	38,060	**1,715,743**
TAM, 2022 (€/year)	11,161,824	973,244	357,738	1,082,990	307,981	**13,883,778**
TAM, 2030 (€/year)	28,950,982	2,524,353	927,882	2,809,006	798,826	**36,011,048**

Sources: Authors' calculations using Cheru (2016), Mohammed and Dijk (2017), Gelan (2021), Xie and Mito (2021) and Teshome (2021)

3.1.2 Agro-processing or agro-industrial waste

Waste in rural areas is largely organic, and often from agriculture. In rural areas, resources are limited, thus recycling practices are often a necessity. For instance, cow dung can be used as a material to build house walls (mixed with straw), as fuel for cooking, or as fertiliser. Household organic waste is fed to free-roaming chickens or other animals. As confirmed by the International Centre of Insect Physiology and Ecology (ICIPE) in Ethiopia, the waste in rural areas is for the most part well managed, as farmers reuse all kinds of wastes, by-products and residual streams for animal feed or other agricultural and construction purposes. Consequently, rearing BSF in rural areas may be challenging, at least from the supply perspective. There are, however, some opportunities that could be explored. Market waste, although partially reused as animal feed, is often left rotting in the vicinities and creates nuisance (e.g. smell, rodents, etc). Technically, rural dwellers could pull their resources together to collect available waste from different local streams based on the seasonal availability and use them as substrates to feed small-scale BSF farms.

BSF biotechnology for waste management could be adopted not only by public stakeholders or in rural areas as mentioned above, but also by the private sector. Food processing companies, such as avocado oil processors, chicken nurseries and slaughterhouses, have been struggling with the disposal of their by-products and wastes for many years because of, inter alia, the lack of effective local infrastructure. For instance, the organic residues from a large avocado oil processor can be almost 9,500 tons/year, of which 70–75% of the waste is pomace, 20% is seeds and around 5% oil. The company tries to recycle the pomace by drying it in a greenhouse and then selling it as a feed ingredient (with around 4% protein content) to livestock farmers. However, if high amounts of pomace are feed to poultry, it could lead to persin intoxication. So far, there is no alternative use for avocado seeds because it contains antinutritive substances hindering its ability to be used as a feed ingredient, and it therefore ends up in the landfill.

Slaughterhouses also face challenges with offal and blood by-products which, for the most part, end up in landfill at a rate of 50+ tons/year. The company’s chicken manure is currently sold to cattle farmers as feed. The company has also expressed interest in reducing its environmental impact and improving its business model. It has had a few unsuccessful attempts to rear BSF solely on its by-products but is exploring various avenues on how to integrate other waste sources as well as making BSF biotechnology an integrated part of its current outgrower business model.

Both examples (avocado oil and chicken slaughterhouse) are representative of the private sector’s possible use of BSF as a waste management technology. In both cases, a careful understanding of the chemical and nutrient composition of their by-products will be required, however, to ensure successful operation. Depending on these results and first trials, it may also be necessary for companies to add one or two external substrates to their by-products to ensure successful processing of waste by BSFL. Yet for some substrates the competition is already high, particularly between ruminant and poultry producers that are buying the wastes, such as spent grain from breweries. If the same waste streams that are currently used as animal feeds would be used for BSF production, these substrates might attract a (high) price, and subsequently increase the production cost of the BSF. Furthermore, access to certain waste streams, such as HORECA food leftovers or crop residues, may be periodic. For instance, the experimental BSF facility at Hawassa University relies mainly on canteen leftovers, which during holiday or summer periods are much reduced. This either halts production or forces researchers to spend additional effort sourcing other waste not as easily and practically available, accessible and/or transportable, which for any private sector producer would increase production costs.

This could increase competition and raise the price of residual streams in these areas. ICIPE sees the production of BSF in rural areas of Ethiopia at a scale above 0.25 tons of fresh larvae/day to be difficult because of the scarcity of local substrates or the prohibitive cost, such as of brewery by-products.

4 Livestock feed

4.1 Livestock feed gap

With 70 million cattle, 43 million sheep, 52 million goats, 8 million camels and 57 million chickens in 2021 (CSA, 2021), Ethiopia has the largest livestock population in Africa and an animal-to-people ratio twice that of the continental median. Livestock is a major source of animal protein, manure for farmland and household energy, a form of security in times of crop failure, a means of wealth accumulation, soil cultivation and transportation, and an export commodity. In 2017, the sector's contribution was around 40% of agricultural Gross Domestic Product (GDP), 20% of total GDP, and 20% of national foreign exchange earnings (Mekuriaw and Harris-Coble, 2021).

There are several livestock production systems. The predominant production system is the extensive system with indigenous breeds and low-input/low-output husbandry practices. The productivity of the livestock sector is constrained by several factors, including poor genetics, low reproductive performance, poor-quality and varying seasonal availability of feed, high disease incidence and parasite challenges, and poor access to services and inputs. In recent times, however, there has been an increase in semi-intensive and intensive production systems, particularly for poultry.

In the past few years, the cost of animal feed has been steadily increasing. Figures 4 and 5 illustrate the price trends in feed ingredients and compound feeds, respectively. This escalation in animal feed prices is seen as a major cause of the price increase of animal-sourced foods in Ethiopia, as feed costs account for 60%–75% of production costs. As animal-sourced foods become less affordable for the poor, the fight against stunting and malnutrition becomes more problematic (Mekuriaw and Harris-Coble, 2021).

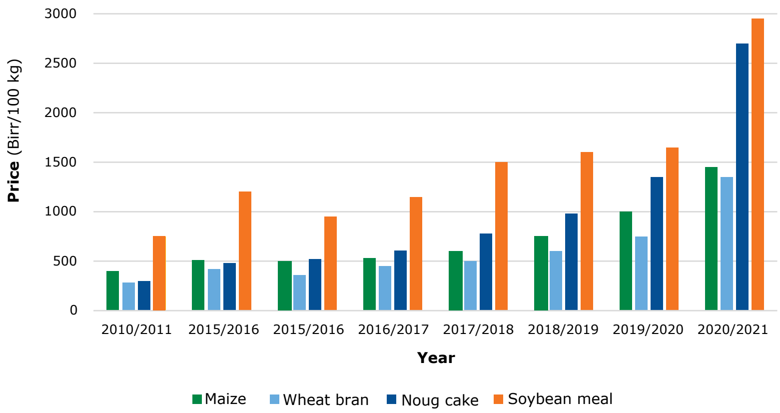

Figure 4: Price trends of major feed ingredients in Ethiopia

Source: Mekuriaw and Harris-Coble (2021)

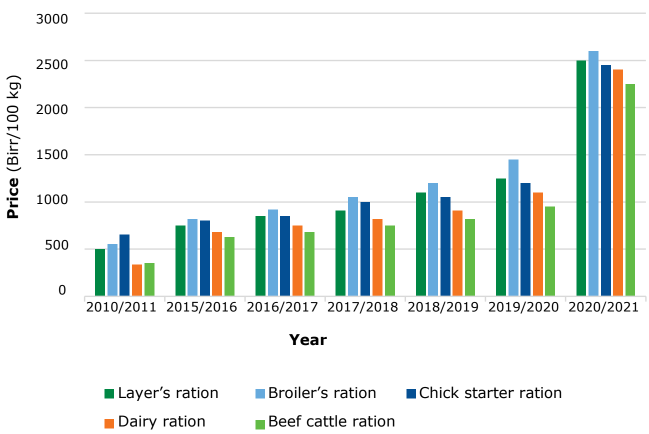

Figure 5: Price trends of compound feeds in Ethiopia

Source: Mekuriaw and Harris-Coble (2021)

4.2 Poultry

Poultry is one of the livestock species with the greatest population increase over the past decade (75%) and is forecast to be the subsector that will have the greatest marginal increase in the future. Indeed, chicken production offers considerable opportunities for generating employment, improving family nutrition, empowering women (especially in rural areas) and ensuring household food security. It is also healthier and more environmentally friendly than beef, for instance.

Along with the increase in production, the cost of poultry has increased for the consumer. The price of adult birds (cocks and hens) increased five-fold between 2006 and 2023: from €0.99–€1.36 (58–80 ETB) to €4.95–€6.82 (290–400 ETB) (Mekuriaw and Harris-Coble, 2021; Personal Communication, 2023). This pattern of rising prices indicates the growing demand for poultry, particularly during holiday periods, which is an opportunity for poor poultry producers to generate income.

Poultry feed is largely produced locally. Key ingredients to produce feed, including premixes and vitamins, are imported from abroad. Most of the large- and medium-scale commercial farms have their own processing plants, which produce feed for internal consumption only. Some large-scale feed processors specialise in the production and supply of poultry feed.

As part of this study, several commercial feed millers and poultry farmers were contacted and their price information was collected. The average price in 2021 for soya bean meal was 3,700 ETB/quintal. By Q2 of 2022, the price had increased to 4,600 ETB/quintal. A sharp increase is forecast in the coming year by local experts and industry stakeholders. Table 5 confirms not only the price increase but also the seasonal volatility of soya bean meal, the major protein source for poultry feed.

Table 5: Soya bean meal price trend

Soya bean	Q1 2021	Q2 2021	Q3 2021	Q4 2021	Q1 2022	Q2 2022
ETB/quintal	2,500	3,940	4,500	4,700	4,500	4,600
€/ton	450	709.2	810	846	810	828

Source: Authors' calculations informed by personal communication with feed companies

Although the production of soya bean and maize (the main ingredient of animal compound feed) has been steadily increasing, much of it is exported as cash crops, resulting in supply shortages, price increments and volatility. Consequently, the price of poultry is increasing and becoming less affordable for households with limited resources. Soya bean and maize are subject to the Liebig's 'Law of the Minimum' in that when one essential nutrient is deficient, plant growth and yields will be poor.

There is a clear, significant economic gap to match for the local production of protein-rich ingredients for compound feed. There have been incentives and reports that support investment and the development of soya bean production, particularly highlighting the country's favourable climatic conditions and, to a certain extent, land availability. To stabilise the sector and allow its steady growth, it seems crucial, however, to find alternative ingredients to soya or maize. Insects, particularly BSFL, have been widely explored as an economically viable and environmentally sustainable alternative to soya bean meal for compound feed, particularly for poultry and fish.

To summarise, the overall increasing demand for animal protein, the shift in consumption from cattle to poultry, and the transition to more commercial production systems are promising trends for the development of the poultry sector and particularly for the compound feed subsector. The most significant cost of poultry production is the cost of feed. Consequently, the supply of feed to poultry farms is determined by the success of the feed miller, which is in turn determined by the consistent and sustainable supply of feed ingredients at affordable/competitive prices. Figure 5 illustrates the challenges the feed and livestock sector is facing.

5 Business case for BSF

5.1 Suitability

Ethiopia has several climatic zones, several of which could be propitious for the onset of BSF production. Climatic zones with an annual average daytime temperature of 20ºC–30ºC degrees and with higher rainfall (for the increased humidity) have a greater potential for BSF production (Figure 6).

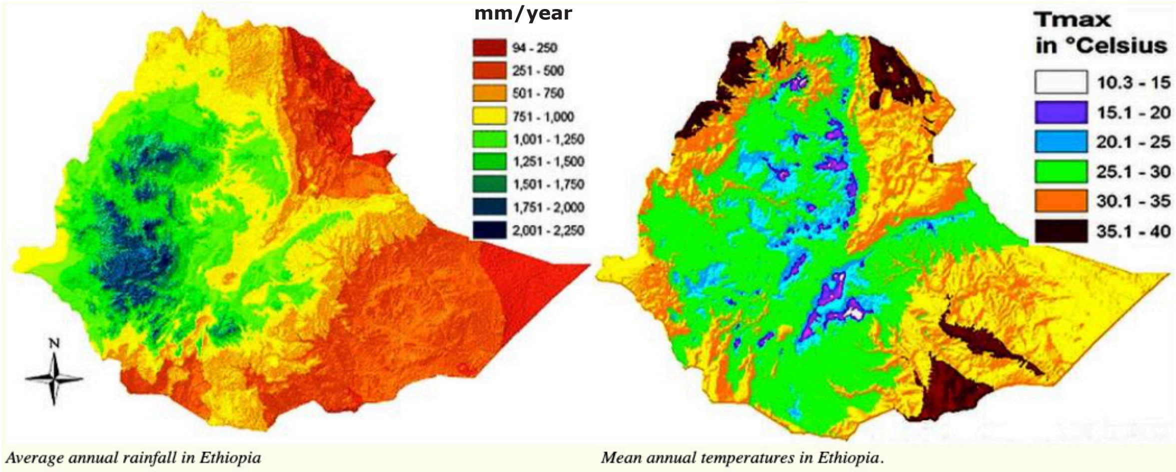

Figure 6: Annual rainfall and temperature in Ethiopia
Source: www.nationalparks-worldwide.com

Furthermore, there have been growing agro-processing industrial zones raising in several regions of the country, which could facilitate the associated logistics for BSF production with nearby access to substrate/waste streams and reciprocally foster an industrial ecology mindset, see Figure 7.

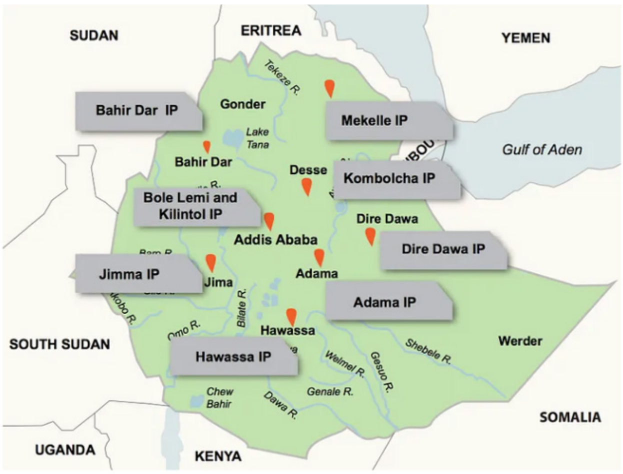

Figure 7: Existing or future industrial parks in Ethiopia
Source: Industrial Parks Development Corporation, 2020

The overlay of the most adequate climatic zones and the several agro-processing industrial zones could indicate hotspots of opportunity for the development of BSF production. Adama and Hawassa are such examples, particularly since they comprise a high concentration of stakeholders involved in poultry and livestock farming (commercial farmers, and feed millers) and agro-processing factories.

5.2 BSF production systems

BSF production has already been successfully implemented to varying degrees in Kenya, Uganda, South Africa, Malaysia, Singapore, USA and the Netherlands (among other EU countries). The performances of the BSF vary greatly based on the initial conditions (e.g. climatic conditions, substrate nutritional value), yet it remains an insect highly resilient to changes in external factors – capable of digesting many different substrates and under a wide range of climatic conditions. This intrinsic resilient property has fostered the development of several types and scales of production systems.

The scale of BSF production depends on two main factors: the availability and volume of the substrates and the size of the market. The notion of BSF scale is, however, not fixed worldwide, and what is large scale in one country may be considered medium in another. ICIPE assumes that a production of 3 to 5 tons of BSF may be challenging in Ethiopia due to the complex accessibility (quality, quantity, cost, transport) of waste streams for BSFL. Yet, this may differ between cities and regions and should be assessed by the entrepreneur to understand the BSF business 'supply chain', as well as key stakeholders and respective responsibilities to ensure smooth procurement of waste for the larvae.

Table 6 outlines the different types of BSF production system and ballpark indications of their respective characteristics. The variety of models indicates the possibility for the BSF technology to be disseminated at different levels/scales (from smallholders to industrial) and with the inclusion of different and diverse stakeholders.

Table 6: Characteristics of four different BSF production scales

Scale of BSF system	Waste processed (tons/day)	Fresh larvae (tons/day)	Products	Technologies	Automation level	Capital expenditure (€)
Small	<1	<0.25	• Fresh larvae • Fresh frass	• Low level • DIY hardware • No automation	–	500–1,000
Medium	1–10	0.25–3.0	• Dry larvae • Soil enhancer	• Medium level • Minimum automation • Mix of DIY and industrial grade technologies	Low to medium	50K–500K
Large	15–90	5–30	• Protein powder • Lipids • Chitin • Organic fertiliser	• High level • Medium automation • Industrial grade technologies	Medium to high	2–10M
Industrial	100+	30+	• Refined protein powder/pellets • Refined lipids into different acids • Chitosan • Organic fertiliser	• Very high level • Fully automated • High-end industrial grade technologies	Full	100M+

Note: The numbers in this table are indicative and may not represent the full potential of each system.

Sources: Dortmans et al. (2017) and authors' field experience with projects across the African continent

As mentioned above, BSFL feed on almost any decomposing organic matter. Many substrates have been explored as potential feed sources for the insect. Agro-processing waste/by-products (e.g. brewery waste, coffee leftover, rice kernel, various fruit and vegetable pulp and peel, chicken feed, livestock manure, human faeces, slaughterhouse leftovers, HORECA food leftovers, market fruit and vegetables that are unfit for sale) are just some of the substrates that have been tested solely or mixed as feed for BSFL. Different substrates and rearing conditions can lead to significant differences in performance in terms of, inter alia, bio-conversion and protein, lipid and frass profiles. It is important, therefore, to have a thorough understanding of the waste streams available – their quantity and quality – to be able to develop feed mixes that can maximise the performance of the production.

5.3 Business case

5.3.1 Service: Waste processor

The production of BSFL is, in theory, a two-sided business model: providing a service as a waste reducer and a producer of several products (e.g. protein, lipids, chitin, fertiliser). The proteins and the lipids are some of the most valuable products from the larvae that can be commercialised. Although the protein content remains generally high (from 30% to 50% of DM), the total lipid and protein contents in the larvae significantly depend on the type and quality of the organic matter ingested by the larvae. As Barragan-Fonseca et al. (2017) note, "larvae are what they eat". Thus, if the focus is to maximise the production of good-quality products, one needs to tailor the diet of the insects, which may not align with the composition of the raw organic waste available. However, the versatility of BSF also allows the focus to be geared solely on waste management or product provision. These choices will impact the cash flow of the project.

5.3.2 Product: Proteins

With more than 60 million heads of poultry, Ethiopia's current (2022) total demand for protein-rich ingredients for compound feed is estimated at around €45 million (based on the current price of soya bean cake, which is around €747 per ton). The projection (see Annex I) for 2030 is also very promising, with a TAM ranging from €48 million to €66 million depending on the price of the competitive/alternative products. It is important to note these figures comprise household and commercial livestock farming. Yet there are different levels of BSF processing possible (fresh, dry, powdered larvae) which allow feeding of the larvae directly to poultry or opt for a more tailor-made option that incorporates a dry or powdered version into a balanced compound feed (bought or self-made). Nevertheless, the different product forms could target different market outlets or fit into different production systems implemented across the country, and be beneficial to the whole livestock supply chain.

BSF has highly been experimented for its potential as a protein alternative to soya bean meal in many countries, yet as aforementioned, its production results in several other products.

5.3.3 Product: Fertiliser

In the case of fertiliser in Ethiopia, there are additional high investment opportunities. In recent decades, the country has heavily increased its use of inorganic fertiliser. With the recent rise in price of chemical fertiliser due to geopolitical reasons, many farmers are on the verge of not being able to cover their costs. The provision of good-quality and nutrient-rich organic fertiliser could partly address this situation and bring both economic and environmental benefits to the country. Table 7 shows the trend in the inorganic fertiliser prices and import quantities. With the sharp increase in price, farmers will seek more affordable options. The production of frass, which can be post-processed into organic fertiliser, could tap into a market of almost €1 billion per year.

Table 7: Total addressable market (TAM) for inorganic fertiliser

Year	2008	2021	2022	2023
€/ton	200	300	600	800
Million tons imported	0.5	1.8	1.8	1.2
TAM (€)	100	540	1,080	960

Sources: Authors' calculations using Rashid et al. (2013), ENA (2022), Addis Standard (2022), Addis Fortune (2022), Ethiopian Monitor (2022)

5.3.4 Other products and export

Although it has been harder to evaluate the TAM for lipids and chitin, both national and export opportunities should be considered in the financial assessment of future businesses. Lipids can be integrated into compound feed and thus could be sold to feed millers. Additional processing of lipids could lead to biodiesel production. Both are increasingly demanded by food and beverage, cosmetics, and agrochemical industries and thus present high-value products. Last but not least, Ethiopia borders several countries, such as Somalia and Sudan, which may not have the same favourable climatic conditions. Although the national demand for BSFL could already be vast, the potential for export should also be considered. Indeed, exporting part of the production could help improve foreign financial exchange and thus facilitate investments to scale up local production.

5.4 Market size

To confirm the macro analysis highlighting the market gap, we approached several livestock farmers and confirmed the 'demand' for this technology and ensuing products. In Debre Zeit, two poultry farms of different sizes were assessed as potential users of BSFL as an ingredient or as a whole in their feeding strategy.

Both layer farms, with sizes of 10,000 and 1,000 layers, respectively, relied on commercial chicken feed produced locally by commercial feed millers for their production. Both do not have the necessary resources (space, infrastructure, money or logistical access to ingredients) to make their feed mixes. Sourcing feed from commercial providers has, however, a few hindrances. The major one is the volatility of price depending on the season. Indeed, depending on the harvest of the major ingredient (soya, maize) and international geopolitics affecting imports, prices will vary. These variations severely impact production costs (feed being the highest contributor) and were reported by the farmers to impair their business significantly. Although commercial feed mixes vary in quality between suppliers, they generally allow the farmers to be assured that the nutritional needs of their flock are met and that the highest laying rates are maintained.

Both farmers confirmed their willingness to use commercial poultry feed containing BSFL as an ingredient. The main two caveats are productivity and affordability, which must not decrease for them to adopt the new products. Both farmers have adopted different manure/waste management strategies. The larger producer sells chicken manure to cattle farmers, whilst the smaller one incorporates chicken manure from his farm into his cattle diet, and yet faces issues with disposal of his cattle manure. The two farmers – entrepreneurial and pragmatic – recognise the potential of BSF biotechnology to tackle both their manure and feed issues. They have also expressed their willingness to invest in their own production facility on the basis that they would receive adequate training and institutional support (e.g. legal) and that the business model would guarantee productivity and profit.

5.5 Business models

As noted above, there are different scales and thus different business models for the production of BSF. We present here two business models associated with identified business cases. The first model is small scale; the second is close to medium scale with potential to grow.

5.5.1 Small scale

This could be done at the farm level, especially poultry or fish farms, similar to some in neighbouring Kenya. These would mainly use their waste or waste from nearby surroundings and would also mainly produce BSF to cover their own feed needs. Investments are likely to be minimal. Figure 8 shows a very simple design for a BSF unit in Kenya constructed locally. This unit has a wooden frame with love cages in the top row and trays made from jerry cans below it. Such a unit shown can produce about 5 kg of BSF larvae per week in a continuous production system. Each tray produces about 1.5 kg of fresh BSF larvae per harvest. Production, therefore, depends on the number of trays that are in use, which also depends on the amount of substrate available. Substrates for such a system are likely to vary daily because farmers would use diverse household wastes in addition to animal wastes as substrates. Because of the minimal infrastructure, the productivity in such systems is more likely to fluctuate with seasonal changes. When combined with the production of indigenous or dual-purpose chicken, the fresh larvae could directly be fed to chickens without processing. There are also self-harvesting designs for BSF where the mature larvae crawl out of the substrate and fall into a container or are directly picked by the chicken. Larvae can also be incorporated, sun-dried – whole or crushed into a powder, with other feed ingredients with different replacement ratios.

Figure 8: Simple design for smallholder BSF unit (Hawassa University)

As mentioned above, production outputs depend on multiple factors such as substrates and rearing conditions. Table 8 provides an approximation of the costs for a small BSF production unit, similar to the unit currently active at Hawassa University.

Table 8: Investments and operational costs

Capital costs	Number owned	Cost per unit (ETB)	Average lifespan	Annual depreciation
Greenhouse structure	1	200,000	3	66,667
Love cages	10	4,000	2	20,000
Racks (wooden)	8	6,000	5	9,600
Trays	300	95	5	5,700
Tables	5	4,000	10	2,000
Sieve	2	300	2	300
Small equipment	Lumpsum	20,000	2	10,000
Storage containers	2	2,800	5	1,120
Starter colony	1	7,000		7,000
Subtotal				**122,387**

Operational costs	Number	Cost per unit (ETB)	Amount per month	Annual cost
Labour	2	3,500	7,000	84,000
Electricity	Lumpsum	1,500	1,500	18,000
Water	Lumpsum	1,500	1,500	18,000
Transportation	Lumpsum	1,000	1,000	12,000
Feeding substrate (kg)	2,400	2	4,800	57,600
Sub-total				**189,600**
Total costs				**311,987**

Source: Authors' calculations informed by personal communication with Hawassa University

Table 8 indicates that a unit producing 190 kg of dry Black Soldier Fly (BSF) per month would have an annual cost of approximately ETB 312,000, with operational costs constituting around 60% of this amount. In the absence of an established market price for BSF in Ethiopia, our analysis considers two potential pricing scenarios based on comparable products: the international fishmeal price, given BSF larvae (BSFL) often replace fishmeal, and the local price of soybean meal, a widely used protein source in global animal feed, albeit with limited availability in Ethiopia.

Factoring in the projected sales of sundried BSFL and Frass as inorganic fertiliser, the anticipated annual revenue for the former scenario is ETB 207,480, resulting in a profit of ETB 27,493 per year (Table 9). Notably, the international market price used does not include import duties and transportation expenses to the farm, which are difficult to estimate due to Ethiopia's market regulations - all international imports of these commodities are exclusively approved and traded via the government. Considering these factors could raise the farm gate price of fishmeal, potentially improving profitability for BSFL producers.

Conversely, in the second scenario where BSFL is considered a substitute for soybean meal and sold at prevailing soybean meal prices, the BSFL producer would incur an annual loss of ETB 88,787. Therefore, within the current production system and local soybean meal price framework, BSF meal does not appear to be a financially viable alternative to soybean meal.

Nevertheless, given potential differences in composition among the three feed ingredients, especially in protein content, a comprehensive cost-benefit analysis of various feed rations for different livestock, such as poultry and fish, is advisable before drawing firm conclusions on economic viability.

Assuming production costs and frass sale prices remain constant, the calculated break-even price for BSF meal in this production system is ETB 79 per kilogram of BSFL. It is important to recognise that prices of production inputs, alternative products, and frass are subject to significant fluctuations, particularly influenced by geopolitical dynamics, which could impact (positively or negatively) the profitability of BSFL farms. Since BSFL production is still in its early stages in Ethiopia, pioneering farmers could generate additional revenue by selling eggs or 5-day-old larvae to others looking to start BSF production units. Improved management practices within the described system are also advisable to increase BSF larvae production and enhance profitability. It is critical to note that these calculations are based on assumptions that maintain numerous factors as constant, such as waste input quality and price, prevailing weather conditions, and larvae conversion ratios. However, in reality, these factors can vary significantly without strict operational protocols, leading to varying profitability outcomes (Liu et al., 2019; Nyangena et al., 2020). Investments in equipment such as a shredder for waste pre-processing or a dryer for faster and more uniform drying processes could improve production efficiency and product quality but would require additional capital investment.

Table 9: Revenues and profit from BSFL sales

Income source	Scenario 1 (Using fishmeal price*)	Scenario 2 (Using soybean meal price#)
Dried BSF larvae price (ETB/kg)	91	40
Dried BSF larvae production (kg/month)	190	190
Frass price (ETB/kg)	**10**	**10**
Frass production (kg/month)	1,100	1,100
Annual revenue from BSF larvae sales	**207,480**	**91,200**
Annual revenue from BSF frass sales	**132,000**	**132,000**
Total annual revenue	**339,480**	**223,200**
Total annual cost (from Table 8)	**311,987**	**311,987**
Annual profit/loss	**27,493**	**(88,787)**

*The fishmeal price used is the world market price for February 2024 obtained from Fishmeal - Monthly Price (Euro per Metric Ton) - Commodity Prices - Price Charts, Data, and News - IndexMundi. Import duties and transportation costs to the farm have not been included.

The soybean meal price used is obtained from a local feed processor at factory and farm's gate.

5.5.2 Medium scale

The project could be a stand-alone or spin-off company. The mass-rearing of BSF to process organic waste provides a local source of protein to animal producers and good-quality organic fertiliser to crop farmers. The project could opt for a decentralised approach and could set up either:

i. a network of three medium-sized rearing plants strategically located next to waste sources, or
ii. a fly breeding nursery.

This approach allows for resilience and efficiency, considering logistical, infrastructural and political challenges. The project would collect organic waste from industrial waste producers, and/or be used part of its waste in case of a spin-off; feed the waste to the larvae in a controlled environment; and harvest the larvae and the remaining organic material, and process them into five different products.

The project could be divided into three phases over eight years:

- Phase 1 – Initiation (years 1 to 2)
- Phase 2 – Establishment (years 3 to 5)
- Phase 3 – Scale-up (years 6 to 8).

Phase 1 would include a fully operational and sizeable factory. It is beyond a simple pilot low-tech production. It is the first scale production before it can switch to full-rearing production.

This progressive approach allows a step-wise market entry to secure local presence and create a strong operational environment. It also ensures a dynamic product development and launch, and allows continuous implementation of learning about the production process. The project will explore the most strategic locations within the country, such as Hawassa or Debre Zeit. Figure 9 and Table 10 illustrate, respectively, the business model and financial model profile of such a project.

Key partners	Key activities	Value propositions	Customer relationships	Customer segments
3. (Inter)national Universities 4. Insect Hardware Suppliers 5. Animal feed experts	1. Sourcing organic matter 2. Rearing BSF 3. Selling products 4. R&D **Key resources** 1. Knowledge in insect rearing 2. Adequate and efficient industrial machinery 3. Knowledge in poultry nutrition	1. Allievate waste handling 2. Provide affordable, stable and quality protein 3. Provide alternative organic fertilizer 4. Provide affordable, stable and quality lipid 5. Selling eggs to BSF outgrowers ...Using Black Soldier Fly Larvae	1. Direct sales 2. Wholesalers **Channels** 1. Sensibilisation (demo and workshop) 2. Facebook farmers group 3. Farmers association and cooperative	1. Feed millers 2. Poultry commercial farmers 3. Crop and greenhouse farmers 4. Cosmetic and agri-processing industries 5. Municipalities 6. BSF outgrowers

Cost structure	Revenue streams
1. Energy 2. Operation labour 3. Subtrate and transport 4. R&D analysis	Sales of protein pellets, organic fertilisers, lipids, BSF eggs, dry whole BSF

Environmental costs	Societal costs	Societal benefits	Environmental benefits
1. Energy & water but very low	1. Amonia and waste odors – mitigated	1. Increase access to affordable animal protein to population 2. Improve health from removing great disease vector: organic waste	1. Save land, water, deforestation, CO_2 from waste and production/importing altenative: soya

Figure 9: Business Model Canvas

Table 10: Financial plan

Phase/Year	Phase 1: Initiation (yr 1–2)	Phase 2: Establishment (yr 3–4)	Phase 3: Scale-up (yr 5–6)
Factory counts	0.3	1	3
Technology	Racks	Racks	Racks
Automation	low	medium	medium
Pre- and post processing	medium	high	high
Waste processed	9.4K tons	31K tons	94K tons
Animal protein produced	520 tons	1.7K tons	5.2K tons
Organic fertiliser produced	770 tons	2.5K tons	7.7K tons
Labour	20 employees	35 employees	60 employees
Total CAPEX	2M EUR	-	6M EUR
Sales	1.1M EUR	4.1M EUR	12.2M EUR
EBIDTA	~0.5M EUR	0.9M EUR	4.6M EUR
Total addressable market for poultry	30M EUR	62M EUR	96M EUR
Total addressable market for fertiliser	730M EUR	1B EUR	1.5B EUR
Market growth	10–15%	10–15%	10–15%
Main clients	Poultry/Crop farmers	Feed millers/Crop farmers	Feed millers/Crop farmers

Table 11 indicates the beneficial impacts of BSFL in comparison to the major alternative product: soya (see also Table 1). The project activities would reduce water and air pollution from waste methane emissions and leachate to the ground, and thus have beneficial impacts on public health, sanitation and, consequently, the local economy. The insect protein will lead to improved livelihoods and food security, and a higher quality of nutrition for the human population thanks to:

- reduced competition for soya and fishmeal for food (feed vs food dilemma)
- competitive and highly nutritional protein that improves livestock efficiencies and thus farmers' livelihoods.

Higher efficiencies will attract new livestock for farmers and increase yields, and lead to larger and more affordable total animal protein, increasing the nutritional status of the population, particularly the most vulnerable. In addition, by-products such as organic fertiliser (underused and imported) will increase soil quality and farm efficiency, and thus improve the livelihoods and food security of farmers.

Table 11: Local impacts

Impact category	Indicator equivalent	Phase 1: Initiation*	Phase 2: Establish-ment*	Phase 3: Scale-up*
Deforestation avoided	Football pitches	570	1,900	5,700
Water preserved	Bathtubs	7,400	24,000	74,000
CO_2-eq not emitted	Cars off the road	5,300	17,000	53,000
Waste recycled	Tons	9,400	31,000	94,000
Farmers beneficiaries	Number of smallholders	12,000	42,000	128,000

* Annual average. Impacts are calculated in comparison to a soya equivalent production.

Source: Authors' calculations using Table 1 sources

5.5.3 Opportunities for BSF production in Hawassa

Hawassa University has a small-scale experimental BSF unit with ongoing trials, and leads BSF production in the region. The outputs fluctuate greatly in quantity depending on the quantity of waste and leftovers collected from the university canteen (more during term time and less during holidays and after the end of the academic year). The energy usage is minimum (only for grinding the waste and larvae). The climate (temperature and humidity) of the production unit is controlled thanks to natural ventilation, passive cooling and heating, which has the advantage of low capital and operational expenditure. The ground larvae are placed into a pond-size fish production unit also on campus, and the frass is used for research purposes with ICIPE. The unit managers are looking into and testing additional affordable sources of substrates for BSF. A trial with avocado seeds was not successful, even when mixed with other nutritious products. The tannin content of the substrate remained too high for BSF production. Yet, the university set-up is ideally located near an economically active region and eco-industrial park with several agro-food industries such as avocado oil and potato chips, and thus could serve as a centre for knowledge, training and a platform to promote a local eco-system around BSF production. The main challenge in Hawassa is that organic waste is not separated from other municipal waste and ends up in landfill or on the streets. Yet much of the waste and by-products from agri-food industries are not being used, and, if collaboratively managed, could be used to foster BSFL production in Hawassa using an industrial ecology mindset.

5.5.4 Opportunities for BSF production in Debre Zeit

Ethiopian commercial poultry (broiler and layer) production is concentrated in Debre Zeit. Local companies produce a huge amount of slaughterhouse waste consisting mainly of digestive tracts, since other organs are sold to the pet food industry. There are several other waste streams (e.g. chicken manure, brewery by-products, fruits and vegetable waste) available in large quantities in Debre Zeit. Currently, many of them are sold to livestock producers or as feed ingredients to commercial feed millers. Consequently, the substrates will not be freely accessible, and their prices will impact the waste streams, and any BSF producer in the region will have to guarantee the profitability of the business. Yet the diversity and plurality of local waste streams and the environmental conditions (temperature and humidity) make this region highly suitable for BSF production. One slaughterhouse intends to support its out-growers to produce BSFL on its farms, and wants to provide knowledge, starter material and substrates to the farmers. Successful initiatives could support BSFL production in Debre Zeit region. Such success could then spill over to other strategic areas across the country.

A large feed miller in Debre Zeit is keen to incorporate BSFL into poultry feed mix. As a large producer, it has strict specificities regarding the incorporation of new ingredients. They must be supplied to the factory:

i. as BSF protein powder or pellets
ii. in large enough quantities, and in a storable form
iii. at a competitive protein-to-price ratio vis-à-vis the direct alternatives, such as soya bean or cake.

Finally, Debre Zeit suffers from urban waste problems in which 432m3 of unsegregated waste is produced per day and is collected door to door by the municipality and ends up in landfill. The municipality has recently been proactive and is funding a plan to teach the community and raise awareness of the waste problem and how to solve it. The plan is divided into four steps:

- waste reduction
- waste separation
- waste handling
- waste management.

The residents of Debre Zeit will be trained to reduce waste production and to separate waste at source, where at least the biodegradable waste and plastic will be separated. Three-quarters of the waste produced in Debre Zeit is from residential premises and not separated. Currently, some private enterprises are collecting waste from the municipality and separating the biodegradable part that is transformed into compost. Only 15% of the collected waste is separated and used for composting, although biodegradable waste forms 47% of the total waste collected.

A combination of public and private incentives could create a fruitful synergy in the fostering of BSF production in Debre Zeit. It is a promising hotspot for BSF production and marketing. Agro-industry and residential organic wastes, if well managed, could be used as BSF substrates. Additionally, the poultry sector is open to applying BSFL as poultry feed (Personal communication, 2023).

6 Enabling factors and bottlenecks

6.1 Logistics

For any industry to thrive, a steady supply (and logistics) of sufficient and good-quality inputs are paramount, and this is no different for a BSF production farm. Thus, a deep and thorough understanding is required of the sourcing of the waste in terms of quality and quantity. More in-depth research on waste procurement is required, involving interviews with many, public and, especially, private stakeholders.

The entrepreneur has to secure long-term partnerships with reliable suppliers who can provide a steady supply of organic matter. For this, the business would probably support waste collection service providers in optimising their collecting methods and so that they collect and transport organic matter segregated as much as possible from all other waste streams. The enterprise may also work in direct collaboration with private and public organisations that produce waste continuously and find it a burden, and thus incur a cost to dispose of it. It is highly recommended that the entrepreneur or other organisation should conduct a study to have a full understanding of the waste streams at the micro level of the operational environment of the BSF farms, as well as all related logistics associated with the transportation from the source to the insect farm. An evaluation of the potential biohazards that could be found in the waste should also be evaluated, with the help of experts, if necessary, to ensure the continuous well-being of the larvae, livestock and humans.

6.2 Legal aspects

Public and private key stakeholders who were interviewed in this study all emphasised the importance of legislation and regulations governing BSF production in the country. The production of BSF needs to be standardised and regulated for quality and safety purposes. ICIPE Ethiopia, in collaboration with the Ethiopian Standard Agency, drafted a proposal for production standards that cover hygiene, rearing conditions, safety (chemical and microbiological hazards) and the harvesting of BSF. The draft does not have any restrictions on the types of substrates to be used. The National Technical Committee for poultry feed assessed the suitability of BSFL as a poultry feed ingredient and has already approved the standards. These standards have been published by the Institute of Ethiopian Standards and implementation of this standard shall be effective as of 29 June 2023. This crucial step of formally standardising and regulating BSF production was said, by these key stakeholders, to be likely to have a great impact on potential producers and users of BSF. Ethiopian society tends to trust government decisions more than ideas suggested by the private sector and NGOs. Its officialisation will serve not only as an authorisation to produce BSF products but also as a compelling argument to convince sceptics about their suitability and safety, as well as to promulgate the innovative concept.

6.3 Cultural aspects

Cultural perception and acceptance are key for the uptake of any innovative technology. The aforementioned commercial poultry farmers' perspectives showed an open-minded attitude towards and a promising theoretical acceptance of the use of insect-based protein and lipids in poultry feed. Although the ingredients listed in poultry feed are usually not mentioned on labels, the nutritional composition is. Farmers might not know about the presence of insect products in their poultry feed unless such labelling is stipulated. Besides, some stakeholders mentioned that the inclusion of BSF products in animal feed will not be problematic because Ethiopian society will easily understand that insects are the basal part of free-roaming chickens' diet. Nevertheless, confirmation from a larger and more diverse sample may be needed.

From discussions with a few poultry consumers, producers and other stakeholders, mixed opinions were shared on their (and Ethiopian society's) willingness to consume chicken or fish fed with BSFL. Whilst some consumers and farmers had no issues, others found it unacceptable to produce or consume animals fed with insects reared on organic waste. An additional point to consider is the reluctance that may be expressed by city officials and residents to use biotechnology such as insect production to solve the problem of waste. Indeed, people often perceive insects as pests and a nuisance to humans (e.g. locusts, mosquitos).

Given the high price of chemical fertilisers, the BSF frass could not only be a great alternative but also a crucial introductory step towards the adoption of BSF production. The value of frass as an additional by-products should not be ignored for the adoption of BSF. Indeed, it may stand as a competitive alternative to already alarmingly expensive imported inorganic fertilisers. It may also help to bypass people's cultural barrier to adopt other products such as protein or lipids into their chickens. In short, organic fertiliser from BSF may be a less sensitive product to be adopted by farmers than chicken that are fed insects, and thus may be considered as a foot-in-the-door marketing strategy.

This innovative concept could thus face some objections. Indeed, across many countries in the world, people generally have a negative association with insects. In all the above cases, to foster a mindset change, it is important to draw parallels with what is familiar to the user. Neighbouring countries have already undertaken the development of the insect industry, and by supporting, empowering and creating a competing viewpoint and introducing this to officials and communicating with the residents, mindsets could be shifted.

Finally, the ratification of the standards will endorse the production of BSF, should have a reassuring effect on the population (producers, users and consumers), and could be employed in communication and marketing strategies, if necessary. For a long-term introduction of BSF in the country, a more detailed consumer study may be required. Such a study could help target customer segments that do not have a concern with consuming chicken fed with BSFL.

6.4 Training and skill development aspects

Currently, BSF production in Ethiopia lacks trained and skilled personnel. BSF are newly domesticated insects that have different life cycles and requirements compared to other farmed insects (e.g. bees and silkworms). Therefore, training farmers/personnel is indispensable for successful production. ICIPE, in collaboration with Hawassa University, is running three courses (one PhD and two master's programmes) on the production of BSFL as fish feed and on the social acceptance of BSFL in poultry feed. The results of these studies will be a starting point for spreading knowledge about BSF using scientific evidence. It is expected that these results will attract potential BSF producers to be trained and thereafter start production. Hawassa University showed interest and availability to work more on BSF production and aims to make the university a reference centre for BSF production in Ethiopia. Its activities will include research on optimising BSF production under Ethiopian conditions and providing training for interested potential producers. The university, however, lacks adequate lab facilities to conduct certain research and could partner with other international organisations or private companies that have access to more advanced measurement technologies. The ongoing study on rearing BSF using university canteen food waste is the only example of BSF production and it is attracting students, farmers and potential producers. Furthermore, as mentioned above, the municipality of Debre Zeit is taking the initiative in raising awareness and training residents and waste producers (restaurants, hotels, etc.) on waste separation and management. This will result in more organic waste being segregated and thus available for BSF production.

7 Conclusions and recommendations

From this research it is apparent that Ethiopia faces the triple burden of:

1. inadequate handling of the increasing waste generated in and around urban areas due to poor infrastructure
2. a lack of substantial provision of animal protein to the population due to a high and volatile production cost, leading to a high and unaffordable consumer prices
3. increasingly expensive fertilisers, as a result of infrastructural and geopolitical shifts.

BSFL innovative biotechnology has been shown to successfully tackle these three challenges in a profitable and environmentally sustainable manner worldwide. This technology has recently been introduced into Ethiopia. Several public, academic and private actors have shown willingness and proactiveness in testing and fostering the onset of the technology in the country.

The successful onset of BSF production is the result of five key parameters:

1. availability, accessibility, affordability and quality of waste streams (substrates)
2. competent and skilled producers and research in BSF
3. the necessary infrastructure for BSF production
4. a cultural acceptance by a sufficiently large amount of users and consumers of several value chains (waste management, poultry or fish production) to ensure demand for the products
5. price competitiveness, vis-à-vis the alternatives.

Many of these parameters are present in Ethiopia and particularly in Hawassa and Debre Zeit regions. Yet many challenges remain to be overcome before a complete sector can grow and proliferate. Unless directly collected from agro-industrial sources, organic waste is very often mixed with other waste streams (plastic, paper, metals, etc.) and therein adds a cumbersome and costly additional activity for BSF producers. For waste management purposes, municipality and local authorities will have to further enforce waste segregation, and invest in infrastructure and the education of citizens to increase the efficiency of organic waste collection.

Legal approval, field showcase examples, and effective communication and marketing strategies should overcome the cultural barriers and empower young entrepreneurs to start up BSF production. However, it will be necessary for these future actors to receive capacity-building and technical support before and during the onset of BSF production. Indeed, BSF production, though successfully achieved with a very low-key approach, will demand that actors have a greater understanding of the production processes to reach commercial viability.

BSFL could be a competitive ingredient for animal feed in Ethiopia, eventually lowering its cost and, in turn, the price of animal food sources, which would improve affordability and access to animal protein, particularly for the poor. BSF biotechnology could also play a crucial role in providing an alternative to inorganic fertiliser, currently expensive and under supplied, and thus support short-term crop farmers and long-term soil health. BSF biotechnology as a service to reduce waste could also be a cost-effective solution for municipalities to tackle organic waste management more efficiently and effectively, ultimately leading to economic returns from a cleaner, more attractive and improved environment.

To facilitate the onset of the sector and the smooth adoption of the innovative biotechnology we recommend the following activities:

1. A micro-level waste flow analysis of future project farms should be conducted to acquire an accurate understanding of the waste streams; their respective availability (time and quantity), quality (nutrient and moisture content), and costs (purchase and transport). In other words, understanding the project supply chain is paramount to its success.
2. Consumer market research could help with customer segmentation and the design of targeted marketing strategies to overcome potential cultural barriers.
3. Open discussion with local cleaning administration departments and cleaning administration agencies on how BSF farms, with a focus on waste reduction, could provide an affordable service to the municipality and community, and thus establish mutually beneficial partnerships regarding access to organic waste and collection infrastructure.

4. As the first steps to a legal framework (draft and publication of standards), effective communication should be undertaken to as early as possible to inform municipal government officials, reassure consumers, and trigger interest from entrepreneurs. Efforts in developing an attractive legal environment for insect production and processing should be pursued.
5. Scientific research on BSF in different universities should be pursued and extended to:
   i. acquire an understanding of the species in its Ethiopian environment
   ii. develop specific, adapted production techniques to maximise throughput in local conditions
   iii. attract and train future BSF farmers/entrepreneurs.
4. Field demonstrations showcasing the safe and effective benefits that BSF products (fresh, dry, proteins, lipids, fertilisers) have for livestock and crop growth should be made accessible, and implemented to support product adoption and sector onset.

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Annex I – Projected poultry feed demand in Ethiopia till the year 2032

Year			2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Total poultry meat production (tons)			54,000	60,500	54,000	60,500	63,909	67,510	71,314	75,333	79,578	84,062	88,799	93,802	99,088	104,672
Commercial poultry meat production share (tons)			14%	14%	14%	14%	15%	15%	15%	16%	16%	17%	17%	18%	18%	19%
Commercial meat production (tons)			7,750	8,683	7,750	8,683	9,409	10,196	11,049	11,973	12,974	14,059	15,235	16,510	17,890	19,387
Commercial egg production (tons)			73,357	73,357	73,357	73,357	77,491	81,857	86,470	91,342	96,489	101,926	107,670	113,737	120,145	126,916
Egg production non-commercial (tons)			14,760	14,760	14,760	14,760	15,592	16,470	17,398	18,379	19,414	20,508	21,664	22,885	24,174	25,536
Feed demand meat commercial (tons)	FCR	2.0	15,500	17,366	15,500	17,366	18,818	20,392	22,098	23,946	25,949	28,119	30,471	33,019	35,781	38,773
Feed demand eggs commercial (tons)	FCR	3.5	256,750	256,750	256,750	256,750	271,217	286,500	302,644	319,697	337,712	356,741	376,843	398,078	420,509	444,204
Feed demand meat non-commercial (tons)	FCR	1.0	46,250	51,817	46,250	51,817	54,500	57,314	60,266	63,360	66,604	70,002	73,563	77,293	81,198	85,285
Feed demand eggs non-commercial (tons)	FCR	1.5	22,140	22,140	22,140	22,140	23,388	24,705	26,098	27,568	29,122	30,762	32,496	34,327	36,261	38,305
Total feed demand commercial (tons)			272,250	274,115	272,250	274,115	290,035	306,892	324,741	343,643	363,660	384,860	407,314	431,097	456,290	482,978
Total feed demand non-commercial (tons)			68,390	73,957	68,390	73,957	77,888	82,020	86,363	90,928	95,725	100,765	106,059	111,620	117,459	123,589
Dry BSFL replacement commercial (tons)	Replacement rate (%)	18%	49,005	49,341	49,005	49,341	52,206	55,241	58,453	61,856	65,459	69,275	73,317	77,597	82,132	86,936
Dry BSFL replacement non-commercial (tons)	Replacement rate (%)	10%	6,839	7,396	6,839	7,396	7,789	8,202	8,636	9,093	9,573	10,076	10,606	11,162	11,746	12,359
Total addressable market (€'000) – commercial only	Using soya cake's price - 2022	€747 /ton	36,607	36,858	36,607	36,858	38,998	41,265	43,665	46,206	48,898	51,748	54,767	57,965	61,352	64,941
Total addressable market (€'000)			41,715	42,382	41,715	42,382	44,816	47,392	50,116	52,999	56,048	59,275	62,690	66,303	70,127	74,173
Total addressable market (€'000) – commercial only	Using soya cake's price - 2020	€550 /ton	26,953	27,137	26,953	27,137	28,713	30,382	32,149	34,021	36,002	38,101	40,324	42,679	45,173	47,815
Total addressable market (€'000)			30,714	31,205	30,714	31,205	32,997	34,893	36,899	39,022	41,267	43,643	46,157	48,818	51,633	54,612

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