Public Disclosure Authorized

Public Disclosure Authorized

# Insects for Impacts

## *Models for farming Black Soldier Fly in Africa*









Dorte Verner, Hans Kelstrup, Glenn Surabian, Line Åstrom, Nada Omeira, and Laura Martinussen

WORLD BANK GROUP

© 2026 International Bank for Reconstruction and Development / The World Bank
1818 H Street NW, Washington, DC 20433
Telephone: 202-473-1000; Internet: www.worldbank.org

Some rights reserved

This work is a product of the staff of The World Bank with external contributions. The findings, interpretations, and conclusions expressed in this work do not necessarily reflect the views of The World Bank, its Board of Executive Directors, or the governments they represent. The World Bank does not guarantee the accuracy, completeness, or currency of the data included in this work and does not assume responsibility for any errors, omissions, or discrepancies in the information, or liability with respect to the use of or failure to use the information, methods, processes, or -conclusions set forth. The boundaries, colors, denominations, and other information shown on any map in this work do not imply any judgment on the part of The World Bank concerning the legal status of any territory or the endorsement or acceptance of such boundaries.

Nothing herein shall constitute or be construed or considered to be a limitation upon or waiver of the privileges and immunities of The World Bank, all of which are specifically reserved.

**Rights and Permissions**
This work is available under the Creative Commons Attribution 3.0 IGO license (CC BY 3.0 IGO) http://creativecommons.org/licenses/by/3.0/igo. Under the Creative Commons Attribution license, you are free to copy, distribute, transmit, and adapt this work, including for commercial purposes, under the following conditions:

**Attribution**—Please cite the work as follows: Verner, Dorte, Hans Kelstrup, Glenn Surabian, Line Astrom, Nada Omeira, and Laura Matinussen. 2026. *Insects For Impact; Models for Farming Black Soldier Fly in sub-Saharan Africa.,* Washington, DC: World Bank.

# Table of Contents

*Acknowledgments* ..... *i*

*About the Authors* ..... *ii*

*Overview* ..... *iii*

**The African evidence base shows what works, where, and under what conditions** ..... **iii**

**Four BSF farming models have been identified that work under different conditions** ..... **v**

**Madagascar provides lessons on scaling BSF models** ..... **vii**

**Ways forward** ..... **viii**

*Introduction* ..... *1*

*Chapter 1. The Case for BSF Farming in Africa* ..... *2*

**1.1 Organic Waste and the Protein Gap** ..... **2**

**1.2 African Settings and Scaling** ..... **7**

**1.3 BSF Larvae Outputs: Feed, Food, and Soil** ..... **24**

*Chapter 2. BSF Farming in Practice* ..... *70*

**2.1 Conditions for Viability** ..... **70**

**2.2 Farming Scenarios** ..... **80**

**2.3 Black Soldier Fly Production in Madagascar: Two Models, Shared Lessons** ..... **106**

**2.4 Pathways Forward** ..... **110**

*Chapter 3. Madagascar Black Soldier Fly Value Chain Analysis* ..... *124*

**3.1 Sector Overview of Black Soldier Fly Farming in Madagascar** ..... **124**

**3.2 Value Chain Analysis** ..... **140**

**3.3 Recommendations for Improving the Enabling Environment for Madagascar's Insect Sector** ..... **180**

*Chapter 4. Lessons from the BSF Pilot Program in Kenya, Malawi, and Zimbabwe* ..... *194*

**4.1 Insect Farming Pilots** ..... **197**

**4.2 A Quantitative Assessment of the Insect Farming Pilot Program** ..... **213**

**4.3 Beneficiary Testimonies from the Insect Farming Pilot Program** ..... **217**

**4.4 Conclusions and Recommendations** ..... **218**

*Chapter 5. Recommendations and Ways Forward* ..... *224*

# Acknowledgments

This project was developed and led by Dorte Verner (Lead Economist, Agriculture and Food Global Practice, World Bank Group). Lead-authors of the reports were Hans Kelstrup (Director of Applied Insect Rearing Systems at the Madagascar Biodiversity Center; Consultant, World Bank Group) of Chapter 1 and 2, Glenn Surabian (Consultant, World Bank Group) of Chapter 3, and Dorte Verner (Lead Economist, World Bank Group) of Chapter 4 and 5. Contributing authors to Chapter 4 were Nada Omeira (Livelihoods and Economic Inclusion Officer, UNHCR), Line Åstrøm (Senior Livelihoods and Economic Inclusion Officer, UNHCR; Consultant, World Bank Group) and Laura Martinussen (Consultant, World Bank Group). Contributions the Pilot Program came from Juliet Murugi Ngari (Economic Recovery Officer – Insect Farming, DRC, Kenya), Hassan Aden (Livelihoods & Economic Inclusion Associate, UNHCR, Kenya), Ignatius Simiyu Nyongesa (Economic Recovery Assistant – Insect Farming, DRC, Kenya), Khadija Shabel (Livelihoods & Economic Inclusion Associate, UNHCR, Kenya), Esther Nyirenda (Insect Farming Expert, UNHCR; Consultant, World Bank Group), Philmon Luke Chimwe (Livelihoods and Economic Inclusion Individual Contractor, UNHCR; Consultant, World Bank Group); Lovemore Dumba (Livelihoods and Economic Inclusion Officer, UNHCR, Zimbabwe); Brian Masango (Livelihoods Officer, World Vision, Zimbabwe). We would also like to acknowledge the contributions for the task from Tom Bry-Chevalier (Observatoire national de l'élevage d'insectes), Corentin Biteau (Observatoire national de l'élevage d'insectes), Valerie Stull (interdisciplinary environmental health scientist, University of Wiscounsin), Nanna Roos (Professor, University of Copenhagen), Laura Skrubbeltrang Hansen (Postdoctoral Researcher,University of Aarhus), Time Hapana Fatch (Senior Agriculture Economist, World Bank Group), Easther Chigumira (Senior Agriculture Specialist, World Bank Group), Stephen D'Alessandro (Senior Agriculture Specialist, World Bank Group), Esayas Nigatu Gebremeskel (Senior Agriculture Specialist, World Bank Group), Franck Berthe (Senior Agriculture Specialist, World Bank Group), Felamboahangy Henintsoa Rasoarahona Ep Randevoson (Consultant, World Bank Group), Sandy Razafinjoelina (Consultant, World Bank Group), Eliot Cohen (Consultant, World Bank Group), and Mario Mendez (Senior Program Assistant, World Bank Group). The authors acknowledge Maximillian Ashwill (Consultant, World Bank Group) for his excellent editing of this report. Finally, the team expresses its deep appreciation to the refugees who participated in and contributed.

The team is grateful for support from Frauke Jungbluth (Practice Manager, World Bank Group); appreciates guidance and peer review comments from peer reviewers Jeffrey Tomberlin (Professor Texas A&M University, Presidential Impact Fellow, Director National Science Foundation Center for Insect Biomanufacturing and Innovation); Joanne Catherine Gaskell (Senior Economist, World Bank Group); and Franck Berthe (Senior Agriculture Specialist, World Bank Group); and acknowledges the support from the leadership in the World Bank Group, including by Anna Wellenstein (Regional Practice Director) and the United Nations High Commissioner for Refugees, including Raouf Mazou (Assistant High Commissioner for Operations), Betsy Lippman (Senior Advisor for Innovations and Partnerships), and Sajjad Malik (Director, Division of Resilience and Solutions). The team also acknowledges the support of the Government of Denmark through its Innovative Solutions funding to UNHC and at the World Bank Group's Korean Green Growth Trust Fund, Chinese World Bank Trust Fund, and the Food System 2030 Trust Fund. The team is also very grateful for the guidance provided by the trust funds' managers and teams.

# About the Authors

**Hans Kelstrup, PhD,** is the Director of Applied Insect Rearing Systems at the Madagascar Biodiversity Center in Antananarivo. From 2016 to 2024, he served as Chief Science Officer at Beta Hatch (Seattle, USA), where he led mealworm breeding and production. From 2024 to 2026, he was Chief Insect Breeding Officer at EXA Feed in Madagascar, directing black soldier fly and cricket farming operations. Before entering commercial insect agriculture, he trained as an entomologist, earning a PhD at the University of Washington and conducting postdoctoral research at Stellenbosch University on the behavior and endocrinology of social insects.

**Laura Martinussen**, is a sustainable development professional specializing in design, research and implementation of Black Soldier Fly and circular agricultural models for vulnerable communities across sub-Sahara Africa. Her approach is data-driven and combines business modeling with technical BSF knowledge and hands-on experience in refugee and host community settings.

**Nada Omeira,** works at UNHCR, the UN Refugee Agency, advancing private sector partnerships that support refugee economic inclusion, employment and self-reliance. With over 20 years of experience across humanitarian and development contexts, her work has focused on sustainability, agrifood systems, and women and youth economic empowerment, promoting inclusive development through policy, partnerships and impact to improve lives, strengthen communities and protect the planet.

**Glenn Surabian,** is a development consultant whose expertise lies in competitiveness diagnostics and enhancement using a value chain analysis approach. He has worked throughout Africa applying this and other methodologies to critical topics including food security, job creation, greenhouse gas management, and resource conservation.

**Dorte Verner, PhD,** is a Lead Economist in the Agriculture and Food Global Practice, The World Bank, where she leads on alternative protein, food security, food system transformation, climate change, jobs, and the fragility, conflict, and violence agenda. She has more than 30 years' experience with innovation, research and development knowledge, and projects. Previously, Dr. Verner served as the principal economist at the Inter-American Development Bank, where she led the evaluation of climate change. She has published in peer-reviewed journals, produced books, and served as an advisor to governments. Before joining the World Bank, Dr. Verner worked as a researcher at the OECD, the European University Institute, and Paris I (Sorbonne) and worked in the private sector in São Paulo, Brazil.

**Line Åstrøm,** is an international development specialist with over 20 years of experience leading global initiatives on economic and social inclusion, labor market development, and food security in contexts of forced displacement. Her expertise includes strategic partnerships, risk assessment, and institutional reform, working with governments, donors, UN agencies, the private sector, and international financial institutions. Within UNHCR, she led the organization's work on insect farming for refugees, advancing innovative approaches to food security and economic development.

# Overview

**This report assesses the role of black soldier fly (BSF) farming in sub-Saharan Africa's emerging circular food economy.** It examines whether BSF can help address three linked pressures: insufficient affordable protein, unmanaged organic waste, and soil fertility constraints. The report focuses on BSF larvae as animal feed, frass as fertilizer, and the market systems, production conditions, and enabling environment needed to make BSF farming viable at different scales. Feed is the nearest-term market and the report's central focus, but human consumption is developed as a full pathway in its own right, including the conditions for its viability, because its development significance, shortening the food chain and delivering scarce nutrients directly to deficient populations, is potentially the largest of any BSF application.

**The analysis combines scientific research, African sectoral evidence, operational case studies,** and pilot program data. It reviews evidence on organic waste streams used as larval feed, substrate-borne contaminants, livestock and aquaculture feeding trials using BSF larvae frass agronomy, farm economics, market demand, and regulatory conditions. It also draws on operational evidence from African BSF farms and detailed pilot evidence from displacement-affected settings, including production logs, beneficiary surveys, interviews, focus groups, field observations, partner meetings, missions, and a learning workshop.

**BSF offers a practical response to both sub-Saharan Africa's structural protein deficit and its unmanaged organic waste burden.** Nearly 300 million Africans faced hunger in 2023, and the number is rising. Animal-source foods supply complete, bioavailable protein, but they remain financially inaccessible to many food-insecure households. Feed costs and constrained feed supply help drive that problem. At the same time, biodegradable waste accounts for nearly half of solid waste generation in low- and middle-income countries and remains largely untreated. BSF farming addresses both at once. Larvae convert organic waste into protein-rich biomass, which is usable as animal feed, while frass, the waste and excrement of the insects, becomes a high-value fertilizer.

**The report finds that BSF farming can recycle organic waste into animal feed and fertilizer, but introducing the technology does not by itself deliver all its benefits.** BSF can support food security, waste recovery, farm productivity, and new livelihood opportunities when projects build the right operating conditions around it. These conditions include reliable access to suitable substrate, sites that can receive and process that material, infrastructure matched to the operation's objectives, and operators who can use data to manage substrate quality, production, and outputs. Viability also depends on product markets, realistic pricing, extension and business support, financing that fits the production cycle, and clear rules for feed, food, and fertilizer products. Scale can expand the benefits of BSF farming, but only when these conditions are built into the model from the start. The report therefore treats BSF as a set of models suited to different African contexts, rather than a single technology package.

## The African evidence base shows what works, where, and under what conditions

**Substrate is the binding constraint for BSF economics.** Substrate is the organic material that feeds BSF cultivation and often takes the form of waste or agro-processing byproducts. For operations that depend on

purchased inputs, substrate sourcing can account for 81–90 percent of the cost structure. Evidence from East Africa and Madagascar shows that BSF economics depend on substrate that is cheap, reliable, and available in sufficient volume. When those conditions hold, profitability is possible. When substrate becomes priced, supply becomes contested, or volume falls below what the operation needs, the economics deteriorate quickly. Moreover, waste collection and transport often turn nominally free substrate into a paid input. The pivotal question is whether substrate is paid or genuinely free at the farm gate. BSF investments are most credible when projects establish what substrate costs, where it comes from, and how much can be supplied before committing capital.

**African trials show that BSF can perform on par with conventional feed proteins, with the strongest cost case against fishmeal.** Once substrate is secured, the next question is whether larvae perform as a feed ingredient. Across African poultry and aquaculture trials, BSF meal has supported comparable growth, feed conversion, and product quality. Even modest substitution rates can produce substantial cost savings when BSF replaces imported protein sold at premium prices. The economic case is stronger against fishmeal than against plant-based protein. Fishmeal supply across East Africa is structurally constrained, while soybean meal remains a low-cost commodity that BSF rarely undercuts. The trial evidence is therefore most actionable in fishmeal-dependent aquaculture and high-feed-cost poultry.

**Frass can work as a credible fertilizer, especially when it is composted before use.** Field trials across African contexts have shown composted BSF frass matching or exceeding mineral fertilizer and outperforming commercial organic fertilizers on net income at equivalent nitrogen rates. Kenyan farmers who used frass on their own fields generated 30–232 percent higher net income than farmers buying similar fertilizer. Trials in Madagascar suggest that frass remains profitable for smallholders even at prices well below the cost of equivalent nutrient supply from cattle manure or mineral NPK. Results are not uniform. Fresh, uncomposted frass has produced germination failure under otherwise comparable conditions. Composting consistently emerges as the most reliable way to unlock frass value, but it adds time, cost, and infrastructure that smallholders cannot always absorb. Frass recirculation into feed substrate offers a faster alternative and may increase larval yields per unit of waste, though the evidence base is still developing.

**BSF can recover value from mycotoxin contamination already present in African food and feed systems.** Aflatoxin B1, classified as a Group 1 carcinogen by the International Agency for Research on Cancer, contaminates staple crops across much of sub-Saharan Africa at levels that routinely exceed regulatory limits. Contaminated grain often remains in the food and feed supply because no practical alternative exists. BSF larvae do not accumulate the major regulated mycotoxins at levels that compromise end-product safety, and bioconversion appears to suppress the Aspergillus fungi responsible for aflatoxin production. BSF therefore offers a way to recover economic and nutritional value from contamination that has already occurred.

**BSF can succeed in fragility, conflict, and violence settings when communities have a clear reason to support it.** FCV conditions make community buy-in a precondition for site and beneficiary selection, not a soft implementation variable. The 2022 World Bank-UNHCR Jamjang proof-of-concept pilot in South Sudan demonstrated this in both directions. At sites where the community had a concrete reason to want BSF to work, colonies took root using only remote training. Parallel sites with weaker engagement produced weaker outcomes. The same pattern recurs across the MAMAH program in Uganda's Kyaka II settlement,

a DanChurchAid pilot in Kakuma, and the World Bank-UNHCR pilot program in Kenya, Malawi, and Zimbabwe.

## Four BSF farming models have been identified that work under different conditions

**The report identifies four BSF production models that fit different starting conditions, capital structures, and risk profiles.** Treating them as variants of the same investment category risks misallocating support because each model depends on a different operating logic. The four models share one discipline. Successful operations expand what they understand, not what they hope will work. Operations that commit infrastructure or capital before the learning phase fail at every scale, from household micro-farms to industrial facilities.

**The household model integrates BSF into existing farm systems, with returns realized mainly as costs avoided rather than sales gained.** In household-scale BSF, kitchen scraps and crop residues feed larvae, larvae feed poultry or fish, and frass fertilizes a kitchen garden. Capital requirements are minimal, with viable operations launched in Madagascar for under US$60. Returns come mainly from reduced costs, including purchased feed avoided and fertilizer not bought, rather than from commercial revenue. Training and market linkage emerge as the most useful forms of support for smallholders. Whether a household operation becomes commercial depends largely on whether a buyer emerges, either through external market linkage or through the operation's own demonstration and outreach.

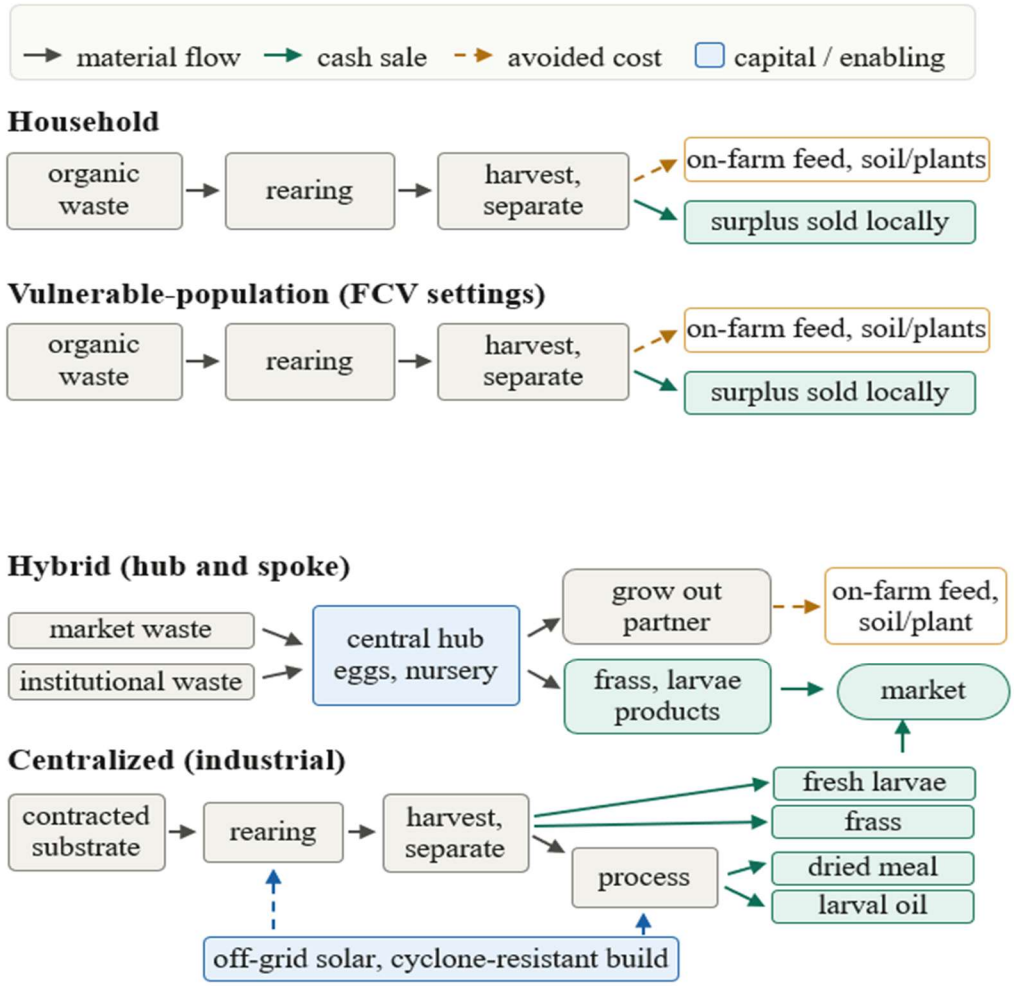
**The hybrid model centralizes the most demanding biological stages and distributes grow-out, expanding reach while concentrating risk at the central node.** A Malagasy producer's partnership with a 100,000-chicken poultry operation illustrates the model. Juvenile larvae placed beneath cages consumed manure and grew into harvestable biomass within ten days, reducing the farm's purchased feed expenditure by approximately 30 percent. This makes the hybrid model a plausible bridge between household integration and full industrial scale, but only when the central node is resilient. When Cyclone Gezani destroyed BSF Tamatave's infrastructure in early 2026, downstream producers lost their biological supply. The household model distributes risk, while the hybrid model concentrates it. Resilience at the central node therefore determines whether downstream producers can keep operating.

**The centralized model works only where substrate, energy, climate, capital, and learning conditions align before scale-up.** EXA Feed, in northern Madagascar, meets all five conditions through a long-term brewery feedstock agreement, an off-grid solar facility with marginal energy costs at a fraction of national grid tariffs, cyclone-resistant construction, and a two-year pilot in Antananarivo that developed protocols before transfer to a larger site. The South African failures of AgriProtein and Inseco show that the binding risks at scale are execution, infrastructure dependency, climate, and overreach.

**The vulnerable-population model can support livelihoods in refugee and displaced settings, but its main risk comes after technical success.** These BSF operations are established under donor or development financing in refugee, displaced, or other vulnerable-population settings. Participants are selected from those populations rather than from commercial entrepreneurs. The four-country BSF pilot

program in Kenya, Malawi, Zimbabwe, and South Sudan illustrates the model. Substrate is typically secured through beneficiary collection, sometimes paid, or through formal supply contracts. Outputs are partly absorbed internally through integrated poultry and crop production. Success criteria also extend beyond commercial viability to food security and livelihood income. The distinctive risk is the funding cliff. Technical viability is often achieved before commercial viability, and the transition catches programs unprepared when implementing partners exit. Operations survive handover when business-model development begins early enough to bridge that gap.

**Figure O1: The four BSF production models, including cost and revenue**




Source: Authors.

**Figure O1 shows the cost and revenue structure of the four BSF models.** A legend defines five elements: gray boxes are production stages, dark arrows are material flow, green arrows are cash sales, dashed amber arrows are avoided cost, and blue boxes are capital or enabling investment. Avoided-cost (dashed amber arrow) returns are realized on-farm; cash sales (green) enter markets and capital (blue) de-risks the stages it feeds. The household and vulnerable-population models share one chain and may differ in who finances it. The household panel runs kitchen and crop waste into larval rearing, yielding larvae, and frass. Two outputs follow: a dashed amber arrow to on-farm feed and soil for planting, and a green arrow to surplus

sold locally. The vulnerable-population panel repeats that chain, with collected waste, and household food alongside feed as the avoided-cost output. BSF Tamatave illustrates the hybrid model and EXA Feed the centralized model. Both are early-stage Malagasy operations whose long-run viability remains to be demonstrated. The hybrid panel begins with a blue central hub handling eggs and nursery. Three arrows fan out to partner waste streams: a cafeteria, a poultry farm, and market waste. A dashed amber arrow runs from those to grow-out on partners' waste. The centralized panel runs a four-stage chain of substrate, rearing, harvest, and processing. Three green arrows lead from processing to dried meal, larval oil, and frass. A blue box marked off-grid solar and cyclone-resistant build sits beneath, with dashed blue arrows feeding rearing and processing. Read down the figure, returns shift from avoided cost in the upper panels toward cash sales in the lowest.

## Madagascar provides lessons on scaling BSF models

**The report's Madagascar case studies show that BSF operations work best when they learn locally before they scale.** EXA Feed, a commercial BSF producer in northern Madagascar, spent two years testing production in Antananarivo before building a larger facility in Diego Suarez. BSF Tamatave, a smaller Malagasy BSF enterprise, spent two years testing production in a garage before registering as a company. Both operations started small, tested local substrate and production systems, and expanded only after they understood the biology, feedstock supply, and operating protocols well enough to justify growth. Both also made mistakes. Breeding-cage designs failed, substrate protocols did not transfer, and infrastructure proved vulnerable. Those failures improved the models because they occurred at a scale where the operators could absorb them. EXA Feed's site selection, capital structure, and energy strategy reinforce one another. BSF Tamatave's diversified substrate base, low-cost infrastructure, and farmer-training role do the same. Both scaled only what they had already proven at smaller scale — the discipline that separates the operations that survive growth from those that fail it.

**Madagascar also shows how household support and clear rules can help a young BSF sector grow.** The Madagascar Biodiversity Center's network of 266 micro-farms shows how sustained facilitation, peer learning, and local experimentation can support household-scale BSF adoption. Madagascar also contributes evidence on frass agronomy, BSF for human consumption, and behavioral acceptance. Its regulatory experience adds a further lesson. In March 2025, the Bureau de Normes de Madagascar developed NMG 132-13, the world's first national standard for dried BSF larvae and larval powder for direct human consumption, through a coordinated process anchored by a certified production facility. Ethiopia shows that coordinated BSF standards development is also possible outside Madagascar. Kenya shows the cost of fragmented authority across multiple agencies. Together, these cases show that BSF sectors develop faster when operational learning and regulatory pathways are built around clear institutions, defined products, and practical compliance routes.

**These conditions are demanding, and none of them is automatic.** The same evidence that shows where BSF works shows how readily it fails when the conditions are absent. Substrate economics are unforgiving: an operation viable on free or near-free waste can be uncompetitive the moment substrate must be bought, and free waste tends to acquire a price as demand grows. Reliable production is a skill built over repeated cycles; the technology alone does not confer it, and overestimated capability is among the most common and preventable causes of failure. Markets remain thin, and enterprises are often viable only when they earn

from both larvae and frass together. Climate is an advantage in much of Africa but a serious risk where heat exceeds the larvae's tolerance or power is unreliable. BSF does not by itself make an unsafe substrate safe or guarantee an environmental benefit, and mass rearing carries genetic and biosecurity risks where escaped insects reach established wild populations. These are outcomes to be managed and verified. And because the four models rest on different operating logics, treating them as one, or committing capital before the biology is understood, is a recurring path to failure. None of these constraints is disqualifying, but each has to be met deliberately. The recommendations that follow set out how governments, financiers, and development partners can help put those conditions in place.

## Ways forward

**The report provides final recommendations for policymakers and institutions that can shape the conditions for responsible BSF scaling in sub-Saharan Africa.** These recommendations focus on actions that governments, IFIs, financial institutions, development partners, and private sector actors can finance, regulate, or co-develop. The eight recommendations work as a package rather than a sequence. They target the regulatory, institutional, financing, and knowledge-system gaps that constrain BSF sector development and investment.

1. **Establish a single regulatory pathway for BSF production and market access.** Fragmented regulatory systems keep many operators in an informal grey zone and make compliance difficult for small and mid-scale producers. A single pathway from production to market, anchored by a lead technical agency and product-specific standards, would help producers navigate requirements for feed, food, and fertilizer products.

2. **Integrate BSF technical training into national agricultural extension systems.** Farmers across Africa often accept BSF once they understand the technology, but adoption remains limited when technical support stops after one-off training. Extension systems should build BSF capacity into existing agricultural support structures, including training on BSF biology, husbandry, substrate cost accounting, frass valuation, and market linkages.

3. **Establish BSF producer associations and coordination mechanisms early in market development.** The African evidence shows that competitive dysfunction, knowledge hoarding, and misinformation intensify as markets mature. Producer associations, industry councils, shared research platforms, and knowledge-sharing networks can help translate capable individual operators into sector capacity before those problems take hold.

4. **Require substrate security and commercial viability assessments before publicly financed BSF investments.** Successful operations secured substrate before investing in sites, infrastructure, or training. Assessments should document available substrate volume, farm-gate cost, reliability across seasons and market cycles, and collection and transport **costs**. They should be paired with a preliminary business case that defines break-even points, minimum viable production, pricing against local alternatives, and the number of operators a facility can support as profitable enterprises.

5. **Select BSF operators based on motivation, not vulnerability alone, across BSF delivery models.** The operators who succeed are those who actively chose BSF, not those who were chosen for it. Vulnerability indicators remain valid as one screening filter, but selection should also weigh willingness to participate, time availability, expressed interest, entrepreneurial intent, and trust within the candidate pool.

6. **Develop the scientific and regulatory infrastructure that BSF frass markets require.** Frass can determine whether BSF enterprises are profitable, but the science base is not yet settled enough to support a single national standard. Investment should be staged: standardized testing methods and comparable datasets first, tiered product categories second, certification and labeling pathways accessible to small producers third, and formal regulatory standards once the evidence base supports them.

7. **Establish blended finance facilities that match BSF cash-flow realities.** Standard loans do not work well for BSF farming because repayment often begins before operations are stable and profitable. Credit lines should have tenors of three to five years, grace periods of six to twelve months, and performance milestones tied to biological benchmarks, including cycle-on-cycle larval yield improvement and substrate conversion ratios, rather than revenue alone.

8. **Match climate claims to the evidence and build the data foundation for African BSF life cycle assessment.** The environmental case for BSF in Africa rests largely on assessments of temperate systems and small research-scale operations, none of which represent a well-located commercial African operation on low-carbon energy. Until that evidence exists, climate benefits should be presented as plausible but unverified and carbon-credit revenue treated as contingent. Public co-financing should make independent environmental assessment and primary-data collection (energy use, substrate flows, yields) a condition of support, so that representative operations are studied rather than left as gaps, with methods and datasets developed as shared continental infrastructure. The same proportionality applies to biodiversity: invasion-risk standards calibrated to regions where BSF is absent fit poorly where it is already naturalized, and the risks that remain are best managed by requiring locally sourced strains rather than imported domesticated ones.

# Abbreviations

| | |
|---|---|
| **AFB1** | aflatoxin B1 |
| **AFFIA** | Asian Food and Feed Insect Association |
| **AFL** | Aflatoxicol |
| **AFM1** | aflatoxin M1 |
| **AFP1** | aflatoxin P1 |
| **AGP** | α-1 acid glycoprotein |
| **AGRIVET** | AGRIVET (Madagascar agricultural supplier) |
| **ASF** | African Swine Fever |
| **B12** | vitamin B12 |
| **BBEST** | BBEST Project (IITA-led, Ghana) |
| **BCR** | benefit-cost ratio |
| **BEA** | Beauvericin |
| **BMEL** | German Federal Ministry of Food and Agriculture (Bundesministerium für Ernährung und Landwirtschaft) |
| **BNARI** | Biotechnology and Nuclear Agriculture Research Institute (Ghana) |
| **BNM** | Bureau de Normes de Madagascar |
| **BSF** | black soldier fly |
| **BSFL** | black soldier fly larvae |
| **BSG** | brewer's spent grain |
| **BUGS** | Biomass Utilization by Insects for Green Solutions |
| **°C** | degrees Celsius |
| **C3** | C3 (carbon-3) plants |
| **CARD** | Community Agriculture and Rural Development (implementing partner) |
| **CCAC** | Climate and Clean Air Coalition |
| **CEO** | chief executive officer |
| **CFU** | colony-forming units |
| **CGEAF** | CGEAF farm advisory services (DEFIS-affiliated) |
| **CIF** | cost, insurance, and freight |
| **$CO_2$** | carbon dioxide |
| **$CO_2eq$** | carbon dioxide equivalent |
| **COVID-19** | coronavirus disease 2019 |
| **CRP** | C-reactive protein |
| **CSB** | corn-soy blend |

| | |
|---|---|
| **CUT** | Chinhoyi University of Technology |
| **DCA** | DanChurchAid |
| **DDGS** | distillers' dried grains with solubles |
| **DEFIS** | Development of Inclusive and Resilient Agricultural Value Chains (Programme) |
| **DIAAS** | digestible indispensable amino acid score |
| **DON** | Deoxynivalenol |
| **DRC** | Democratic Republic of the Congo |
| **DRC** | Danish Refugee Council |
| **EAC** | East African Community |
| **EAWAG** | Swiss Federal Institute of Aquatic Science and Technology |
| **EC** | European Commission |
| **ECOWAS** | Economic Community of West African States |
| **EDBM** | Economic Development Board of Madagascar |
| **EED** | environmental enteric dysfunction |
| **ETH** | ETH Zürich (Swiss Federal Institute of Technology) |
| **EU** | European Union |
| **EUR** | Euro |
| **EXA** | EXA Feed (Madagascar BSF producer) |
| **FAMI** | Fahasalamana Mirindra |
| **FAO** | Food and Agriculture Organization of the United Nations |
| **FAOSTAT** | FAO Statistical Database |
| **FB1** | fumonisin B1 |
| **FB2** | fumonisin B2 |
| **FB3** | fumonisin B3 |
| **FCA** | Madagascar Agricultural Council Forum (Forum du Conseil Agricole) |
| **FCDO** | Foreign, Commonwealth and Development Office (United Kingdom) |
| **FCR** | feed conversion ratio |
| **FCV** | fragility, conflict, and violence |
| **FIAR** | Foire Internationale de l'Agriculture (Madagascar) |
| **FISH4ACP** | FISH4ACP initiative (FAO/OACPS/EU) |
| **FSA** | Food Standards Agency (United Kingdom) |
| **FSSC** | Food Safety System Certification |
| **g** | Grams |
| **GDP** | gross domestic product |

| | |
|---|---|
| **GHG** | greenhouse gas |
| **GIC** | GIC (Madagascar institutional partner) |
| **GIZ** | Deutsche Gesellschaft für Internationale Zusammenarbeit |
| **ha** | Hectares |
| **HACCP** | Hazard Analysis and Critical Control Points |
| **HIH** | Health In Harmony |
| **IARC** | International Agency for Research on Cancer |
| **IBS** | irritable bowel syndrome |
| **ICIPE** | International Centre of Insect Physiology and Ecology |
| **IDP** | internally displaced person |
| **IFAD** | International Fund for Agricultural Development |
| **IFI** | international financial institution |
| **IITA** | International Institute of Tropical Agriculture |
| **ILRI** | International Livestock Research Institute |
| **IPAA** | Insect Protein Association of Australia |
| **IPCC** | Intergovernmental Panel on Climate Change |
| **IPIFF** | International Platform of Insects for Food and Feed |
| **IQ** | intelligence quotient |
| **ISO** | International Organization for Standardization |
| **JICA** | Japan International Cooperation Agency |
| **JKUAT** | Jomo Kenyatta University of Agriculture and Technology |
| **JKUATES** | JKUAT Enterprises (commercial spinout of JKUAT) |
| **KEBS** | Kenya Bureau of Standards |
| **KEPHIS** | Kenya Plant Health Inspectorate Service |
| **KES** | Kenyan Shilling |
| **kg** | Kilograms |
| **KIC** | Knowledge and Innovation Community (EIT Climate-KIC) |
| **KPI** | key performance indicator |
| **KWS** | Kenya Wildlife Service |
| **LCA** | life cycle assessment |
| **LOE** | level of effort |
| **LUANAR** | Lilongwe University of Agriculture and Natural Resources (Malawi) |
| **$m^2$** | square meters |
| **MAMAH** | Mothers Against Malnutrition and Hunger |

| | |
|---|---|
| **MBC** | Madagascar Biodiversity Center |
| **MGA** | Malagasy ariary |
| **MINAE** | Ministry of Agriculture and Livestock (Ministère de l'Agriculture et de l'Élevage, Madagascar) |
| **MSF** | Médecins Sans Frontières |
| **MT** | Metric tons |
| **MVCR** | marginal value-cost ratio |
| **MWK** | Malawian Kwacha |
| **NACIA** | North American Coalition for Insect Agriculture |
| **NDC** | Nationally Determined Contribution |
| **NE** | necrotic enteritis |
| **NEMA** | National Environment Management Authority (Kenya) |
| **NGO** | non-governmental organization |
| **NMG** | Norme Malagasy (Malagasy national standard) |
| **$N_2O$** | nitrous oxide |
| **NPK** | nitrogen, phosphorus, potassium |
| **NRCRI** | National Root Crops Research Institute (Nigeria) |
| **ONEI** | Observatoire National de l'Élevage d'Insectes |
| **ONN** | National Nutrition Office (Office National de Nutrition, Madagascar) |
| **PADM** | PADM (GIZ programme, Madagascar) |
| **PAFIE** | Platform for Alternative Feed Ingredients Evaluation |
| **PATH** | PATH (global health nonprofit) |
| **ppb** | parts per billion |
| **PREVENT** | PREVENT Waste Alliance |
| **RAISE** | Research & Action for Income Security |
| **RCT** | randomized controlled trial |
| **RDA** | recommended dietary allowance |
| **REPLOID** | REPLOID Group (BSF systems developer) |
| **RFU** | ReFarmUnit (modular BSF production system) |
| **ROI** | return on investment |
| **RUNRES** | Rural-Urban Nexus: Establishing a Resource-Efficient and Sustainable Food System |
| **SDG** | Sustainable Development Goal |
| **SIANI** | Swedish International Agricultural Network Initiative |
| **SIGA** | SIGA (Ugandan non-governmental organization) |

| | |
|---|---|
| **SIMBA** | SIMplified BSF Approach |
| **SMEP** | Sustainable Manufacturing and Environmental Pollution programme |
| **SWIFT** | Sustainable Waste-based Insect Farming Technologies |
| **SWRE** | Stichting Wageningen Research Ethiopia |
| **t** | metric tons |
| **TBS** | Tamatave BSF Shop |
| **TRAIDE** | TRAIDE Foundation |
| **TVET** | technical and vocational education and training |
| **UCAD** | Cheikh Anta Diop University (Université Cheikh Anta Diop, Senegal) |
| **UK** | United Kingdom |
| **UN** | United Nations |
| **UNCTAD** | United Nations Conference on Trade and Development |
| **UNDP** | United Nations Development Programme |
| **UNEP** | United Nations Environment Programme |
| **UNHCR** | United Nations High Commissioner for Refugees |
| **UNICEF** | United Nations Children's Fund |
| **US** | United States |
| **USADF** | United States African Development Foundation |
| **USAID** | United States Agency for International Development |
| **US$** | United States dollar |
| **VSLA** | village savings and loan association |
| **WASCAL** | West African Science Service Centre on Climate Change and Adapted Land Use |
| **WB** | World Bank |
| **WFP** | World Food Programme |
| **WHO** | World Health Organization |
| **WTP** | willingness to pay |
| **YISA** | Youths in Sustainable Aquaculture |

# Introduction

**This report assesses the role of black soldier fly (BSF) farming in Sub-Saharan Africa's emerging circular food economy.** It examines whether BSF can help address three linked pressures: insufficient affordable protein, unmanaged organic waste, and soil fertility constraints. The report focuses on BSF larvae as animal feed and potential food, frass as a soil amendment, and the production conditions, market systems, and enabling environment needed to make BSF farming viable at different scales.

**The analysis combines scientific research, African sectoral evidence, operational case studies, and pilot program data.** The report reviews evidence on substrates, contamination, feeding trials, frass agronomy, farm economics, market demand, and regulatory conditions. It also uses operational evidence from African BSF farms and detailed pilot evidence from displacement-affected settings, including production logs, beneficiary surveys, interviews, focus groups, field observations, partner meetings, missions, and a learning workshop.

**The report is organized in five chapters, moving from the case for BSF to the conditions for implementation and scaling.** Chapter 1 examines the biological and contextual case for BSF in African food systems. Chapter 2 tests whether that case translates into viable farming models, comparing household, hybrid, and centralized systems. Chapter 3 looks at the active and rapidly growing BSF sector in Madagascar. Chapter 4 draws lessons from World Bank-UNHCR pilots in refugee and host-community settings in Kenya, Malawi, and Zimbabwe. Chapter 5 provides final recommendations that identify policy, financing, institutional, and knowledge-system actions to support responsible sector development.

**The report finds that BSF farming is a proven way to recycle organic waste into animal feed and fertilizer, but simply introducing the technology does not deliver all its benefits.** BSF can support food security, waste recovery, farm productivity, and new livelihood opportunities when projects build the right operating conditions around it. These conditions include reliable access to suitable substrate, sites that can receive and process that material, infrastructure matched to the operation's objectives, and operators who can use data to manage substrate quality, production, and outputs. Viability also depends on product markets, realistic pricing, extension and business support, financing that fits the production cycle, and clear rules for feed, food, and fertilizer products. Scale can expand the benefits of BSF farming, but only when these conditions are built into the model from the start. The report therefore treats BSF as a set of models suited to different African contexts, rather than a single technology package. Household systems can reduce feed and fertilizer costs. Hybrid systems can connect small producers to specialized hubs. Centralized systems can process larger waste streams. Vulnerable-population models can support livelihoods when participant selection, training, and handover are designed well.

# Chapter 1. The Case for BSF Farming in Africa

**This chapter makes the case for Black Soldier Fly farming in African food systems.** It examines how BSF can help address three linked pressures in Africa: protein gaps in African diets, unmanaged organic waste, and soil fertility deficits that constrain agricultural productivity. These pressures reinforce one another. Food systems lose organic material that could be recovered, farmers face high feed and fertilizer costs, and many households still lack affordable sources of high-quality protein. The chapter uses African sectoral evidence and scientific research on substrates, contamination, feeding trials, and frass agronomy to assess whether BSF has a credible biological and contextual case in African settings.

**The chapter has three main sections, with detailed subsections and boxes supporting each part of the analysis.** Section 1.1, Organic Waste and the Protein Gap, explains the linked problems BSF is positioned to address, including hunger, protein quality, food loss and waste, insect farming's recent setbacks, and the specific case for BSF. Section 1.2, African Settings and Scaling, reviews feed-cost pressures, farm-level economics, farmer and consumer readiness, market development, regulation, and BSF's role in fragility and displacement contexts. Section 1.3, BSF Larvae Outputs: Feed, Food, and Soil, examines what BSF production can generate, including larvae as feed for livestock and aquaculture, larvae as food for human consumption, and frass as an organic soil amendment.

**Overall, the chapter finds that BSF farming has a strong biological and contextual case in Africa, but local conditions determine whether it works in practice.** BSF larvae can convert organic waste into protein-rich feed, potential food products, and frass that support crop production and soil fertility. African evidence shows promise for BSF in smallholder, livestock, aquaculture, waste-management, and displacement settings, especially where feed is costly, organic waste is available, and frass has value. The evidence also shows clear limits. BSF operations depend on secure substrate access, reliable markets, realistic labor and processing costs, food and feed safety controls, and regulation that producers can navigate. The chapter does not present BSF as a universal solution. It argues that BSF farming can be a practical African circular-economy model when projects test local costs, design around available waste streams, and match production systems to the market they intend to serve. Chapter 2 takes up the next question: whether this case translates into viable operations under specific farming and business conditions.

## 1.1 Organic Waste and the Protein Gap

### Hunger and protein quality

**Africa's food systems face worsening hunger, child undernutrition, population growth, and climate-driven yield and nutrient losses.** Africa has the highest share of people facing hunger in any region: 20.4% of the population, or nearly 300 million people in 2023. The situation has deteriorated steadily since 2015 (FAO et al. 2024). If current trends continue, 582 million people will be chronically undernourished by 2030. More than half will live in Africa, and the total will be roughly 130 million above the pre-pandemic trajectory. The prevalence of moderate or severe food insecurity in Africa already stands at 58%, nearly double the global average (FAO et al. 2024). The burden falls hardest on children. Approximately one in three children in sub-Saharan Africa is stunted by chronic undernutrition, affecting physical and cognitive

development, and inadequate nutrition underlies nearly half of all deaths in children under five globally (Black et al. 2013). Sub-Saharan Africa's population is projected to reach 2.2 billion by 2054 (UN DESA 2024), and climate change is projected to reduce yields of key staple cereals by 5–17% by mid-century (Knox et al. 2012). These pressures will further strain the region's food systems. Climate change threatens not only yields but also their nutritional quality. Field experiments show that C3 staple crops, including wheat and rice, grown under the elevated atmospheric $CO_2$ concentrations projected for mid-century contain lower concentrations of protein, zinc, and iron than crops grown under current conditions (Smith et al. 2021; Smith and Myers 2018). Current emissions trajectories could push an estimated 175 million additional people into zinc deficiency and 122 million into protein deficiency by 2050. This effect would fall mainly on sub-Saharan Africa and South Asia, where diets depend heavily on these crops and baseline nutritional deficits are already severe (Smith and Myers 2018).

**Hunger persists because of food system failures in access, nutrition, and food waste, not because the world lacks enough calories.** The conventional agri-food model fails to feed one in five Africans, but not because the world cannot produce enough food. The world currently generates enough calories to nourish its entire population. Modelling suggests this could remain true even for a projected population of 9.7 billion in 2050, though only with radical changes to distribution, diet, and waste (Berners-Lee et al. 2018). Hunger is driven mostly by failures of access, equity, and conflict (FAO et al. 2024). Calories are also not nutritionally equivalent. A diet sufficient in energy can still leave entire populations deficient in the protein, iron, and zinc that determine long-term health and development. Food loss and waste compound the problem. Roughly one-third of all food produced globally is lost or wasted before it can be consumed (FAO 2011), although the location of these losses in the value chain differs by context. In high-income countries, waste is concentrated at the consumer end, in homes, restaurants, and retail. In low- and middle-income countries, losses occur mainly at earlier stages: at harvest, during storage, and between farm and market. Inadequate infrastructure, limited cold chain capacity, and poor post-harvest handling drive these losses. They take food out of systems that cannot afford to lose it (FAO 2011).

**Staple-based diets are typical in sub-Saharan Africa but lack high-quality protein due to high costs.** Protein deserves particular attention within this broader nutritional picture. Across sub-Saharan Africa, diets are dominated by cereal and starchy staple crops that provide calories but supply protein of limited quality. Plant-based proteins are typically low in one or more indispensable amino acids. Lysine is the primary limiting factor, and all major African cereals, including maize, rice, and cassava, are deficient in lysine (Leinonen et al. 2019). Antinutritional factors naturally present in these staple crops, including phytate, tannins, and trypsin inhibitors, further reduce protein digestibility and absorption, compounding the quality deficit (Gilani et al. 2012). A deficiency in even one indispensable amino acid can prevent the body from synthesizing protein for growth and maintenance. As a result, populations may appear to meet crude protein intake targets while remaining functionally deficient. Protein quality adjustments make this deficit clearer. The digestible indispensable amino acid score (DIAAS) accounts for amino acid composition and true digestibility; using that measure, the average habitual diet in sub-Saharan Africa scores 76%. On this basis, average daily protein requirements are not met across the region (Moughan 2021). Animal-source foods directly resolve this deficit. They supply complete, highly bioavailable protein alongside iron, zinc, and other micronutrients that are chronically scarce in plant-dominated diets. But they remain financially inaccessible to most food-insecure households and are resource-intensive and environmentally costly to produce at scale (Schönfeldt and Hall 2012). Affordable alternatives that supply nutritionally complete protein are therefore a practical necessity, not a dietary preference.

**Box 1.1: The Black Soldier Fly — A Brief Biology**

The black soldier fly (*Hermetia illucens*) is a tropical and subtropical insect native to the Americas but now distributed worldwide. It undergoes complete metamorphosis through four distinct life stages: egg, larva, pupa, and flying adult, completing the full cycle in approximately one month under optimal conditions. Every aspect of this cycle — development period, larval growth rate, survival, and egg output — is sensitive to temperature, humidity, substrate quality, and rearing density, all of which are discussed in detail elsewhere in this report.

Though not native to Africa, BSF spread worldwide long before it was farmed and is now naturalized across the continent, so mass-rearing introduces no new species, but some escape of adults is inevitable. Escapes are a recognized pathway for the genes of globally traded domesticated strains to introgress into local wild populations and disrupt locally adapted genetics, a concern that is still limited but grows as farming expands. Rearing locally sourced BSF is the prudent default, since regional populations may be both better adapted and a valuable genetic resource; imported specialized strains can raise performance but carry genetic and biosecurity considerations that the report examines in chapter 2 (Kaya et al. 2021).

Adult females typically deposit a single clutch of eggs in sheltered spaces near decaying organic matter before dying shortly after oviposition. Field clutches commonly contain 300–600 eggs, and laboratory trials have recorded counts exceeding 1,000 depending on substrate and rearing conditions. Eggs hatch within a few days into neonate larvae less than 1mm long. Larvae feed continuously on organic material, growing over 10–16 days to individual weights exceeding 200mg under well-managed conditions, an increase of roughly ten-thousandfold from hatching. Moisture, temperature, density, and substrate quality all affect development significantly, and field performance routinely falls short of laboratory benchmarks. At the end of the larval stage they stop feeding and darkening, marking the entrance into the prepupal phase. Prepupae actively seek out a dry place to pupate, migrating away from the wet rearing substrate in the process. This self-sorting behavior, whereby prepupae separates themselves from the frass and residual substrate, is biologically significant for production. Many rearing systems are designed to exploit it, allowing farmers to harvest larvae with minimal manual intervention by providing a ramp or collection channel that prepupae naturally migrate toward. The pupal stage lasts at least eight days, after which adults emerge. Adults are slender black flies 15–20mm long and bear a resemblance to wasps. They mate approximately two days after emergence. In captive production settings, adults do not require food, relying primarily on reserves accumulated as larvae. Wild adults may feed opportunistically, and sugar supplements are sometimes provided in captive colonies to extend adult longevity and support mating activity**.**

For production purposes, this biology creates two structurally distinct modules that require different infrastructure and management attention. The larval grow-out phase, during which organic waste is consumed and biomass accumulated, is the simpler stage to manage. The adult reproduction phase, which requires adequate temperature, humidity, and light intensity for mating and oviposition, is technically more demanding than grow-out and accounts for a disproportionate share of both infrastructure costs and management attention in industrial settings. In tropical climates with stable warmth and sufficient natural light, however, mating can occur outdoors or in simple open structures, substantially reducing the infrastructure burden that makes this stage so capital-intensive in temperate settings. This asymmetry shapes infrastructure decisions at every scale and in every climate, but its severity varies considerably depending on where the operation is located.

## Organic waste as an unused resource

**Food systems generate large organic waste streams that could help address nutrition gaps but remain costly to recover.** These systems produce organic material at every stage. If recovered and reused rather than discarded, this material could help close the gaps already noted. By 2050, solid waste generation is projected to reach 3.4 billion tons, with biodegradable materials accounting for nearly half and a still higher share in low- and middle-income countries (Kaza et al. 2018). Food waste is estimated to account for 8–10% of global greenhouse gas emissions and the equivalent of 28% of the world's agricultural land, meaning land used to produce food that is ultimately lost or discarded (FAO 2013; UNEP 2024). Government-funded initiatives manage most waste streams in high-income countries, but the organic fraction remains largely unmanaged in low- and middle-income countries. The problem is recognized, but the cost of collecting, sorting, and treating biodegradable waste usually exceeds the revenue from recovered products (Lohri et al. 2017). In sub-Saharan Africa, waste streams are mostly organic and largely untreated. The gap between current practice and recoverable value represents both a missed resource and a compounding environmental burden (Kaza et al. 2018).

## Insect farming: promise and recent setbacks

**Insect farming offers a practical protein alternative, but its value depends on the species, business model, and operating context.** Insects convert organic material into protein efficiently, require far less land and water than conventional livestock, and can be reared on organic waste streams that would otherwise go unmanaged (van Huis 2013). These advantages materialize only when the business model fits the scale of operation and the surrounding conditions support it, including climate, infrastructure, substrate access, and market demand. The recent collapse of several large insect-farming companies has raised legitimate questions about industrial viability, but these failures span species, regions, and business models. They should not be read as a single sector-wide verdict. Insects differ substantially in feed requirements, lifecycle length, thermal tolerance, and suitability for waste-derived substrates. The economics and environmental credentials of one species in one context therefore do not transfer to another. Many of the most prominent failures were capital-intensive, heavily mechanized operations that, despite their circular economy framing, depended largely on feed-grade grain inputs rather than genuine waste streams (Biteau et al. 2026). In mature European livestock markets, an established livestock industry already absorbs cereal co-products, so insect operations that purchase them inherit input costs that track conventional feed parity.

**Evidence from grain-fed crickets shows that insect farming's benefits depend on species and feed inputs, not the insect model alone.** These cost dynamics matter for both major end uses of farmed insects: animal feed and human food. Lundy and Parrella (2015), studying high-density populations of the house cricket (*Acheta domesticus*) at production-relevant scale, found that cricket protein conversion efficiency on grain-based diets was only slightly better than broiler chickens fed the same grain. That margin is small enough that the environmental case for grain-fed insects rests almost entirely on the upstream grain footprint they share with conventional livestock. The authors note that other species, including BSF, may be better suited to converting low-quality organic side streams.

**Evidence has not yet shown clear environmental advantages for industrial insect-based animal feed, but results vary with energy source, substrate, and production efficiency.** For animal feed, recent life cycle assessments of industrial insect operations provide the most relevant evidence. Biteau and colleagues identify a more fundamental problem: the environmental credentials of insect farming at industrial scale remain undemonstrated. Most supporting evidence comes from small trials that may not transfer to commercial operation (Biteau et al. 2025, 2026). Recent comprehensive life cycle assessments (LCAs) from the UK (Ricardo 2025) and France (Javourez et al. 2025) found insect-based feed underperforming against conventional alternatives across most environmental indicators under the energy and substrate conditions modeled. If those conditions are not met, insect-based feed can create a heavier environmental burden than the conventional products it is meant to replace. These are weaknesses of a model built on assumed inputs and projected efficiencies, not inherent properties of insect farming itself. Modeling work suggests that environmental burdens can fall sharply under the right conditions: renewable energy, optimized use of food-industry side streams, and credit for the avoided footprint relative to soy (Francis et al. 2025). These favorable projections, like the unfavorable ones, rest on assumed inputs, and the published evidence base has not yet caught up with commercial practice. The environmental case against industrial models weakens considerably when those conditions exist (this argument is developed in Farming Scenarios in chapter 2).

## Why African conditions may differ at every scale

**Insect farming in Africa may avoid some industrial cost pressures, but its advantages are site-specific and not yet well documented at scale.** Smallholder insect farming in lower-resource contexts operates under different conditions: ambient tropical temperatures, low capital requirements, and genuine waste-derived substrates that avoid many of the cost and input dependencies that have undermined large industrial operations. Capital-intensive operations in tropical Africa can also begin from structurally different conditions than their temperate counterparts: abundant organic waste streams that are largely unmanaged and available at low cost; year-round warmth that reduces the heating infrastructure that dominates energy budgets in temperate settings; lower labor costs; and energy economics that can favor, or even require, off-grid renewable solutions over unreliable and expensive national grids. These conditions may exist at particular sites, but they are not advantages that apply uniformly across the continent. The peer-reviewed literature has not yet documented commercial success at industrial scale in Africa, though operational practice on the continent has begun to move faster than the published evidence base. Treating these conditions as design parameters, rather than operational assumptions, would allow industrial insect farming in Africa to be designed around them from the start instead of requiring the sustainability retrofitting that has proved so difficult elsewhere.

## The case for black soldier fly

**BSF farming can effectively convert unmanaged organic waste into feed and fertilizer, but its benefits depend on operating conditions.** In many African settings, black soldier fly (BSF; *Hermetia illucens*) farming may operate under favorable conditions, but those advantages do not remove the need for attention to substrate security, infrastructure, energy reliability, processing capacity, market development, and the production expertise needed to run the biology reliably (see Box 1.1 for a brief biology of the species). Organic waste that accumulates unmanaged in urban and peri-urban environments contributes to disease

vectors, water contamination, and greenhouse gas emissions. BSF farming converts that same waste into nutritious larval protein and frass fertilizer. It can help close the protein gap, valorize a wasted resource, rebuild soil fertility, and address food security, waste management, and environmental degradation together (van Huis 2013; Verner et al. 2021). BSF bioconversion also compares favorably with composting, the main managed alternative for diverting organic waste from landfill. An LCA of a single Indonesian facility found that composting carries roughly two times the global warming potential of BSF treatment per ton of biowaste processed (Mertenat et al. 2019). The contrast with unmanaged disposal is even starker: organic waste landfilled without diversion generates methane equivalent to approximately 930 kg $CO_2$ per ton, compared with 50–300 kg $CO_2$ equivalent for BSF bioconversion of the same material (see Diener and Storey 2025). BSF also shows notable material conversion performance. A nine-week continuous-flow reactor study found that BSF larvae degraded over 55% of incoming organic material on a total solids basis while converting 11.8% into harvestable larval biomass, with near-complete elimination of *Salmonella* spp. in the treatment residue (Lalander et al. 2015). This reduction is measured in the processed substrate, not in the larvae themselves, which can still carry pathogens from the substrate and require post-harvest steps such as gut-voiding and/or heat treatment before use (see the discussion of pathogen reduction below). These findings are suggestive, not definitive. The favorable evidence for BSF comes from individual studies under specific operational conditions.

### A continent of approaches

**BSF farming in Africa serves different feed, waste, and soil fertility roles depending on local needs and constraints.** Operations range from small rural units to larger semi-industrial facilities, each shaped by local opportunities and constraints. Many primarily produce larvae for animal feed, with frass as a secondary by-product. In other contexts, particularly in waste-management systems, BSF's value lies in its ability to decompose organic material cheaply and quickly. In these models, the combined frass-and-larvae output may be applied directly to improve soil fertility rather than separated for sale, as at Marula Proteen in Uganda. The same species, reared on the same waste streams, can function as a feed ingredient, a waste treatment mechanism, or a soil fertility input. It often serves more than one of these functions at once, depending on what the surrounding system needs most. The chapters that follow examine the conditions under which each model can succeed, drawing on the African evidence base where it exists and naming its limits where it does not.

## 1.2 African Settings and Scaling

### The feed cost problem in African livestock systems

**Feed costs and shortages make smallholder livestock and fish production vulnerable, strengthening the case for local alternatives.** Feed is the central input for smallholder livestock and fish farmers across Africa, but it is also their central vulnerability. It is the largest production cost and one over which farmers have little control. Field evidence from Kenya shows the severity of this squeeze at farm level. A survey of smallholder livestock and fish farmers in the central highlands found that feed costs fell in the 61–70% band for the largest group of respondents (54%), and that 99% experienced feed shortages of varying frequency. A further 82% reported that they always struggled to secure adequate feed (Ndambi et al. 2025). Kenya's domestic soybean production meets less than 35% of national demand, and the livestock sector

consumes approximately 90% of all soybeans in the country, most of it imported (Onsongo et al. 2018). Fishmeal dependency tells a sharper story. Silver cyprinid (*Rastrineobola argentea*) harvested from Lake Victoria has been depleted to the point that seasonal fishing bans are now in force across Kenya, Tanzania, and Uganda. Kenya still imports 80% of its feed-grade silverfish from neighboring countries to meet demand it can no longer supply domestically (Onsongo et al. 2018). The cost of silver cyprinid rose from US$0.26/kg in 2009 to US$1.40/kg in 2015, a more than fivefold increase in six years, and regional estimates place the price at US$1.70–1.90/kg (Ibengwe 2023). These are not independent risks. Both major protein sources are constrained at the same time, and demand is still growing. Kenya's animal feed production more than doubled between 2008 and 2018, rising from 375,000 to 900,000 tons (Vernooij and Veldkamp 2019). Per capita consumption of meat and fish across sub-Saharan Africa is projected to increase by 54–69% if per capita if the region's GDP doubles, with the steepest growth among the poorest households, which are currently furthest from regular meat and fish consumption (Desiere et al. 2018). The case for locally produced, affordable feed alternatives has never been stronger or more urgent.

**BSF farming is a local alternative that relies on organic waste already available on smallholder farms rather than costly or scarce feed inputs.** Smallholder farming systems already contain many of the conditions for their own solution. Organic waste accumulates continuously on and around smallholder operations, including manure, kitchen scraps, crop residues, and spoiled feed, but it goes largely unused. BSF integration does not require farmers to adopt an unfamiliar production logic. It fits production systems in which inputs are scarce, waste is available, and any reduction in purchased feed costs has immediate economic value. Even farmers operating well below commercial scale often have organic waste streams that could meaningfully reduce their feed expenditure. This substitution opportunity remains largely unrealized when that material is simply discarded. Organic waste becomes raw material for larval production; larvae reduce the feed bill; frass replaces or supplements mineral fertilizer. At each step, value that currently leaks out through purchased inputs is retained within the farm or the local community. The farmer who was a dependent buyer of imported protein becomes a partial producer of it, selling larvae to local feed millers, incorporating them into self-formulated feed, or both.

## Farm-level economics: what the evidence shows

### Free versus paid substrate

**Translating the circular logic into viable economics requires confronting a price comparison that has long worked against insect feeds**. Plant-based feed proteins are cheaper than modeled insect feeds, especially when BSF systems must pay for labor and substrate**.** Plant-based proteins—soybean meal, cottonseed meal, and palm kernel meal—are commodity inputs produced at scale with established supply chains, and global benchmark prices make them difficult for BSF to match. A life cycle cost analysis of small-scale insect-based feed production systems in West Africa found that the most efficient system modelled, a housefly operation under natural oviposition, could compete with imported Peruvian fishmeal on price. The BSF system modelled could not, largely because maintaining a captive adult colony required more labor (Roffeis et al. 2018). No system approached the cost of plant-based feeds: soybean meal was priced at roughly a quarter of the lowest insect-feed breakeven price, and labor and substrate procurement were the dominant cost drivers across all systems (Roffeis et al. 2018). The benchmark prices used in the model excluded inland transport costs that smallholders in rural areas actually face. The authors noted in

follow-up work that poor road infrastructure could make delivered fishmeal substantially more expensive than assumed (Roffeis et al. 2020). A more recent Kenyan study sharpened the picture from the substrate side. Beesigamukama et al. (2022) found that rearing substrate alone accounted for 81–90% of total BSF production costs, and that BSF farming is unprofitable on paid substrate unless frass revenue is also captured. The substrate in that study was brewery spent grain, a purchased agro-industrial by-product, so the figure reflects a paid-substrate scenario rather than substrate cost in general. Both studies model conditions in which substrate is paid for at market rates, a condition that does not hold across all settings, as subsequent African evidence has made clear.

**Smallholder BSF farms can become more profitable when substrate is free and family labor substitutes for hired labor.** A 2022 census of 34 smallholder BSF farmers across six Kenyan counties identified substrate availability and household labor as the dominant correlates of profitability (Mutuku et al. 2022). A regression model across eight farm and operator characteristics, drawn from farmers mostly under two years of experience and almost all under one acre, explained 93.6% of the variation in gross margins. Substrate volume had the strongest positive effect, but the mechanism was not cost. The authors note that in some cases farmers obtained substrate for free, paying only for transport and handling. Additional substrate produced more-than-proportional gains in gross margin, with farmers still short of the point of diminishing returns. Labor showed the opposite pattern. Additional man-hours were negatively correlated with gross margins, which the authors interpret as evidence that farmers had passed the point of diminishing returns on management time and were deploying family labor more generously than small operations could productively absorb. Household size, meanwhile, was a significant positive predictor. Family labor substituting for hired hands improved profitability even as excess labor hours eroded it, a distinction that only makes sense given the scale and cost structure of these farms.

**The studies point to substrate price as the main factor shaping whether BSF feed production can cover its costs.** Roffeis and Beesigamukama both model conditions in which farmers pay for substrate, and in both cases the cost structure becomes punishing. The West African modelled systems were labor-dominated, and the Kenyan operations were substrate-dominated, but both crowded out the margin BSF needs to compete with conventional protein sources. Mutuku's smallholder census sits on the other side of the divide. Farmers who obtained substrate for free or near-free saw substrate volume become the strongest positive predictor of profitability rather than the largest cost burden, because every additional unit of input flowed almost directly to gross margin. The practical implication is that for operations that can run production reliably, the most consequential economic variable is whether the substrate is genuinely free at the farm gate. Smallholder economics can work under that condition. Without it, the model depends on co-product revenue, especially frass, to close the gap, or fails outright. The secondary constraint under free-substrate conditions is whether family labor is deployed productively rather than simply generously.

**BSF operations may lose their cost advantage as previously free substrate has to be purchased, competed for, or supplemented.** Substrate costs tend to rise along a predictable arc as BSF farming scales. The first pressure is competition: waste generators may begin charging for material that was once freely available, and other users intensify the contest for the same streams. Field research found competition for market waste already emerging around Nairobi, with BSF producers competing directly with pig farmers for the same organic material (Meerts et al. 2023). The second pressure comes from within the production system. BSF larvae do not perform well on market waste alone, and producers across the Global South

commonly blend it with higher-nutrient inputs such as brewery or grain waste, supplements that are typically purchased rather than recovered (Barragán-Fonseca et al. 2025). The third pressure is external. In Ethiopia, brewery by-products were already being purchased by ruminant and poultry producers for direct use as animal feed, meaning a prospective BSF operation would face both competition and a purchase price for the higher-nutrient input it depends on (Chaix-Bar et al. 2023). The transition from free to paid substrate, and from uncontested to competitive sourcing, is therefore a planning reality for operations in established urban markets rather than a future risk. Refugee settlement contexts intensify all three pressures, with program-financed collection or transport typically required to secure substrate at facility scale (see chapter 4).

### The competing protein side

**The price advantage of plant-based feeds over insect-based feeds is less clear-cut than benchmark prices suggest.** Wholesale soymeal prices in Kenya rose steeply through 2022–2024, with retail prices reaching KSh 115/kg (US$0.80) by mid-2024 (Competition Authority of Kenya 2024; Association of Kenya Feed Manufacturers 2024). Regional supply shocks in Zambia and Malawi pushed prices to US$0.70–0.90/kg over the same period (African Market Observatory 2024; Mahuma and Landani 2025). The competitive opportunity for BSF widens when plant-based feed markets tighten, but it remains conditional on local input costs and substrate access rather than reflecting any inherent price advantage of BSF production. The structural case is clearer for fishmeal, where supply constraints are persistent and the price differential more consistently favors BSF.

### Substitution trials: poultry and fish

**BSF has its clearest cost advantage when it replaces fishmeal, as Kenyan poultry trials found similar bird performance and lower feed costs.** In Kenya, Onsongo et al. (2018) fed commercial broilers on diets in which BSF prepupal meal replaced soybean and fishmeal protein at three levels. The highest level replaced 42.0% of conventional crude protein in the starter phase and 55.5% in the finisher phase. At this substitution rate, broiler growth, feed conversion, carcass characteristics, and meat taste and aroma were statistically indistinguishable from the conventional control diet. Feed cost fell by 14.3% per bird, the cost-benefit ratio improved by 16%, and return on investment improved by 25% relative to the conventional diet. The savings came from BSF prepupal meal being cheaper than both protein sources at the prices used in the trial: US$0.85/kg for BSF meal, compared with US$0.90/kg for soybean meal and US$1.20/kg for fishmeal. In most markets, BSF will not undercut soybean meal in this way. A parallel trial on improved indigenous chicken, which accounts for over 80% of Kenya's poultry population and is central to smallholder livelihoods, found similar results. Waithaka et al. (2022) tested BSF larval meal at inclusion levels up to 20% as a replacement for fishmeal in starter and grower diets. The study found no significant effect on final body weight or feed conversion ratio in the grower phase. Birds fed the highest BSF larvae inclusion diet had the lowest feed costs, the highest gross profit margin, and a cost-benefit ratio of 2.12, compared with 1.76 for the conventional fishmeal diet, a 20% improvement.

**A western Kenya tilapia trial also found similar growth with BSF larvae and higher returns than commercial feed alone.** Feed-cost pressure is also acute in fish production. A field trial at the Bukani Aquapark in Busia County, western Kenya, illustrates the point. The aquapark is an aggregation of 100 fishponds owned by smallholder farmers and collectively managed by the farming community, alongside crops and livestock on surrounding land (Kals et al. 2024). The trial tested three feeding strategies for Nile

tilapia over 84 days across nine ponds: commercial diet only, commercial diet with 20% substitution by dried BSF larvae, and commercial diet with 20% substitution by dried freshwater shrimp (*Caridina nilotica*), a by-product of the Lake Victoria Omena fishery. Growth and survival showed no significant differences across the three treatments. The economics were not equivalent. The net return above total costs was 247% higher for fish on the BSF-substituted diet than for fish on commercial diet alone, and 116% higher for the freshwater shrimp substitution. One important caveat matters. The trial used BSF larvae purchased at the prevailing market retail price of US$1.02/kg rather than larvae produced on-site, so these returns were achieved without factoring in on-farm production costs.

**The size of the savings depends on BSF prices and the cost of the conventional protein it replaces.** Onsongo, Waithaka, and Kals all priced BSF at market rates rather than at an on-farm production cost, but the reference prices and the displaced proteins differed: Onsongo used a BSF meal price of US$0.85/kg against a soybean-and-fishmeal blend, Waithaka priced obtained BSF meal at prevailing ingredient rates against fishmeal, and Kals used the market retail price of US$1.02/kg against a commercial diet. Each yielded a substantially different cost-benefit improvement, driven by the gap between the BSF price and the price of whatever it displaced. Notably, none of the three tested larvae produced on the farm itself. The implication is that BSF profitability for feed users is shaped not only by feed performance, which the trials confirm is competitive, but also by whether on-farm or community-scale production can deliver larvae below retail and how that cost compares with the conventional protein it replaces. The favorable economics demonstrated here are real, but they depend on substrate access, production pathway, and local prices for both BSF inputs and the proteins it displaces.

**The aquapark trial shows the economics of BSF feed substitution, while circular production depends on local waste and handling costs.** The aquapark structure makes the result more relevant beyond individual farms because it aggregates production and supports shared learning. The authors note that real scaling is most likely on privately owned farms, with the cooperative structure providing an enabling environment for the private investment and risk-taking that scaling requires (Kals et al. 2024). This trial used larvae purchased externally at market price, so the result demonstrates substitution economics, not circular integration. The circular loop would close if the aquapark used its own crop and livestock waste to produce larvae on-site, with frass returning to the fields as fertilizer. That decision depends on the aquapark's own waste streams. Abundant organic waste and low handling costs could make on-farm larval production cheaper and close the nutrient loop. Limited waste or complex logistics could make purchased larvae the more practical arrangement. The trial establishes the substitution case independent of whether on-farm production is added to it.

### On-farm production: smallholder cases

**A Malagasy smallholder case shows on-farm BSF production can reduce feed costs and reliance on imported aquaculture feed.** A tilapia farmer whose on-farm BSF operation was supported by training from the Madagascar Biodiversity Center (MBC) produced larvae at a cost 41% below the per-kilogram import price of commercial fish feed. Actual savings against retail prices would be larger because the import comparison excludes inland freight, importer margins, and retail markup. The operation generated gross margins of 42–65% across survival rate scenarios from 60% to 100% (see chapter 3). Madagascar currently imports 93 to 100% of its commercial aquaculture feed from a single foreign source, Mauritius, making the supply reliability case for domestic BSF-based feed at least as strong as the cost case.

**A Colombian case shows BSF-fed tilapia can match commercial-feed outcomes and outperform conventional production without a price premium.** Smallholder farmers in Icononzo replaced 25–38% of traditional tilapia feed with sundried BSF larvae and produced fish with growth and mortality outcomes comparable to those raised on commercial feed alone (Barragán-Fonseca et al. 2023). Frass sales added margin, making the combined enterprise more robust than larvae-only production. The study adds a four-scenario economic model that varies two operational choices independently: whether BSF and fish are produced at the same location, and whether the circular product commands a price premium. The model did not require a price premium to be viable. In the base scenario, BSF-fed and conventionally fed fish sold at the same price, but the circular model still outperformed conventional production by €199 per four-month cycle when BSF and fish were produced at separate locations. Co-locating the two cut fixed costs by roughly €300 per cycle — mostly avoided land rent, marketing, and organic-waste transport — lifting the advantage to €499. A modest premium expanded the profit advantage to €2,199–€2,499 per cycle, using €1.00 per fish for the circular model and €0.71 for conventionally produced tilapia, based on observed local prices and consumer willingness to pay for more sustainably produced food. The premium is real but not automatic: realizing it requires direct marketing and quality positioning, which add cost and complexity and may not be accessible to all smallholder operations.

### Frass as structural precondition

**Frass can make combined BSF systems more viable than larvae-only production, but only under the right price and substrate conditions.** In Mali and Ghana, bulk organic fertilizer prices of around €15.70/ton meant that frass revenues offset only 4–26% of total production costs. The market context shaped this outcome. In West African settings, organic fertilizer competes against cheap conventional inputs (Roffeis et al. 2018). The economics shift when frass can be priced as a commercial organic fertilizer. In the Kenyan context modeled by Beesigamukama et al. (2022), frass was valued at US$0.30/kg, and combined larvae-and-frass systems moved from loss-making into profit in scenarios in which larvae-only systems remained unprofitable. Frass income accounted for most gross returns. Farmers who used frass directly on their own fields rather than selling it fared better still, generating 30–232% higher net income than farmers purchasing similar fertilizer. Two caveats apply. First, the Beesigamukama analysis uses brewery spent grain as its substrate, a commercially traded agro-industrial by-product that requires proximity to a brewery, transport, and increasingly a purchase price as breweries recognize its value. The favorable outcomes depend heavily on the zero-substrate-cost scenario, which spent brewery grains do not naturally satisfy in most smallholder settings. Field data from Uganda, for example, recorded brewery spent grain trading at around US$24 per ton exclusive of transport, with logistics adding significant cost for producers not located next to a brewery (Meerts et al. 2023). The result can generalize to any free or near-free high-quality substrate, but only if that substrate exists locally.

**The same substrate choices also affect whether a BSF operation earns more from frass or larvae.** On agro-industrial substrates such as brewery spent grain, Beesigamukama et al. (2022) recorded 10–34 kg of dry frass per kg of dried larvae, with the upper end of the range driven by mineral-amended substrates. Producers using these substrates generate proportionally more frass and proportionally less larval revenue. Frass market access is therefore more critical for them than for operations running on nutrient-dense organic inputs. The choice of substrate determines not only yield but also the revenue structure of the enterprise. Field observations in Kenya support this point in a counterintuitive way. Across the range of BSF products surveyed, frass commanded the highest profit margin, ranking above wet larvae, solar-dried larvae, and

industrially dried larvae (Meerts et al. 2023). Industrially dried larvae had the lowest margin of all, despite being the most processed and capital-intensive output. The implication is that the processing investment required to reach formal feed markets does not automatically improve enterprise economics. Frass, sometimes treated as secondary in project design, may provide the margin that determines viability.

**Kenyan farmer data show that larvae and frass cleared the viability threshold only when sold together.** Omondi et al. (2025), drawing on data from 373 BSF farmers in Kenyan counties, found that neither larvae nor frass was commercially viable as a standalone product. Farmers selling larvae alone or frass alone both fell short of viability, with benefit-cost ratios of 0.61 and 0.57, below the break-even threshold of 1. Only the joint enterprise cleared it, at a BCR of 1.18 (with a 51% gross profit margin and an 8.8% return on investment). At smallholder scale in Kenya, capturing frass value is not an optional revenue supplement but a structural precondition for commercial viability. The same study found that farmers who purchased substrate rather than sourcing it as waste were significantly less efficient in their input cost choices, confirming the substrate strategy argument at field level. These figures should be read with one caveat: the sampled counties had been selected for prior BSF project support, so the farmers studied may not represent the broader population of unsupported adopters.

**Madagascar field cases show the same pattern more starkly, with frass use and sales offsetting weak larvae margins.** At Nutrix, a semi-commercial operation in Antananarivo, wet larvae sold below production cost. Egg sales and the avoided cost of purchased compost, which BSF frass fully replaced, together converted a loss into a positive weekly economic benefit. At BSF Tamatave, a more diversified ten-product enterprise, the three larvae-processing products—wet, dried, and powdered—were the lowest-margin items in the portfolio at 56–59%, while pelletized frass margins reached 92.5% and bulk frass margins reached 97.8% (see chapter 3). Both cases corroborate the Kenyan pattern that frass valorization is not a supplementary revenue stream but the structural condition that determines whether the enterprise is viable at all.

### Scale and the family-labor accounting question

**A single-farm Malawi analysis complicates the assumption that scale improves BSF economics because the smallholder's higher benefit-to-cost ratio appears to rest on unpaid family labor rather than on greater efficiency.** A cost-benefit analysis of BSF farming in Malawi offers a useful point of comparison, but the evidence should be treated as indicative rather than representative (Munthali et al. 2023). The analysis draws on data from a single pilot farm at LUANAR's Bunda College, a researcher-managed demonstration unit rather than an independent commercial operation. It found BSF farming viable at both smallholder and commercial scales, with benefit-cost ratios of 10.0 and 2.7, respectively. Commercial operations nonetheless generated much higher absolute revenues, about three times the annual income of smallholder operations. Sensitivity analysis found the viability conclusion robust to a 10% variation in production costs, output prices, and yields. The higher smallholder ratio, however, need not reflect greater production efficiency. The model assigns the smallholder unpaid family labor while costing the commercial operation for three paid laborers, so the same tasks that carry no cash cost on the family farm enter the commercial denominator as wages. The benefit-cost gap therefore appears to be substantially an accounting artifact rather than evidence that small farms are more economically productive than large ones. It also reinforces the earlier caution that benefit-cost ratios can only be interpreted in relation to the labor assumptions embedded in them.

### Sector-level implication

**Modelling shows that BSF adoption could benefit Kenya's wider poultry feed system, not just individual farms.** Modelling for the Kenyan poultry sector estimates that replacing 5–15% of conventional feed sources with BSFL meal across the entire poultry sector could generate US$69–206 million in annual income gains, equivalent to 7–21% of Kenya's poultry GDP (Abro et al. 2020). In the commercial sector alone, the same adoption range would generate US$16–47 million per year. Foreign currency savings from reduced feed imports range from US$1 million per year at 5% adoption to US$10 million per year at 50% adoption across the full sector. The waste management co-benefits are also large. At 15% adoption in the commercial sector alone, BSF farming would consume substrate volumes equivalent to Nairobi's entire annual organic waste output, reframing BSF as both an urban waste management opportunity and a feed solution. Displacing fishmeal would also have food security implications. Silver cyprinid freed from feed use at 5–15% adoption rates could feed an additional 432,000 to 1.3 million people at current per capita fish consumption levels, transferring a constrained resource from feed to food. A 50% long-run adoption scenario yields larger benefits across all these dimensions, though it requires sustained policy investment and supply chain development that make it aspirational rather than near-term. These are modelled projections built on plausible assumptions rather than observed outcomes, and should be read as indicators of potential rather than forecasts. They show why BSF adoption has implications beyond the farm level, reaching across food systems, urban waste management, and the foreign exchange position of feed-importing economies.

**Published BSF cost figures are unreliable as project investment benchmarks unless tested against local costs.** The most reliable starting point for any prospective BSF project is a local cost estimate, not a literature-derived one. Projects need to know what it costs, using the feedstock actually available on site, to produce one kilogram of fresh or dried sellable larvae plus frass. That baseline can then be expanded to include labor requirements, processing costs, and by-product revenues, producing a model specific to the context. Projects should compare that model with locally available alternatives, including fishmeal, plant-based protein sources, and conventional livestock, before making investment decisions. Projects that skip this step and rely on published figures from different contexts, or on optimistic assumptions about substrate availability and labor efficiency, build on foundations that may not hold. Much of the farm-level economic evidence is generated under active researcher or expert involvement, with substrate quality controlled, biological inputs monitored, and technical problems identified and corrected in real time. Independent operators working without that support may find that the same inputs produce more variable results, and that the gap between trial performance and farm performance is wider than the literature suggests. Published yield and cost figures should therefore be read as indicative rather than as benchmarks an independent operator can expect to hit. A pilot-scale feasibility assessment before expansion is the analytical core of any serious BSF investment.

## Agro-climatic variation across the continent

**The conditions that favor BSF are not uniform across sub-Saharan Africa.** Tropical warmth lowers the energy cost of temperature control in humid and highland Africa, but in arid and Sahelian zones the same climate becomes a risk that must be confronted at the design stage. Daytime maxima can exceed the larvae's thermal tolerance, and water scarcity and thinner, more dispersed organic-waste streams raise further questions in drylands. But heat is not only a dryland problem: at the Tongogara pilot in Zimbabwe,

well outside the Sahelian drylands, extreme temperatures destroyed 480 kg of larvae and collapsed the colony in March 2024, a loss the project later addressed with a climate-controlled production unit (see chapter 4). Heat waves, drought years, and poorly shaded facilities can push temperatures past the larvae's tolerance in settings that would not appear on an arid-zone risk map at all. BSF can work in hot regions, but viability there turns on constraints that must be assessed in advance, and evidence from milder settings should not be expected to transfer without that scrutiny. Some low-cost measures have helped (flooded floors, shade, and fans showed results at one Kenyan site even above 45°C), while engineered fixes like air conditioning and climate-controlled containers have so far given mixed results; the expertise to manage heat in these settings is still developing, not settled. Much of what protects a colony is anticipatory rather than technological: tracking heat forecasts to pre-position cooling before a spike, and simple evaporative measures such as damp cloths or wetted sacking over trays, can blunt the worst of an event that would otherwise arrive unprepared (see chapter 4 for examples from Dadaab, the arid part of Kenya). The Tongogara loss was a single discrete heat event, the kind that forecast awareness and a prepared response are best suited to catch (see chapter 4 for examples from Zimbabwe). Agro-climatic zone, alongside substrate, market, and institutional context, is a dimension along which BSF's requirements genuinely vary, and no part of the continent is automatically exempt.

## Farmer and consumer readiness

**African insect farming is partly commercial, but wider BSF adoption depends on markets, extension support, and processing capacity.** BSF is a growing component of African insect farming, which currently sits between subsistence and commercial production. A 2019 farm-level survey across 13 countries found that 48% of insect farmers sold all of what they produced, 25% sold half, and 27% sold less than a quarter, with the remainder consumed on-farm or fed directly to livestock. Most farmers nonetheless derived some revenue from by-products, with 55% selling biofertilizer or insect compost and 49% selling co-products such as eggs, nymphs, or young larvae (Verner et al. 2021). The sector’s commercial footprint remains far below its modelled potential. What limits adoption is less any doubt about BSF's value than the uneven availability of the conditions that convert interest into uptake: reliable markets, extension support, and processing infrastructure. Farmer awareness and the knowledge–adoption gap

**Kenyan farmers often know and accept insect feed, but actual use remains lower and BSF acceptance trails other insects.** A survey of 957 Kenyan smallholder poultry, fish, and pig farmers found that over 70% of poultry farmers and 80% of fish farmers knew insects can serve as feed, held positive attitudes toward their use, and were willing to pay (WTP) 12–28% above market price for insect-based fish feed, depending on feed type (Chia et al. 2020). Yet only 25–38% of poultry and fish farmers had actually used insects as feed, with male fish farmers significantly more likely than female,, and fewer than 20% made their own feed. This confirms the persistent gap between knowledge and adoption. The acceptance data also contain an important species-level distinction: BSF larvae had the lowest acceptance of all insect species tested, below termites, crickets, housefly, cockroaches, and grasshoppers, with termites commanding the highest acceptance by a significant margin (Chia et al. 2020). This distinction affects program design. Farmer acceptance of insect feed in general is not the same as acceptance of BSF, and conflating the two risks overestimating demand for BSF larvae meal. Regression analysis from the same survey found that extension services were a significant positive predictor of WTP among both fish and poultry farmers, indicating that extension contact predicts not only awareness but also stated purchasing intent (Chia et al. 2020).

**Across several African settings, low awareness appears to constrain BSF adoption more than farmer acceptance.** The same knowledge-adoption gap appears across the region. Across DRC, Ghana, Mali, and Niger, actual BSF larval adoption stood at just 4% among fish, poultry, and pig farmers surveyed in five peri-urban cities, against an estimated potential of 16% if all farmers in the sample were aware of the technology (Nyamuhirwa et al. 2025). A follow-up study of 790 vegetable farmers in the same cities found that extension access alone increased the probability of intending to buy BSF frass by 5–6 percentage points, and group membership alone by less than 1 percentage point; farmers with both were 8 percentage points more likely to intend to buy (Nyamuhirwa et al. 2026). Awareness is also uneven across farmer types in Kenya. The Nyeri survey found that aquaculture farmers were markedly more aware of BSFL as a feed ingredient than dairy, pig, or poultry farmers, consistent with the pattern that BSF recognition is highest where fishmeal dependency, and therefore feed-cost pressure, is greatest (Ndambi et al. 2025). A farmer survey in Ghana's Ashanti region found a similar gap: BSF awareness among 595 smallholder poultry, fish, and vegetable farmers was very low, ranging from less than 1% in the least-informed district to 14.5% in the most-informed district. Acceptance of the technology was high once it was explained, with the large majority agreeing that BSF could sustainably produce animal feed and organic fertilizer. Around 8% of farmers in the district with the highest prior exposure had already attempted BSF farming on a small scale, suggesting a promising entry point for scale-up (Dzepe et al. 2024). The consistent pattern across Kenya, Ghana, and the multi-country survey is that low awareness rather than low acceptance is the binding constraint.

### Peer exposure in displacement contexts

**Peer exposure can accelerate acceptance among displaced communities with different insect-eating traditions.** In South Sudan's Jamjang camps, refugees from tribes with stronger insect-consumption traditions acted as informal ambassadors to those without that history. In Yei, Congolese refugees played a similar role among the South Sudanese host community (Verner et al. 2022). In Kenya's Kakuma refugee camp, South Sudanese Dinka refugees, who had no prior tradition of insect consumption, expressed willingness to try cricket-based food once peer exposure normalized it (Kamau et al. 2021). Where insect-eating traditions vary within a community, peer exposure appears to accelerate acceptance more efficiently than formal promotion campaigns can.

### Correlates of awareness and consumer acceptance

**Group membership and off-farm income raise BSF awareness, while older farmers are less likely to know about BSF larvae.** A survey of smallholder farmers in Nyeri County found that group membership increased the likelihood of BSF larvae awareness by 51%, and having an off-farm income source increased it by 32% (Ndambi et al. 2025). Both findings reinforce the Nyamuhirwa results above: farmers' social and economic networks are significant independent predictors of awareness. The same survey found that older farmers aged 55 and above were significantly less likely to be aware of BSF larvae, suggesting that programs relying on digital or social media channels may miss a significant share of the target population.

**Consumer acceptance is high, but country, education, income, and price effects shape willingness to consume BSF-based products.** Consumer-side evidence points the same way on acceptance but adds a counterintuitive twist on income. A stated-preference survey of 4,412 consumers across Ghana, Mali, and Niger found strong baseline acceptance: 88% were willing to consume vegetables produced with BSF frass and 87% were willing to consume meat from BSF-fed animals (Traoré et al. 2024). Acceptance varied by

country, from 95–96% in Mali to 76–77% in Niger. Education level was among the strongest positive predictors of willingness to consume, which likely explains part of the Niger gap given the country's lower rates of formal education. The WTP premium among those willing to pay more varied substantially. For BSF-frass vegetables, respondents in Ghana would pay US$0.26/kg above the US$5/kg baseline, while those in Mali would pay US$2.47/kg above it, a tenfold difference that likely reflects market maturity and consumer familiarity as much as income. The income effect is more striking. Earning an income was a statistically significant negative predictor of willingness to consume BSF-based products, reducing the probability by 2 percentage points for vegetables and 1.5 percentage points for meat. The effect is modest but consistent across both product types and statistically robust. It runs counter to the assumption that novel food products require affluent early adopters and suggests that BSF-based food may find its most receptive consumer base among lower-income populations.

### Gender patterns

**Gender patterns differ across farmer and consumer groups, with no single pattern across countries or uses.** Female smallholder poultry farmers in Kenya were significantly more aware that insects can serve as feed and held more positive attitudes toward their use than male poultry farmers, yet actual adoption rates were identical at 31% for both sexes. This confirms that the knowledge-attitude-practice gap applies equally across genders in this subgroup (Chia et al. 2020). Among fish farmers in the same survey, awareness and attitude did not differ significantly by sex, but male fish farmers had used insects as feed more than female fish farmers, at 38% versus 25%. On the consumer side, a stated-preference survey across Ghana, Mali, and Niger found men more likely than women to accept both BSF-fed meat and frass-grown vegetables, and more likely to pay a premium for them. The authors attribute this pattern to greater male risk tolerance and men's dominant role in household food-purchasing decisions (Traoré et al. 2024). A separate farmer survey in Cameroon found the opposite: women rated BSF frass strongly acceptable both as a fertilizer and for the produce grown with it, while men accepted it with reservations (Tambeayuk et al. 2025). Field observations from South Sudan's pilot communities show women participating actively in consultations, demonstrating strong technical grasp of BSF production, and, in Yei, being independently selected by community members to lead a newly formed cooperative. That outcome emerged from the process rather than from program design (Verner et al. 2022).

## What the sector looks like from the ground up

**Ground-level evidence shows an early BSF sector with small production volumes and uneven market development.** A 2019 price survey of BSF production across 13 African countries found considerable price variation in finished products. Fresh larvae traded at US$940–1,800 per ton, dried larvae at US$600–2,639 per ton, and powdered larvae at approximately US$2,990 per ton (Verner et al. 2021). The same survey put total BSF production across the 13 countries at roughly 293 tons of fresh larvae per year, placing the sector in its early commercial stages.

**The strongest field evidence comes from Kenya and Uganda, but Kenya's more mature sector may not represent earlier-stage markets.** A 2023 FAO-commissioned value chain assessment of Kenya and Uganda offers the most detailed field-level account of BSF value-chain structure available for the region, drawing on 60 interviews with producers, off-takers, and support organizations across both countries (Meerts et al. 2023). The study was circulated as a draft and has not been formally published. It was

conducted by Fair & Sustainable Consulting, which discloses in the report that it owns a BSF operation in Eldoret, Kenya, a relationship worth bearing in mind for findings specific to that region. The broader structural observations are consistent with evidence from other sources. Kenya hosts the most developed BSF sector on the continent and is therefore the most extensively studied, but some of what the study documents reflects the maturity of that sector and may not generalize to earlier-stage contexts elsewhere.

### Price and processing bottlenecks

**Dried BSF meal remains too expensive for feed millers, and uptake is also limited by supply gaps and uncertainty about use.** A Kenyan feed miller interviewed for the FAO value chain study indicated that dried BSF larval meal would only be viable for their operation below US$850 per ton. At the time of the survey, prices were around US$1,400 per ton, well above that threshold (Meerts et al. 2023). Production costs remain above commodity feed-ingredient levels. Price is not the only barrier. Off-takers also flagged inconsistent supply, insufficient volumes, and limited knowledge of how to use BSF as factors limiting uptake.

**The main bottleneck sits in drying and aggregation, leaving small producers with unsold larvae while feed millers lack usable supply.** These barriers concentrate in the processing layer of the value chain. Large volumes of wet larvae and informally dried products are being produced but cannot be sold, while the volumes and qualities feed millers require cannot be supplied. BSF production in Kenya is dominated by small-scale operators without drying infrastructure. Centralized drying and aggregation services do not yet exist, and a small number of large producers with industrial drying capacity account for most of the market-ready products. Sanergy alone processes around 200 tons of organic waste per day and produces between 20 and 50 tons of dried BSF per month, compared with roughly 10.5 tons of waste per week for the largest mid-scale operator interviewed (Meerts et al. 2023). The sector is therefore both over-supplied and under-supplied, depending on product form. This is a processing and logistics gap, not simply a demand or production gap. The price gap is also context-specific: operations with on-site drying capacity, or near shared processing infrastructure, face different economics from those without that access.

### Profitability evidence and its limits

**Kenyan farmer data show combined larvae-and-frass sales can be profitable, but the model assumes fresh larvae can be sold nearby.** A recent farm-level profitability analysis of Kenyan BSF smallholders shows both the promise and the gap. Omondi et al. (2025), drawing on survey data from 373 farmers across 12 counties, found that the combined larvae-and-frass enterprise yielded a gross profit margin of 51%, a return on investment of 9%, and a benefit-cost ratio of 1.18. Larvae-only and frass-only operations both returned negative ROI, at −19% and −21%, respectively, making the combined enterprise the only profitable configuration in the data. The profitability model assumes that sales occur, specifically for fresh larvae. Fresh larvae steadily lose mass after harvest and must reach a buyer within a short radius, whether a poultry house, fish farm, or feed aggregator. The model includes transport costs only on the input side. It therefore cannot capture the same mismatch the FAO documented in the field: a smallholder selling fresh larvae in a village with poor roads and no nearby off taker is not operating in the market the model assumes. Profitability models and market conditions measure different things, and most smallholder operations currently sit in the gap between them.

### The labor accounting gap

**BSF labor costs are hard to compare because studies count labor differently and lack smallholder time-use data.** Labor costs appear consistently across the economics literature as a significant variable, and in some studies as the dominant one. But studies measure labor so inconsistently that cross-study comparison is difficult and farm-level planning guidance remains thin. Roffeis et al. (2018) provides the most detailed treatment: a full life cycle cost assessment covering both housefly and BSF systems, with disaggregated labor cost accounting and sensitivity analysis on wage levels. But it models hypothetical production designs rather than actual smallholder operations. Its labor accounting therefore reflects what labor should cost in a designed system, not what it costs when a farmer absorbs BSF production into an existing farm routine alongside other activities. Most other studies are far less granular. Beesigamukama et al. (2022) values labor at a single flat rate (US$1.25 per hour, the 2019 Kenyan minimum wage) applied uniformly across BSF production activities, without distinguishing skill levels, running wage sensitivity, or reporting how labor was distributed across the production cycle. Mutuku et al. (2022) models man-hours as a single negative predictor without activity breakdown, and Munthali et al. (2023) distinguishes only family from hired labor. Systematic time-use data on smallholder BSF production remain missing, including how labor demands compete with other farm activities across the production cycle and whether feed savings justify the time investment at household scale. Until that gap is filled, viability assessments will continue to rest on labor assumptions that are only partly tested. This gap is most important where labor has opportunity cost even when no wages are paid.

### How donor funding shapes the evidence base

**Trial results often understate the infrastructure needed for commercial BSF, and donor funding narrows the evidence base.** Moving from a favorable trial result to a viable commercial operation requires drying infrastructure, aggregation, quality standardization, working capital, and regulatory clarity. These requirements vary by location and scale, and the trial literature often takes them for granted. A separate concern applies to the evidence base itself. Donor funding has been concentrated in a small number of large commercial producers and research institutions — what Meerts calls a "donor darling" dynamic — whose results are therefore overrepresented in the published record (Meerts et al. 2023).

**Smallholder training programs often count farmers trained, not whether BSF operations continue after training.** Donor support that has not flowed to a small number of large producers has often gone to smallholder training programs. These programs commonly measure performance by the number of farmers trained rather than the durability of their operations afterwards. The technical demands of BSF colony management, discussed earlier in this report, are high enough that exposure through training is not the same as sustained capability. Headcount-based program design can obscure the gap between the two. Whether and how much this gap translates into farmer drop-out in practice is not well documented in the published literature, though operators working across the region have raised it as a concern (see Box 2.7), and unpublished evaluations describe the dynamic in specific project contexts (RefIPro 2026, internal evaluation).

### Reporting against logframes

**Logframe reporting can keep original BSF targets visible even after implementation shows that methods or ambitions need revision.** Practitioners report a related structural feature of how funded

projects report on themselves. Most insect-farming projects begin with an agreed logical framework, or logframe, which is a results table linking the project's expected activities, outputs, outcomes, indicators, targets, and assumptions. Logframe reporting refers to annual project reporting against that original results table. Implementation often shows that core assumptions were wrong, production methods need adaptation, or ambitions need to be scaled back. Projects usually record those revisions in workplans and internal documents, but they rarely appear in the public record. Annual reports continue to list the original logframe targets. The result, as practitioners describe it, is that the public-facing evidence base understates the difficulty of the work and overstates the maturity of the methods. An external evaluation of one Uganda-based program found, for example, that production targets in the project's logframe were missed by an order of magnitude across both BSFL and mealworm workstreams, with annual reports nonetheless continuing to reference the original targets (RefIPro 2026, internal evaluation).

### The Madagascar model: sustained facilitation

**Madagascar's sustained facilitation model may make smallholder BSF adoption more durable than one-off training.** The Madagascar Biodiversity Center applies the model through local demonstration farms, peer-to-peer learning, repeated technical follow-up, and adaptation to locally available waste streams. This support gives farmers a way to keep adjusting BSF production after initial training, including how they manage substrates, colony performance, and farm integration. The center currently supports a network of 266 small farms operating on this model though formal retention analysis is still underway.

### Knowledge sharing and competitive dynamics

**Knowledge sharing weakens when BSF producers also compete for markets, clients, or technical advantage.** Training organizations may also have a commercial stake in the sector as producers, input suppliers, or project implementers. That overlap creates tension between open knowledge sharing and competitive self-interest. In Kenya's BSF sector, Meerts et al. (2023) document high levels of secrecy and deliberate misinformation. Faster-growing producers were particularly reluctant to share technical knowledge, and competitive intelligence-gathering reportedly occurred even within producer WhatsApp groups. An international researcher with more than 15 years of global BSF experience described Kenya as unusually low in sector collaboration by international standards. Producers in areas with less direct market competition, including Eldoret, Kakamega, and Nakuru, reported stronger relationships and active knowledge sharing, including informal farmer groups. The FAO synthesis notes that Uganda's BSF sector, which is at an earlier stage of development, shows much less mistrust. This pattern suggests that competitive dysfunction may emerge as markets mature rather than reflect a fixed feature of the sector. It also suggests that coordination support may be more effective earlier in sector development than later. Practitioners working in Uganda report similar dynamics in their interactions with other regional and international insect-farming actors, with rare exceptions (RefIPro 2026, internal evaluation). This suggests that the secrecy Meerts documents in Kenya is one expression of a broader regional pattern. Training and technical assistance delivered by actors with no commercial stake may reduce the conflict between competitive self-interest and open knowledge transfer. The effect on smallholder durability has not been formally measured, but it is consistent with what operators in the region have observed.

### Kenya's regulatory framework

**Kenya has a formal insect regulatory framework, but fragmented oversight keeps much of the BSF sector informal.** Kenya has had formal standards for insect products for several years. The Kenya Bureau of Standards (KEBS) published a standard for dried insects used in compounding animal feed (KS2711), followed by a Code of Practice for insects in food and feed (KS2921). But the gap between standards on paper and practice on the ground is wide. Field interviews found that most producers, particularly small and mid-scale operators, were largely or entirely unaware of the applicable standards and policies (Meerts et al. 2023). A jurisdictional split helps explain the gap. BSF production in Kenya falls between the Ministry of Agriculture, Livestock and Fisheries and the Kenya Wildlife Service. The wildlife service has jurisdiction because edible insects fall under Kenya's Wildlife (Conservation and Management) Act, which covers their collection, transport, and farming (Niassy et al. 2022). The National Environment Management Authority holds separate oversight over waste handling. The result is a regulatory grey zone in which most producers have simply operated informally. A 2025 International Livestock Research Institute workshop highlighted the practical consequence: producers seeking formal compliance must navigate separate certification processes across KEBS, the National Environment Management Authority, and the Kenya Plant Health Inspectorate Service. Most small-scale operators cannot absorb that burden, which has helped keep the sector predominantly informal (Ouma et al. 2025).

Insect agriculture in other regions has been shaped substantially by industry coalitions — NACIA in North America, IPIFF in Europe, AFFIA in Asia, and IPAA in Australia — that work directly with regulators on standards development and represent the sector in global forums. The African sector has no continental equivalent body and engages with regulators country by country (the institutional consequences of this gap are developed in chapters 2 and 5).

### Ethiopia and Madagascar: coordinated pathways

**Ethiopia used one coordinated pathway to create BSF standards, in contrast to Kenya's fragmented multi-agency system.** The International Centre of Insect Physiology and Ecology Ethiopia worked with the Ethiopian Standard Agency to draft production standards covering hygiene, rearing conditions, safety risks, and harvesting procedures, with no restrictions on substrate type. The National Technical Committee for poultry feed assessed and approved the standards, which were subsequently published by the Institute of Ethiopian Standards and took effect on 29 June 2023 (Chaix-Bar et al. 2023). The contrast with Kenya is structural: Ethiopia had a single pathway from technical drafting through assessment to published standard, while Kenya's fragmented multi-agency arrangement has left many producers operating informally. Stakeholders interviewed in Ethiopia emphasized that formal government endorsement carries particular weight in that context. Official standardization was expected to provide legal authorization and signal credibility to producers and consumers. Whether implementation keeps pace with publication remains to be seen, but the contrast with Kenya's experience suggests that regulatory design — how standards are developed and by whom — is as important as whether standards exist at all. For operators and policymakers seeking a more structured framework for regulatory engagement, including waste audit methodologies, carbon credit pathways, and nationally determined contribution integration, the October 2025 Climate and Clean Air Coalition/United Nations Environment Programme policy guide covers these dimensions in detail for Uganda, Ethiopia, and Côte d'Ivoire (Climate and Clean Air Coalition 2025).

**Madagascar also used a coordinated standards process, producing the first national BSF standard for direct human consumption.** In March 2025, the Bureau de Normes de Madagascar conducted a technical visit to EXA Feed's production facility in Antsiranana to gather information for drafting a national standard for BSF larvae products. The resulting standard, NMG 132-13, was published later that year as the world's first national standard for dried BSF larvae and larval powder for direct human consumption (Bureau de Normes de Madagascar 2025; see chapter 3). The standard formally legitimizes BSF as a human food product and provides a quality and safety framework for commercial development. Three features distinguished the process: a clearly defined technical partner, a single standards body, and a product scope narrow enough to be actionable. Whether the standard translates into market access depends on dissemination and a practical compliance pathway, the same gap that has limited Kenya's framework, but its development shows that regulatory clarity in BSF is achievable in an African context without multi-agency fragmentation.

## BSF in fragility, conflict, and displacement contexts

**South Sudan's Jamjang BSF pilots showed refugees could establish colonies with remote support and no prior experience.** In 2022, two groups of five refugees in South Sudan's Jamjang camps established functioning BSF colonies. None of the participants had prior experience in insect farming, and they operated without on-site technical supervision. Working remotely via WhatsApp with experts in Juba and Zimbabwe, they collected wild BSF prepupae from local waste sites to seed their colonies, constructed breeding cages, and began producing dried larvae as animal feed. The Ajuong Thok and Pamir production sites they established were, as far as is known, the first insect farms ever operated in South Sudan.

**The South Sudan pilots extended earlier post-conflict BSF work into active displacement settings with first-time insect farmers.** Interest in BSF as a tool for FCV-affected populations predates these pilots. In post-conflict Colombia, Barragán-Fonseca et al. (2020) framed BSF production as a reintegration pathway for ex-combatants, arguing that low-cost technology and hands-on training could equip rural communities with limited assets to launch BSF-based smallholder operations. Early demonstration work in Icononzo-Tolima documented an ex-combatant operating an integrated BSF-tilapia system on-farm. The South Sudan pilots, which also included Yei in the south, conducted in 2022 by the World Bank and UNHCR, extended the question to active FCV conditions and to populations engaging with insect farming for the first time.

### The case for BSF in FCV settings

**BSF farming is ideal for FCV settings because it needs little land or capital and uses the organic waste that accumulates in those areas.** FCV-affected settings share a combination of constraints that tend to rule out most conventional food production interventions: no access to arable land, no capital for conventional livestock, disrupted supply chains, and deepening dependence on humanitarian food assistance that is itself under pressure. BSF fits this constraint set unusually well. It requires no land, and its capital requirements are minimal. In a non-FCV setting, for example, one entrepreneur launched a viable BSF operation for under US$60 (see chapter 3). The primary input for BSF farming is organic waste, which accumulates even where everything else is scarce. The barriers that most constrain BSF in commercially developed settings — formal market access, supply chain infrastructure, and regulatory compliance — are largely irrelevant at the subsistence-feed scale FCV contexts require. Operating outside formal regulatory frameworks carries

real risks that programs in less constrained settings can avoid. But in contexts where the alternative is severe protein deficiency and humanitarian assistance under sustained pressure, the calculus is different. In these settings, informal small-scale BSF is a reasonable intervention given the alternative, even though it leaves unresolved the safety questions a more developed context would ask of it.

### Jamjang and Yei: motivation as the binding variable

**Jamjang advanced faster than Yei because poultry feed shortages gave refugees a clear reason to make BSF work.** The pilots took place in two FCV-affected communities: Jamjang and Yei. Jamjang hosts over 90,000 Sudanese refugees in the Ajuong Thok and Pamir camps in the country's far north. Yei lies near the DRC border in the south, with a large IDP and returnee population. In Jamjang, the groups moved quickly because the community had almost no poultry production and feed could not reliably reach a camp accessible only by humanitarian airlift three times a week. With commercial feed unable to reach the camp reliably, BSF larvae were the only locally producible option. Participants applied their training with high retention despite low levels of formal education, executing every stage of production without on-site support. Remote technical guidance via WhatsApp was enough to establish the first colony, but the channel provided reactive troubleshooting rather than a systematic knowledge base. This was enough to get started, but the pilot team later identified recruitment of local insect production specialists as a priority for the next phase. In Yei, where stakeholder consultations were less thorough and community buy-in was weaker, production was slower to establish and less consistent. In this case the binding variable was motivation rather than climate or resources, though both pilots still depended on building production know-how from a low base, partly through remote technical guidance. Communities can establish BSF production with limited resources and no prior experience if they are motivated by specific desired outcomes (Verner et al. 2022).

### Substrate availability and substrate access

**Jamjang had enough organic waste as substrate for BSF production, and host communities saw frass as the main benefit.** In Jamjang, the production groups sourced substrate from household waste, market discards, and crop and livestock residues. Modelling estimated that the combined population of the two pilot communities could generate roughly 400,000 kg of organic waste per month, enough to produce between 40,000 and 120,000 kg of BSFL and a roughly equivalent quantity of frass (Verner et al. 2022). Even a refugee camp with almost nothing else has feedstock. In the Jamjang baseline survey, fertilizer production was the most expected benefit among host community participants, cited by 80%, well ahead of any other benefit in that subgroup. Refugees more often cited income, at 72%. In a setting where soils are depleted and mineral fertilizer is inaccessible; frass was what the host community was waiting for.

**Jamjang also showed that free substrate still requires transport, materials, and collection agreements.** Substrate abundance and substrate access are different things. In Jamjang, scarcity of wood complicated love-cage construction, mesh for breeding cage walls had to be transported from Juba, and securing a reliable organic waste supply required negotiated arrangements with local authorities and a partner vehicle. The groups improvised, testing mosquito nets and local curtains as mesh substitutes, but these workarounds reflect a planning gap. Pre-negotiating waste collection agreements and identifying local material sources before implementation would have reduced the disruptions that slowed early production cycles. Unlike operations co-located with a waste source, Jamjang's production sites depend on collection arrangements that require ongoing institutional support. It remains to be seen whether that support holds

once pilot funding phases out. The substrate is nominally free, but the access cost is real. Donor-funded transport and institutional negotiation carry that cost rather than the producer's balance sheet. This is the same proximity-and-cost variable that drives BSF economics elsewhere in this report. In FCV settings, program presence solves it rather than location, and how the cost is carried after pilot funding remains an open question.

#### Peer ambassadors and uptake

**Jamjang's mix of insect-eating traditions helped peer ambassadors build acceptance from within the community.** The tribal diversity of the Jamjang camps was operationally relevant. Among 18 baseline survey respondents, nine tribes were represented, with widely varying insect-consumption traditions. This turned out to be an asset rather than a complication, since refugees with stronger insect-eating backgrounds acted as informal ambassadors to those without. A similar dynamic was observed in Yei among the Congolese refugee population. In displaced, culturally heterogeneous communities, this internal variation in food traditions can itself drive uptake, often more effectively than outside promotion.

## 1.3 BSF Larvae Outputs: Feed, Food, and Soil

**BSF larvae outputs include feed, food, and frass, but the quality and reliability of each output start with substrate.** BSF larvae can displace expensive imported protein in fish and livestock feeds and, in some cultural contexts, enter the human diet directly. Frass can rebuild depleted soils and, emerging evidence suggests, may also have value as a feed ingredient. The sections below examine how these possibilities apply across the African food system and why none of them are achievable without first solving the substrate question.

### Substrate as the Starting Point

#### Substrate Availability in African BSF Production

**BSF larvae are nutrient converters, not creators, so their protein, fat, and mineral content depends on substrate.** Whatever protein, fat, and mineral content the larvae ultimately carry into the feed or food chain is assembled from the rearing substrate's composition. The same biological plasticity that makes BSF attractive — their capacity to feed on a wide range of organic materials — also means that the composition of the end product is not fixed. Nutrients in the substrate are partitioned during bioconversion: a fraction is incorporated into larval tissue, a fraction passes into the frass, and the remainder is lost as heat, carbon dioxide, ammonia, and other gases.

**Low-value organic wastes often offer the best BSF substrate opportunity because higher-value residues are already used elsewhere.** In African settings, BSF substrate is the actual waste of urban and peri-urban life: vegetable and fruit discards from market stalls, spent grain from breweries, offal and blood from slaughterhouses, and manure from poultry and pig operations ranging from backyard holdings to larger commercial sheds. The materials that tend to go unclaimed are those with limited alternative uses, especially mixed municipal organics and market waste that would otherwise enter landfills and generate leachate and methane as they decompose in tropical heat. Higher-value organic residues such as brewery spent grain are rarely idle in mature markets. They typically move into livestock feed or other uses once an

integrated industry has organized around the supply. The strongest environmental case, and often the most reliable supply, lies with waste streams that have few competing uses.

**Smallholders usually work with nearby household and farm waste, while urban producers may access several larger waste streams.** A smallholder operating on the rural fringe will typically work with whatever organic waste the household and immediate community generate: kitchen scraps, crop residues, small amounts of poultry or livestock manure, and seasonal fruit waste. The mix is rarely abundant or consistent enough to optimize, but a steady baseline supply is still essential. Without it, the colony cannot be maintained. An urban or peri-urban producer, by contrast, may sit within reach of several larger and more reliable waste streams at the same time, such as market waste, brewery residues, slaughterhouse waste, or manure from larger livestock operations. That access makes substrate selection and blending a real operational choice.

**Confirming the species and sourcing stock locally are two early decisions worth getting right.** Operations that attract wild flies, a common low-cost method in Africa, can end up culturing one of the many look-alike soldier-fly species rather than true black soldier fly, so expert identification at the outset is a sensible precaution. On strain, as Box 1.1 discusses, rearing locally established BSF is generally the prudent default, on performance, environmental, and biosecurity grounds. These escape and strain-sourcing questions carry biodiversity and biosecurity implications, which recent invasion-risk research has brought into focus; the report returns to them in chapter 2.

**Some location-specific substrates fall outside the main urban and household waste streams but may be useful where concentrated.** The first is sisal decortication waste, the leftover plant material from fiber extraction. Sisal processing is highly inefficient, with only 2% of the plant becoming usable fibre and 98% left as waste. Tanzania, which was the world's second-largest sisal producer as of 2019, generates large volumes of this waste as a result (Msuya and Temu 2025). Recent research has tested this residue as BSF substrate after pre-treatment, reporting larval biomass yields higher than those obtained from fruit waste on a weight-for-weight basis, with 52% waste degradation over the rearing cycle (Konyo et al. 2023). The second is water hyacinth, an invasive aquatic plant that governments and lakeside communities across Africa pay to remove from waterways. Research from Benin tested it as a partial BSF substrate, finding that it functions better as a supplementary component than a primary feedstock (Vodounnou et al. 2024). Both substrates are agro-industrial or ecological in origin rather than urban or household, and they are concentrated in specific geographies rather than present across the continent. In the case of hyacinth, BSF can turn a costly invasive weed into protein.

### Protein stability across substrates

**The amino acid profile stays relatively stable across substrates.** Protein quantity varies widely with substrate. Spranghers et al. (2017), across four substrates ranging from fresh vegetable waste to biogas digestate, found amino acid profiles remaining broadly similar despite large differences in substrate composition. The pattern holds under African conditions. Shumo et al. (2019), working in Nairobi on chicken manure, kitchen waste, and brewers' spent grain, found no significant substrate effect on the amino acids that matter most for non-ruminant livestock nutrition (lysine, methionine, isoleucine, and leucine). Lysine is the first-limiting amino acid in cereal staples, while methionine is limiting in the legumes and soy

that anchor animal feed. A protein source rich in both is therefore valuable where conventional plant protein falls short, for livestock and people alike (Leinonen et al. 2019).

**Protein quantity, by contrast, varies widely with substrate.** Substrate composition sets the level, and larvae reared on protein-poor substrates such as fruit and vegetable waste accumulate less protein than larvae reared on protein-rich substrates such as brewery side streams or poultry feed (reviewed by Gold et al. 2018). Across the five substrates Ogello tested, crude protein in the larvae typically lands between 38% and 46% of dry matter, with a fish-processing waste treatment reaching 53.5% at the upper edge (Ogello et al. 2025). Across the wider published literature, the spread is wider: a systematic review of 23 studies found total larval protein ranging from 12.9% on fruit and vegetable substrates to 78.8% on fish waste (Hopkins et al. 2021). Producers working with lower-protein substrates should expect larval protein toward the lower end of the range, while those using brewers' spent grain or fish-processing residues will see higher values. What changes less across this range is the amino acid profile, discussed below.

**Reported protein figures need careful comparison, because measurement conventions differ.** The standard nitrogen-to-protein conversion factor of 6.25 overstates true protein content in insects by counting non-protein nitrogen from chitin. Insect-specific factors are lower (proposed values for BSF cluster around 4.4 to 4.8) and applying them reduces reported protein substantially, by roughly nine percentage points for the same larvae (Janssen et al. 2017; Hopkins et al. 2021). A systematic review found that many studies do not report which factor they used or whether they corrected for chitin, which makes published protein contents difficult to compare directly (Hopkins et al. 2021). This is a methodological issue rather than a biological one, but it matters when comparing BSF meals to fishmeal and soybean meal benchmarks measured under different conventions.

### Effects from Substrate Variation

**Substrate affects the larval composition unevenly: the amino acid profile shifts relatively little, while fat, ash, and mineral content vary substantially.** A systematic review found that despite wide variation in the amino acid content of the substrates, larval amino acid content differed only modestly, by roughly ±20% within studies, indicating limited scope to alter the larval profile through substrate (Hopkins et al. 2021). Some amino acids do shift with substrate, but the key amino acids for non-ruminant livestock are among the stable ones, at levels meeting or exceeding standard requirements (Shumo et al. 2019). Processing steps such as drying can also affect amino acid content, and the evidence base directly comparing substrate and larval profiles remains thin. Fat is highly substrate-sensitive, and because fat and protein together make up most of the larval dry matter, much of the apparent variation in protein percentage reflects shifts in fat accumulation rather than changes in absolute protein. Larvae reared on energy-dense, carbohydrate-rich substrates accumulate more fat, as carbohydrates are converted to lipids and stored in the fat body (reviewed by Gold et al. 2018). Spranghers et al. (2017) found fat content in prepupae ranging from 218 to 386 g $kg^{-1}$ dry matter across treatments, a near-twofold difference. Ash moved in the opposite direction, ranging from 27 to 197 g $kg^{-1}$ across the same treatments: prepupae reared on energy-rich restaurant waste were highest in fat and lowest in ash, while those reared on nutrient-poor biogas digestate were lowest in fat and highest in ash. Shumo also found calcium and potassium concentrations in the larvae differed significantly with substrate, with calcium highest in chicken-manure-fed larvae and potassium highest in those fed kitchen waste.

**Substrate also changes biomass yield, feed conversion, and egg output enough to shape production volume and input needs.** These compositional shifts matter for feed formulation, but the operational consequences of substrate choice are larger still. Ogello et al. (2025) showed that larval biomass yield varied by more than 20% across substrates, from 1.34 kg per production unit on fish-processing waste to 1.65 kg on the mixed substrate. Feed conversion ratios followed the same pattern in reverse: 1.1 on mixed waste and 3.2 on fish-processing waste, meaning larvae on the worst-performing substrate needed nearly three times the feed input to produce an equivalent weight of biomass. Colony performance tracked substrate as well. Fecundity ranged from roughly 1,150 to 1,409 eggs per female depending on what the parental generation had been reared on, with mixed waste at the top and brewery waste at the bottom despite producing fat-rich larvae. This shows that larval nutrition carries forward into adult reproductive capacity. For the bioconversion metrics that sit at the heart of the business, the differences in biomass yield and feed conversion efficiency are large enough to matter economically, even if substrate costs and labor typically remain the dominant variables in most operations.

**Substrates that maximize larvae may not support breeding colonies equally well, especially outside industrial systems.** For operations dependent on single commodity streams, substrate choices optimized for larval output may not serve colony maintenance equally well. Ogello's data cut both ways on this: the mixed substrate that produced the most larval biomass also produced the highest fecundity, so it is not universal. Brewery waste is the counter-case: high fat accumulation in larvae coincided with the lowest fecundity of any substrate tested. For operations managing their own breeding colony, that trade-off accumulates across every production cycle. Specialization — running dedicated substrate for the breeding line while production lines run on whatever is available — is standard practice at industrial scale. Smallholder and mid-scale operations may or may not benefit, particularly if the substrate optimized for reproductive performance is more costly than what would otherwise feed the production line. For smallholder operations, reliable single-stream input almost always delivers more practical value than substrate-segmented optimization. At mid-scale, the calculus is more variable and depends on the cost difference between substrates and the marginal value of fecundity gains.

### Why blending works: volatile solids, protein, and heterogeneous waste streams

**Balanced substrates help larvae grow faster and convert waste more efficiently.** Two substrate properties drive most of the variation in biomass conversion and larval development time. Lalander et al. (2019), evaluating eight urban organic waste fractions under controlled conditions, identified them as volatile solids content and protein feeding rate. Volatile solids are the organic, potentially digestible fraction of dry matter, which sets the energy available to the larvae. Protein feeding rate determines how quickly larvae can accumulate enough nitrogen to complete development. Larvae grow fast and convert efficiently if both are high. "Protein-poor" and "protein-rich" are relative terms: in Lalander's substrates, fruit and vegetable waste sat at around 13 percent protein on a dry-matter basis, food waste at about 22%, and animal-derived streams higher still. In pure fruit and vegetable waste, volatile solids are high, but protein is low, so larvae eventually reach a reasonable size but develop slowly and convert biomass poorly. Protein-rich substrates can also perform poorly if they spoil quickly or create conditions that reduce larval survival. Blending means deliberately combining plant and animal waste streams, so the final substrate has enough digestible organic matter and enough protein. Lalander et al. demonstrated this principle by combining slaughterhouse waste with fruit and vegetable fractions; Ogello’s equal-parts mixed substrate showed the same principle using locally available East African waste streams.

**Hotel and restaurant waste can perform well because it already combines fats, proteins, and carbohydrates.** A balanced substrate does not have to be engineered by blending. Hotel and restaurant waste is already nutritionally heterogeneous, combining carbohydrates, proteins, and fats from diverse prepared food sources in proportions similar to what deliberate blending tries to engineer. Holeh et al. (2022), working in coastal Kenya with hotel waste, market waste, and a mixture of the two, found that hotel waste outperformed market waste on development speed, growth, and feed conversion. The mixed treatment produced the highest crude protein content of the three, though it yielded less larval biomass than either waste alone, so hotel waste alone was the strongest performer. Spranghers et al. (2017) reported the same strength for restaurant waste in their European trial, where larvae grew well and development was slowest, likely due to high grease content. For operators with reliable access to hotel or catering waste streams, the substrate design problem may largely solve itself, and the colony management trade-off imposed by single-commodity streams may not arise.

**What the larvae reliably deliver is a stable amino acid profile; what varies with substrate is protein quantity, fat, minerals, ash, and frass composition.** Each of these variable components affects product use differently. For feed applications, those differences shape how BSF meal fits into commercial formulations, a question the Larvae as Feed section examines directly. For the frass co-product, substrate composition is equally determinative of agronomic value, examined in detail in the Frass Co-product section.

### Substrate manipulation to improve frass quality

**Raising the substrate's carbon-to-nitrogen ratio improved frass nutrient retention, at a modest cost to larval yield.** Deliberate substrate manipulation can shift the balance toward frass quality. Frass quality depends in part on the substrate's carbon-to-nitrogen (C/N) ratio, which affects nutrient retention. Beesigamukama et al. (2021) demonstrated this by amending brewer's spent grain (C/N ratio 11) with sawdust to obtain C/N ratios of 15, 20, 25, and 30. Raising the ratio increased nitrogen retention in the resulting frass compost by 21% and phosphorus retention by 15% relative to the unamended substrate, but larval yield declined as more sawdust was added: the unamended control produced the highest larval yield, and every amended substrate yielded less. C/N 15 was the best compromise, capturing the frass-nutrient gains while keeping fresh larval yield statistically indistinguishable from the control. The nitrogen is conserved because sawdust's phenolic compounds bind ammonium and, with microbial immobilization, suppress ammonia volatilization in the composting frass. Biomass conversion efficiency itself was not significantly affected; the yield reduction reflects the dilution of nutrient-dense spent grain with high-carbon sawdust rather than a loss of larval performance per unit of available nutrient. The amendment itself, wood waste from a local carpentry workshop in the Nairobi study, is inexpensive. Substrate C/N formulation is most relevant where mineral fertilizer is expensive, and frass has a reliable market.

**Biochar can improve both larval output and frass nitrogen retention, but the amount added changes whether the system favors larvae or waste breakdown.** Biochar is a charcoal-like material added to substrate to help retain nutrients and improve structure. Beesigamukama et al. (2020c), working with the same brewery spent grain substrate examined above, found that 20% biochar inclusion increased wet larval yields by 89%, raised the biomass conversion rate by 195%, improved nitrogen retention in the resulting frass by 21%, and accelerated compost maturity. Sawdust acts mainly on frass chemistry; biochar acts on both sides of the bioconversion process. It suppresses ammonia loss during rearing and improves larval

output. The amendment rate affects the production trade-off. The 20% inclusion rate maximized larval yield and conversion efficiency but reduced overall waste degradation, meaning the larvae produced far more biomass per unit of feed even as a smaller share of the total substrate was broken down. A lower 5% inclusion-maintained waste degradation performance, while higher rates progressively reduced it. Higher biochar rates therefore favor frass quality and larval yield. Lower rates better preserve waste-processing capacity. Chanzi's operation in Tanzania and Kenya applies this principle at commercial scale, incorporating biochar into its bioconversion process and improve substrate structure (SMEP 2024; Diener and Storey 2025).

### The case for pre-treatment: performance and consistency

**Pre-treatment can make fibrous crop residues usable as BSF substrate and improve substrates that already work.** Pre-treatment means changing a substrate before larvae feed on it. It can include milling, heating, fermentation, microbial inoculation, or other steps that make the material easier for larvae to consume and convert. For fibrous agricultural residues, pre-treatment is often necessary. Crop residues such as grass clippings, rice straw, and sugarcane bagasse are abundant, often available at low or zero cost, and largely underused for BSF because their fiber content resists larval digestion. Such fibrous substrates produce bioconversion rates of roughly 2–6% dry mass, compared with 15% or above on nutrient-dense substrates (Peguero et al. 2024). Brewery spent grains sit in a middle position. They function adequately without pre-treatment, but fermentation can improve larval output (Gebiola et al. 2023; Opare et al. 2024)

**Some substrate pre-treatments improve how well larvae convert waste into biomass and protein, but others are ineffective or too technical for smallholders.** Several substrate pre-treatment approaches have been tested. Thermal treatment at 90°C showed neutral or negative effects on larval performance across multiple substrates, possibly because heat disrupts the microbial communities that BSF bioconversion depends on (Peguero et al. 2024). The most recalcitrant substrates, such as sugarcane bagasse, an abundant agricultural residue in sub-Saharan Africa, required combined steam, enzymatic, and microbial treatment to achieve viable conversion rates (Bothma et al. 2024). That combination requires equipment and technical control that smallholders are unlikely to have. Mechanical size reduction through milling improved bioconversion by 0-53% on spent grain and 25–44% on grass clippings, with finer milling down to 0.5 mm producing the strongest results. Larval protein conversion increased by 41% on spent grain and 23% on grass clippings. The size of the bioconversion gain varied with larval density and other rearing conditions, so the specific figures should be treated as indicative rather than directly replicable. The direction of the effect is consistent (Peguero et al. 2024).

**Substrate fermentation can improve larval growth and waste conversion, but results vary by microbe, substrate source, and larval density.** Microbial and fermentation approaches show the most consistent results and the most accessible application. Substrate quality has a significant effect on both bioconversion and larval composition, and a comprehensive review of strategies to enhance bioconversion identifies physical, chemical, and biological pre-treatments — including fermentation — as the main levers for improving the conversion of fibrous substrates (Siddiqui et al. 2025). Anaerobic fermentation using lactic acid bacteria, yeasts, and fungi increased larval biomass by 40%, shortened development time by over two days, and reduced ammonia and $N_2O$ emissions on brewery spent grain. The likely mechanism is pH acidification, which suppresses nitrogen volatilization (Gebiola et al. 2023). Results vary with inoculant composition and substrate source. A separate trial using lactic acid bacteria alone found comparable

biomass gains on fermented spent grain but no reduction in development time (Opare et al. 2024). The divergence between Gebiola et al.'s two-day reduction and Opare et al.'s null result most likely reflects differences in inoculant composition and substrate source between the two studies The benefit also depends on which fibrous substrate is treated. Fermentation increased prepupal mass by 41% on spent grain but only 12% on grass silage, with no survival benefit in the latter, suggesting that substrate type sets a ceiling on what fermentation can deliver. Spent grain results also depended on stocking density: the prepupal mass improvement was significant only at low density, meaning fermentation and rearing density cannot be optimized independently (Opare et al. 2024). More broadly, bacterial inoculation before larval feeding has produced comparable improvements in waste reduction and bioconversion on chicken manure and soybean curd residue (reviewed in Rehman et al. 2023).

**Fermentation can preserve organic waste for later use, helping BSF operations avoid substrate shortages.** Organic waste streams are rarely steady in practice. Seasonal fluctuations, market disruptions, and logistical gaps mean that a BSF operation relying on fresh waste delivery faces periodic shortfalls that can destabilize or collapse the biological system. Fermentation offers a direct solution to this supply problem. Organic waste inputs treated with widely available microbial inocula and sealed in airtight containers can be stored for 6–12 months and drawn on when fresh material is unavailable, maintaining consistent feedstock supply across periods of scarcity (Samson et al. 2025). The stabilization benefit extends to marginal substrates that would otherwise spoil before use. Oranges, on which BSF larvae perform poorly when fresh, become substantially more usable after fermentation. In an industrial-scale trial, bokashi fermentation cut larval development time on oranges by 59% (12 versus 29 days), more than doubled growth rate, and brought performance up to the level of larvae reared on unfermented spent grain, a nutritious standard feedstock (Gebiola et al. 2023b). This suggests that fermentation can rescue substrates that would otherwise be written off entirely (Gebiola et al. 2023b; Samson et al. 2025). In African contexts where waste supply can be irregular, fermentation-based storage is valuable because it may improve yield and helps keep the BSF system fed.

### Rearing conditions as another variable

**Rearing conditions also shape larval protein and fat, so identical substrates can produce different feed profiles.** Substrate composition, manipulation, and pre-treatment are not the only factors shaping larval output. Rearing conditions, such as how larvae are housed and how densely they are stocked, also affect the final product. The milling improvement on spent grain was inconsistent, varying with substrate bulk density and aeration rather than holding steady across conditions (Peguero et al. 2024). Rearing conditions matter independently: a controlled experiment that held substrate constant across four container sizes and two larval densities found crude protein ranging from 32.5% to 36.5% and crude fat from 20.1% to 31.7% (Yakti et al. 2022). These differences reflect the heat dynamics and nutrient competition that emerge at different production scales. Larger rearing units generate more internal heat through larval aggregation, which accelerates growth but shifts the protein-fat balance. Higher larval densities deplete nutrients faster, with similar effects on composition. For feed applications, this means that two operations using the same substrate can still produce larvae with meaningfully different nutritional profiles depending on how those larvae were reared.

## Contaminated Substrates: Pathogens, Mycotoxins, and Heavy Metals

### Pathogen reduction

**BSF bioconversion can reduce some pathogens, but the effect depends on substrate, pH, and pathogen type.** BSF bioconversion does more than convert organic waste into protein and fertilizer; it also modifies the microbial environment of the substrate it processes. Lalander et al. (2015), operating a continuous-flow fly larvae reactor on a mixture of pig manure, dog food, and human feces, recorded near-complete elimination of *Salmonella* spp., reduced from around $10^7$ CFU $g^{-1}$ in the inflow to below the detection limit of 1 CFU $g^{-1}$ in the outflow. All three tested viruses — adenovirus, reovirus, and enterovirus — were likewise below the detection limit within 14 days. The effect is not universal, and substrate conditions matter. Erickson et al. (2004) found the outcome depended entirely on the manure: larvae sped up *E. coli* die-off in chicken manure, made no measurable difference in cow manure, and prolonged the pathogen's survival in hog manure. The underlying mechanism appears to involve the larvae's gut microbiota competing with and suppressing pathogenic organisms in the compost environment. Shi et al. (2024), composting kitchen waste and pig manure at three controlled pH levels, found the larvae's gut bacteria suppressed pathogens by competing for the same niche in the compost, with the sharpest drop in pathogen abundance and diversity when the substrate started at neutral pH. Helminth eggs are a different matter. Lalander et al. (2015) found that *Ascaris* eggs survived the treatment largely intact, a limitation with direct implications for frass safety in contexts where parasitic contamination is a concern.

**Post-harvest heat treatment reduces pathogen risk before larvae are used as feed.** As with any animal-derived protein source, heat treatment or drying of harvested larvae or prepupae improves hygienic status and is standard practice regardless of substrate origin. A related practice, used by some operations, is gut-voiding: holding harvested larvae briefly without feed so the gut empties of residual substrate before use. It is more often considered where larvae are used fresh and unprocessed, since heat treatment addresses gut-borne pathogens by other means, and where the substrate carries higher pathogen loads, such as manure. Practice varies, and the appropriate level of treatment depends on substrate, end use, and local food-safety requirements. A risk assessment of BSF composting systems in southern Benin found that *Salmonella* was present in fresh larvae reared on urban organic waste streams, but blanching — brief immersion in boiling water — eliminated it (Ogbon et al. 2025). The same study found that pesticide residues detected in substrate and frass did not bioaccumulate in the larvae themselves, consistent with findings from controlled trials elsewhere. One important exception applies: cabbage waste with very high pesticide concentrations, reflecting intensive pest management practices common in urban vegetable production, was lethal to BSF larvae. Formal screening for chemical contaminants is rarely feasible at smallholder scale. The more practical precaution is to avoid substrates with known heavy pesticide inputs or explicitly test their effect on larval performance, particularly with intensively managed urban vegetables.

**BSF can lower some pathogen risks, but it does not make contaminated substrates safe by itself.** BSF bioconversion reduces certain pathogen loads in specific substrates under specific conditions. The reductions are meaningful in cases such as Lalander et al.'s 2015 *Salmonella* result, partial or absent in others, and subject to documented failure modes such as enhanced *E. coli* survival in hog manure and intact *Ascaris* egg passage. BSF bioconversion is not a general sanitization step. Heat treatment of larvae, required by EU regulation for products entering regulated markets and shown effective by Ogbon et al. (2025) on urban-market larvae, is the most reliable post-harvest control for substrate-derived pathogen risk. Adoption

of such practices in smallholder African operations is poorly documented. Frass safety standards are less settled overall, with appropriate handling depending on substrate, intended use, and local context.

### The mycotoxin burden in African feed systems

**Mycotoxins create a separate feed safety risk from pathogens, with aflatoxin B1 among the most dangerous.** Mycotoxins are fungal secondary metabolites that pose a persistent threat to food safety, public health, and economic development across Africa. Staple crops such as maize and other high-value foods such as ground nuts are especially vulnerable because they are often cultivated and stored under conditions that support fungal growth (Udomkun et al. 2017). Aflatoxin B1 (AFB1), classified by the International Agency for Research on Cancer as a Group 1 carcinogen strongly linked to liver cancer (IARC 2012), is among the most dangerous. Its chronic and acute health effects range from stunting to immune suppression, and they are compounded by wider socioeconomic effects such as food insecurity (Udomkun et al. 2017; Chilaka and Mally 2020). Aflatoxin ranks as the leading chemical food safety hazard by disease burden in parts of sub-Saharan Africa, and is one of the major non-diarrheal causes of foodborne death globally, with about 20,000 deaths in 2010 (Havelaar et al. 2015).

**The scale of mycotoxin exposure remains difficult to measure and control because surveillance and local enforcement are weak.** Available estimates are fragmented, covering individual countries or specific health endpoints such as stunting or liver cancer rather than the full disease picture. The WHO global burden-of-disease estimates based on 2010 data have not been updated at the continental scale (Meijer et al. 2021). Decades of research and intervention have not resolved the problem. Contamination remains persistent, worsened by climate change, limited regulatory enforcement, and gaps in surveillance and research capacity. Across much of Africa, regulatory limits are often applied only to export crops, with little enforcement for foods consumed locally (Matumba et al. 2017; Chilaka et al. 2022). The WHO estimates that more than 500 million of the world's poorest people, most in sub-Saharan Africa, are chronically exposed to unsafe mycotoxin levels, with lifelong health consequences beginning in childhood (Ezekiel et al. 2019).

**Mycotoxin-contaminated feed can carry food safety risks into animal products and create market losses for farmers.** Animals consuming contaminated feed can carry the risk forward through animal-source foods, including milk. AFM1, the milk metabolite of AFB1, has been detected in Kenyan dairy at concentrations up to 140 times the WHO/FAO limit (Senerwa et al. 2016). A peer-reviewed analysis of aflatoxin standards in Kenya found that strictly enforcing existing limits, without parallel measures to replace discarded food, would be counterproductive: it would cut the national maize supply by roughly 22 percent, with the poorest households bearing the largest losses, even as it averted on the order of 1,400 liver-cancer deaths a year (Sirma et al. 2018). This contamination traces directly to feed. Surveys across Rwanda's dairy and poultry feed value chain found mean aflatoxin levels exceeding 100 ppb among dairy and poultry farmers, more than 20 times the Rwanda Standards Board limit for cattle feed supplements. More than 90% of participants had never heard the words "mycotoxins" or "aflatoxins" (Nishimwe et al. 2019).

### BSF tolerance and degradation

**BSF larvae generally tolerate major regulated mycotoxins without accumulating them, though less-studied toxins may differ.** This pattern holds across aflatoxins, deoxynivalenol, zearalenone, and

ochratoxin A in multiple studies (Bosch et al. 2017; Camenzuli et al. 2018; Purschke et al. 2017; Gulsunoglu et al. 2019; Ivanova et al. 2026), and extends to fumonisins in the study that has tested them (Gold et al. 2023). One exception warrants attention: beauvericin (BEA), a lipophilic *Fusarium* toxin, has been shown to bioaccumulate in larvae at a factor of approximately 1.6 relative to substrate concentrations, likely reflecting its affinity for the larvae's high fat content (Gold et al. 2023). The regulatory significance of this is currently unclear, as BEA lacks established maximum limits in most jurisdictions, but it shows that the non-accumulation pattern should not be assumed to extend to all emerging or less-studied mycotoxins.

**BSF systems reduce aflatoxin risk because larvae and their gut microbes convert some of the toxin into other compounds.** Gold et al. (2023) detected AFP1, a known AFB1 metabolite, in frass but not in larvae or the original substrate, providing direct evidence of active metabolization during bioconversion. Meijer et al. (2019) confirmed that the larvae's own enzymes, independent of gut microbiome activity, actively convert AFB1 into AFP1 and aflatoxicol through distinct biochemical pathways, though approximately 40% of AFB1 remained unconverted in their assay. Gut microbiome activity has since been identified as a further, synergistic degradation pathway (Suo et al. 2023). Substrate-inhabiting microorganisms also contribute independently: when BSFL are absent, but the substrate is non-sterile, degradation still occurs, though it produces different metabolites, AFL rather than the BSFL-specific AFP1. This confirms that the larval enzyme system and substrate microbiota play distinct, complementary roles (Niermans et al. 2024a). The result is a multi-actor degradation system in which BSFL tolerate substrate mycotoxin loads that would harm vertebrate livestock and humans. Heuel et al. (2023) observed impaired larval development only at artificially spiked concentrations of 842 ppb AFB1, roughly ten times the highest concentration tested under realistic field conditions in Rwanda. The same study tracked contaminants through the full production chain to eggs and meat, finding that even where trace AFB1 was detectable in larvae, dilution through feed formulation brought the complete hen diet to only 1.2 ppb, around 6% of the European Commission maximum for adult poultry feed.

**Rwanda's contaminated-maize trial found that larvae did not accumulate aflatoxin or fumonisins under realistic field conditions.** Gold et al. (2023) used naturally contaminated maize purchased from a public market in Kigali, carrying aflatoxin and fumonisin concentrations far exceeding East African Community food safety limits, alongside multiple co-occurring mycotoxins. Substrates were then blended with additional feedstocks to reach concentrations of up to 99.4 ppb AFB1, well above East African Community and EU limits for whole grain maize. Larvae reared on these substrates consistently showed lower levels of AFB1, or none at all, confirming that bioaccumulation did not occur. The same held for co-occurring fumonisins: larval FB1, FB2, and FB3 were within safety limits even when exposed to the highest substrate contamination levels (Gold et al. 2023). This multi-mycotoxin real-world result is meaningful because fumonisin co-contamination with aflatoxins is typical of tropical maize systems.

**A laboratory study using contaminated peanut press cake as BSF substrate found no aflatoxin buildup in larvae or loss of larval performance.** Peanut press cake carries a high aflatoxin risk of its own: surveys of informal markets in Kinshasa and Pretoria found 95–100% of samples carrying aflatoxigenic fungi, with the majority of Kinshasa samples exceeding regulatory limits for AFB1 (Kamika et al. 2014). A laboratory study using naturally contaminated peanut press cake found complete mass balance recovery for AFB1 when known metabolites were included, with no accumulation in larvae and no effect on larval survival or biomass (Niermans et al. 2024b). Similar outcomes have been observed across other major

mycotoxins, with larval concentrations remaining below regulatory thresholds even at high substrate contamination levels (Camenzuli et al. 2018; Gulsunoglu et al. 2019; Ivanova et al. 2026).

### Mycotoxins in frass and the system-level case

**During bioconversion, larvae can excrete residual mycotoxins into frass, shifting the safety question from feed to soil use.** The major regulated mycotoxins are largely not retained in larvae, but they are excreted in frass, with concentrations varying considerably by mycotoxin. In some cases, concentrations are lower than in the original substrate; in others, they are similar or higher (Gold et al. 2023; Ivanova et al. 2026). Frass nutrient content from the Rwanda trial was broadly comparable to local compost benchmarks, though elevated electrical conductivity warrants further plant-trial work before firm application recommendations can be made (Gold et al. 2023). Mycotoxins are not currently regulated in compost or fertilizer at the EU level, and residual frass mycotoxins therefore warrant caution in soil application until clearer evidence is available (Gold et al. 2023). This asymmetry is important in African contexts. Larval bioconversion can convert substrate-bound mycotoxins from a feed-safety problem into a frass-disposal question, but weaker oversight of soil amendments leaves the agronomic and public-health implications unresolved. A key agronomic concern is whether aflatoxin-contaminated frass could reintroduce mycotoxin-producing fungi into soils. Gold et al. (2023) found no *Aspergillus* spp. in any frass sample, including those derived from the most heavily contaminated substrates. This suggests that bioconversion suppresses the fungi responsible for aflatoxin production even as residual toxin passes through. Whether residual mycotoxins in frass pose meaningful agronomic or health risks when applied to soil remains poorly understood. Appropriate post-processing, application rates, and handling precautions are prudent until clearer evidence is available.

**BSF bioconversion can turn unsafe or unsellable contaminated grain into larval protein, reducing food safety risk and avoiding disposal losses.** Across sub-Saharan Africa, mycotoxin contamination destroys crops that cannot enter food aid programs and cannot be exported. In the absence of effective oversight, contaminated grain often remains in the food system, either fed to livestock or consumed directly by people who have no alternative. This compounds economic loss with public health harm. Regulated disposal mechanisms, when they exist, typically rely on incineration, adding cost and emissions while eliminating whatever residual value the contaminated grain still carried after being sold at a discount along the informal market chain. BSF bioconversion offers a system-level recovery mechanism. Contaminated feedstocks identified at markets, mills, or export inspection points can be channeled at reduced cost into BSF operations, converting waste or health hazards into protein-rich larval biomass. The larvae do not accumulate the major regulated mycotoxins at levels that would compromise end-product safety. The benefit here is economic and public-health related as well as agronomic, and it is greatest where feedstock conditions are worst. Conventional mitigation strategies, from resistant crop varieties to postharvest sorting and biocontrol agents, have been extensively studied, but proof of cost-effectiveness is largely absent from the peer-reviewed literature (Meijer et al. 2021). BSF bioconversion does not replace these upstream interventions. What it adds is a way to recover economic value from contamination that has already occurred.

### Heavy metals

**Heavy metal contaminants in substrates can build up in larvae, making them unsafe for feed.** Heavy metals are the third major substrate-derived contamination concern. BSF largely excludes most regulated

mycotoxins from larval tissues and reduces many pathogens during bioconversion, but nonessential heavy metals can accumulate in proportion to substrate exposure. Not all metals behave the same. Essential metals such as copper and zinc are metabolically regulated and show no consistent correlation between substrate and larval concentrations. Nonessential metals, particularly cadmium, lead, mercury, and arsenic, can accumulate (van der Fels-Klerx et al. 2018). Cadmium is the clearest BSF case. Bioaccumulation factors in prepupae range from approximately 2.3 to 2.9 (Diener et al. 2015), and substrates carrying cadmium at the EU maximum limit for complete feed can produce larvae exceeding the maximum limit for feed materials (van der Fels-Klerx et al. 2018). No established process removes heavy metals from larvae once accumulated, so control rests on substrate selection and monitoring rather than post-harvest treatment. One emerging possibility is specific to cadmium: larvae excrete it quickly, with a clearance half-life of about two days, and the authors propose that a short depuration period on clean substrate before harvest could meaningfully lower cadmium in the final product (Zhang et al. 2025). This is cadmium-specific and not a general solution. Whether a similar depuration approach would work for other accumulated metals is untested: manganese, for instance, bioaccumulates strongly in larvae (with factors as high as 5.0), but its elimination kinetics have not been studied, so depuration cannot yet be assumed to extend beyond cadmium (Bessa et al. 2021).

**The same plant-based substrate can carry different metal risks depending on the soil or water from which it came.** Substrate exposure has more than one pathway. Environmental contamination through proximity to industry, traffic, mining, or sewage is one route. Plant uptake from growing conditions is another: some feed ingredients can carry elevated heavy-metal loads even from soil or water that appears clean, because their biology concentrates particular metals efficiently. Sunflower meal in high-clay or high-chloride soils has documented cadmium accumulation. Cocoa from particular growing regions, especially parts of Latin America, has triggered EU regulatory limits for chocolate cadmium content. Water hyacinth concentrates metals from any water it grows in, including contaminated water bodies. These patterns are conditional rather than universal, but they mean operators using such substrates need to know where the material came from, not only what it is.

**The picture across contaminants is consistent.** BSF bioconversion changes the contamination profile of what it processes, reducing some risks, excluding others, and concentrating a few, but it does not by itself make an unsafe substrate into a safe product. The effects vary by contaminant, substrate, and study, and safe use depends on substrate discipline and post-harvest treatment as much as on the larvae themselves. Feed safety must be actively managed; the technology does not supply it on its own.

## Larvae as Feed

### African feeding trials

**African trials show BSF larvae meal performs best as a partial feed substitute, especially where fishmeal is costly or poor quality.** BSF larvae meal is the most thoroughly evaluated insect-based feed ingredient across livestock and aquaculture species, and the evidence base is broadly positive. Interest in BSF as feed is not new: controlled feeding trials in the United States date to the 1970s and 1980s, including early work feeding BSF larvae to poultry and to channel catfish and tilapia, the same species now central to African aquaculture (Hale 1973; Bondari and Sheppard 1981, 1987). The African evidence reviewed here builds on that longer foundation. A recent review of recent trials (2021-2022) covering fish, poultry,

and pigs found that partial substitution of fishmeal or soy at species-appropriate inclusion levels generally delivered comparable growth performance and feed conversion without significant effects on animal health or product quality. Safe inclusion levels vary by species, meal type, and whether the larvae are whole or defatted (Sogari et al. 2023). The African-specific evidence is more limited but consistent with this picture, and in several respects more favorable. Fishmeal is often expensive, inconsistently available, or poor quality, making the economic case for substitution stronger than global averages suggest and lowering the performance bar BSF meal needs to clear compared with trials conducted against high-grade imported products.

**Formal trials often use dried, defatted, or other processed BSF meal, so they do not show how commonly used fresh larvae perform on smallholder farms.** BSF larvae are prepared in several forms: fresh or live larvae fed directly, sun- or mechanically dried whole larvae, dried and ground larval meal, and partially or fully defatted meal from which lipids have been extracted. These distinctions affect feeding outcomes. Defatted meal has a higher and more consistent protein concentration than whole dried larvae, while the fat fraction, which is high in saturated fatty acids, affects the fatty acid profile of the animal product when left in. Most formal feeding trials use dried meal, often defatted, which is not the product form most smallholder operations in Africa currently produce or sell.

**African poultry and tilapia trials show BSF can replace part of conventional feed without reducing fish growth or survival.** The African feeding trials reviewed in the section African Settings and Scale establish the regional baseline across both poultry and aquaculture. In Kenya, BSF prepupae meal replaced up to 55% of conventional protein in broiler diets with no detectable effect on growth, feed conversion, carcass quality, or meat taste (Onsongo et al. 2018). A parallel trial on improved indigenous chicken, the breed that dominates smallholder production in Kenya, found that BSF meal could replace fish meal at up to 20% inclusion without compromising growth performance (Waithaka et al. 2022). For Nile tilapia, a field trial at a smallholder aquapark in western Kenya found that 20% substitution of commercial diet with dried BSF larvae delivered equivalent growth and survival across an 84-day production cycle (Kals et al. 2024). In each case, the larvae performed well enough to justify the economic question, which the African Settings and Scale section examines directly.

**Tilapia trials show that BSF meal can replace part of fishmeal while maintaining growth and feed conversion, but results vary by fish farming system.** The most comprehensive review of tilapia-specific evidence draws on 24 feeding trials across hapas, cages, tanks, and aquaponic systems. Hapas are net enclosures placed in ponds. The review finds that BSFL meal can support growth and feed conversion across culture types, with the strongest results appearing in hapa-in-pond systems at around 50% fishmeal replacement (Munguti et al. 2025). Full fishmeal replacement consistently underperforms partial substitution across all systems. Results in cage and tank systems were generally weaker than in hapa-in-pond trials at equivalent inclusion levels, a pattern the authors attribute partly to the absence of natural food supplementation that buffers nutritional gaps in pond-based systems and partly to nutritional imbalances that emerge at high inclusion levels. In systems without that natural buffer, the effective inclusion ceiling appears lower, and the choice of inclusion level matters more. Direct cross-study comparisons are further limited by differences in methodology, fish size, and culture duration, so the findings are better read as directional trends than precise substitution thresholds. Inclusion levels that perform well in one culture system should not be assumed to transfer to another. The variability in results across systems reinforces the

case for pilot-scale feeding trials before scaling, a precaution consistent with the broader feasibility argument made elsewhere in this report.

**Fish offal can improve the fatty acid profile of BSF meal when larvae feed on it before harvest.** A Benin-based trial found that total replacement of fishmeal with BSF larval meal, enriched with polyunsaturated fatty acids by feeding larvae on locally sourced fish-processing waste before harvest did not substantially affect growth or innate immune status in Nile tilapia juveniles. Whole-body fatty acid profiles in fish fed enriched BSF diets were comparable to fishmeal controls, although protein digestibility was reduced across all BSF diets (Agbohessou et al. 2021). The trial shows that BSF meal's nutritional profile is not fixed: substrate choice shapes the larvae's fatty acid composition, and where fish offal is a local waste stream rather than a purchased input, the enrichment adds nutritional value at negligible cost.

**A Tanzanian hatchery trial showed local BSF meal could replace most fishmeal for tilapia fry without reducing survival.** A tank-based study on Nile tilapia fry in Tanzania covers a production context the pond-focused evidence does not, and the cage and tank underperformance pattern seen in grow-out trials is less directly relevant here, since tanks serve as hatchery nursery systems rather than grow-out units. At hatchery scale, BSF larvae meal sourced from a local producer replaced fishmeal without affecting survival, with growth performance peaking at an estimated 81–84% inclusion; 75% replacement cut feed costs by 30% and delivered a 4% improvement in economic returns (Limbu et al. 2022). The controlled tank setting means the fish had no access to natural food supplementation, making the growth performance result a cleaner test of BSF meal's nutritional adequacy than a pond-based trial.

**A Cameroon catfish trial found higher growth and survival with full-fat BSF meal than with local fishmeal.** For African catfish (*Clarias gariepinus*), Hervé et al. (2025) tested BSF larvae full-fat meal at 50%, 75%, and 100% fishmeal replacement in Cameroon using simple on-farm toasting methods rather than industrial defatting. Growth and survival were significantly better at 75–100% inclusion than on the local fishmeal control, a result the authors partly attribute to the poor quality of locally available fishmeal. Feed costs fell substantially, and the fish-in-fish-out ratio dropped below 1.0 at 75% and 100% inclusion, indicating that the system was no longer drawing down wild fish stocks to produce farmed fish. Consumer acceptability was high across all diets, and the 75% BSF larvae inclusion group received unanimous approval from all panelists, the highest acceptance of any diet tested. The performance advantage over the local fishmeal control is partly a function of how poor that baseline was, which limits direct generalizability. But the use of low-technology processing methods accessible to smallholders, and the strong economics at high inclusion rates, make this among the more practically relevant trials in the African aquaculture literature.

### Beyond growth performance: immune and health effects

**A barramundi fish trial found BSF meal matched fishmeal on growth and improved immune defenses linked to bacterial infection.** Evidence from outside Africa extends the BSF-as-feed argument beyond growth performance. In a controlled feeding study with juvenile barramundi, replacing 30% of fishmeal protein with partially defatted BSF larvae meal produced growth and feed conversion that were statistically equivalent to the fishmeal control. The BSF-fed fish also showed significantly higher bactericidal activity in serum, upregulated expression of immune-relevant cytokines in the intestine, and increased mucin cell counts in both gut and skin, all indicators of improved mucosal immunity (Hender et al. 2021). The authors

link these effects to bioactive compounds in BSF larvae, particularly chitin and antimicrobial peptides. The finding comes from a single controlled trial with one species under laboratory conditions, so caution is warranted before generalizing. Still, if the immune benefits prove robust across species and production contexts, they point to something the growth data alone miss: BSF larvae may provide health benefits fishmeal does not. Economic analyses that benchmark BSF against fishmeal on growth and feed conversion alone may therefore underestimate its value. This consideration becomes more consequential in intensive production systems where disease management costs are high. The Benin tilapia trial discussed above adds a further data point. Even without fatty acid enrichment, BSF meal improved markers of innate immune function, the fish's first-line defense against bacterial infection, relative to the fishmeal control (Agbohessou et al. 2021). This is consistent with the barramundi immune response and suggests the effect may not be species-specific or confined to a single production context.

**Broiler chicken trials found BSF improved growth, and the gains held when chicken were exposed to a damaging intestinal disease.** Adams and Koutsos (2026), running two broiler experiments with whole dried BSF larvae at 2.5% and 5% inclusion, found that BSF significantly improved both feed conversion ratio and body weight gain compared with controls. The second experiment introduced a subclinical necrotic enteritis challenge, the most economically damaging enteric disease in commercial poultry production. Birds receiving BSF showed numerically lower intestinal lesion scores and roughly halved necrotic enteritis-specific mortality, from 7.1% in controls to 4.0% and 4.2% at the two inclusion rates, though the disease outcome differences did not reach statistical significance with the replication used. The growth performance gains are consistent with prior BSF-broiler trials. The additional finding is that they held up under active disease pressure, the setting in which antibiotic alternatives matter most. The barramundi, tilapia, and broiler results converge across three production systems with no shared methodology, suggesting that the immune-modulating effect may track the ingredient rather than any particular trial setup. The broiler study points to specific components behind this: alongside chitin and antimicrobial peptides, BSF fat is high in lauric acid, a medium-chain fatty acid that is rapidly absorbed and has antimicrobial activity against gut bacteria and modulates the gut microbiota (Spranghers et al. 2018), properties linked to improved gut health and, in broilers, to better growth and feed conversion (Adams and Koutsos 2026).

### Niche and premium markets: caviar and pet food

**Caviar producers can effectively use BSF meal, but only if suppliers deliver certified BSF meal at the volume and consistency the farm needs.** The case for BSF-as-feed is not limited to commodity species. Controlled trials with Siberian sturgeon (*Acipenser baerii*), farmed for caviar, found growth performance equivalent to fishmeal controls at up to 25% substitution with defatted BSF meal (Caimi et al. 2020), and improved growth and feed conversion at 5-30% dietary inclusion with full-fat meal (Rawski et al. 2020). A sturgeon producer farming *Acipenser* for caviar in Madagascar has completed a pilot trial using locally produced BSF meal, with satisfactory results on growth, logistics, and supplier communication. Research and development trials across the full operation were expected to conclude in mid-2026, at which point the producer intends to formally approve BSF meal as an ingredient in its feed formula for the entire sturgeon operation, with projected annual procurement of approximately 23 tons (see chapter 3). The case illustrates both the opportunity and the constraint. Premium aquaculture operations dependent on imported protein can accept BSF meal on performance grounds, but actual procurement requires a supplier able to deliver

certified, consistent product at the volumes the buyer needs. Whether the opportunity is realized turns on that supply-side condition rather than on market demand.

**Pet food can use higher-priced BSF larvae for premium pet products because they sell for more than livestock feed.** A different niche market operates on similar principles. BSF larvae provide a high-quality protein source for cats and dogs (Do et al. 2020), and insect-based ingredients are well accepted and do not produce adverse health effects in companion animals (Valdés et al. 2022). This nutritional credibility has made pet food one of the more viable commercial outlets for BSF. Many industrial firms in the Global North, unable to compete economically with bulk commodity proteins like soy and fishmeal in livestock feed markets, have pivoted toward pet food accordingly (Sogari et al. 2023). The pet food premium also matters in African markets with tight livestock feed margins. A Kenyan insect-based pet food company comfortably absorbs current dried BSF prices of around US$1,400 per ton, well above the US$850 ceiling at which feed millers find BSF competitive, because pet food pricing can carry an input cost that commodity feed cannot (Meerts et al. 2023). At smaller scale, the related pet treat segment offers another entry point: BSF Tamatave's roasted "pop larvae," sold at MGA 17,500 per kilogram (4.7 times the wet larvae price), generates the highest daily gross income of any product the farm produces (see chapter 3).

**Export pet food markets favor BSF producers that can prove their larvae are safe, consistent, and traceable.** The sustainability case is more nuanced in pet food than in livestock feed, since BSF in the Global North often displaces animal co-products that already carry a relatively low environmental footprint (Bosch and Swanson 2021). Export-oriented production will likely require food- or feed-grade substrates to meet international traceability standards. Drying infrastructure, processing requirements, and quality control demands make export-oriented pet food markets structurally out of reach for smallholder producers (Barragán-Fonseca et al. 2025). The substrate question also affects domestic markets, even without formal export standards. BSF Tamatave's pet treat operation, for example, rears its larvae on prepared food waste from canteens and restaurants, an economically advantageous substrate but one that would not qualify as feed-grade under European or comparable regulatory frameworks. Prepared food waste can carry pesticide residues, antibiotic traces, and other contaminants that controlled substrates would exclude. BSF larvae do not generally accumulate pesticide residues from their substrate, but the supporting evidence comes from controlled trials rather than prepared food waste, and surveillance to detect problems is largely absent at this scale. For semi-industrial operators with drying capacity and quality control systems already in place, pet food represents a higher-margin outlet worth monitoring as urban pet ownership grows across African cities.

**Local BSF meal may perform differently from trial meal because different rearing and processing conditions change its nutrient profile.** One qualification applies across the BSF-as-feed literature more broadly. BSF larvae meal is not a standardized input. As discussed above, larval composition shifts with rearing substrate, scale, density, and processing method, and these differences are large enough to affect feeding outcomes. As Sogari et al. (2023) note, this variability is part of why results across feeding trials are difficult to compare directly, and why findings from one production context should not be assumed to transfer automatically to another. A project sourcing BSF larval meal locally cannot assume its product matches the nutritional specification of the meal used in a published trial, even one conducted in a comparable setting. Operations that standardize their rearing and processing methods produce a more

reliable feed ingredient, and a more predictable one for buyers who need to match a published nutritional specification.

## Larvae as Food

### Nutritional case for insects as food

**Three practical conditions, not the nutritional case, decide whether BSF can move from animal feed into human food.** Eaten directly, BSF shortens the food chain, delivering animal-source protein straight to the populations that lack it without the losses of routing it through fish or poultry first. BSF larvae can be highly nutritious, but that value is not automatic: it depends on substrate, larval age, and processing, and whether a given product suits its intended consumers has to be judged against the needs and tolerances of that group, which makes formulation a task for nutritionists rather than a fixed property of the insect. What remains are three practical obstacles. A culturally novel farmed product first must win consumer acceptance. It then has to be reared and processed to a food-grade safety standard stricter than anything feed or fertilizer requires, and finally cleared by regulators before it can be sold or enter a nutrition or aid program. The discussion below addresses each. On all three, Madagascar is further along than the "future prospect" label suggests, with product approvals, a national standard, and an active producer already in place; for most of the continent the pathway remains genuinely prospective, but Madagascar shows that the conditions can be met in an African context rather than only in principle.

**Diets dominated by plant-based staples leave many children short of the nutrients that BSF can supply directly.** Diets dominated by plant-based staples and low in animal-source foods often leave children short of protein, iron, and other micronutrients that are poorly available from vegetable sources alone (Headey et al. 2018). This structural deficit helps explain why Africa is the only region where the absolute number of stunted children continues to grow (UNICEF/WHO/World Bank Group 2025). Edible insects can address this deficit with concentrated animal-sourced protein, high caloric density, and essential micronutrients, particularly iron and zinc (Nadeau et al. 2015), which are frequently deficient in the diets of food-insecure populations (Black et al. 2013). BSF larvae are a particularly rich source of calcium, which staple cereal diets supply poorly. Depending on substrate, larval calcium ranges from levels comparable to cow's milk to many times higher, reflecting the calcium carbonate mineralized in the larval cuticle (Spranghers et al. 2017; Rebora et al. 2023). Modelling across Africa and Asia estimates that adding 5 grams of dry edible insects per person per day could remove 67 million people from risk of protein deficiency and 166 million from risk of zinc deficiency, with comparable reductions for folate and vitamin B12 (Smith et al. 2021). The zinc is well absorbed: a stable-isotope trial in Kenyan preschool children found that zinc absorption from cricket-enriched maize porridge was 2.6 times higher than from a plain low-enriched maize meal, and even exceeded absorption from a meal highly enriched with zinc sulfate, likely because cricket protein counteracts the phytate inhibition characteristic of cereal-based diets (Hilaj et al. 2025).

**Edible insects can provide high-quality protein and may also support gut health through chitin.** The overall nutritional profile of edible insects rivals conventional meat in many cases. They are characteristically rich in protein and fat (Boit et al. 2024). Insect protein quality is thought to be high (Belluco et al. 2013), and many insects meet the essential amino acid requirements for human nutrition (Rumpold and Schlüter 2013). Insects also contain chitin, a structural polysaccharide absent from

conventional protein sources that is increasingly recognized as a prebiotic dietary fiber (van Huis 2013; \ Lange and Nakamura 2021). BSF is also high in lauric acid, the medium-chain fatty acid noted earlier for its antimicrobial properties, which is of interest for human nutrition as well as feed. In the first controlled human trial of cricket consumption, whole crickets selectively enhanced beneficial gut bacteria without major side effects (Stull et al. 2018). Mammalian research offers a possible mechanism for these effects: dietary chitin has been shown to trigger a type 2 immune response in the gut, activating innate lymphoid cells and improving metabolic outcomes independently of stomach microbiota (Kim et al. 2023). Laboratory experiments using insect-derived substrates, including chitin, have found associations with favorable microbiome shifts and probiotic activity in fermentation models (Carvalho et al. 2019; Young et al. 2020; Kipkoech et al. 2021). A human intervention trial subsequently found chitin associated with reduced inflammatory markers and improved symptom management in IBS patients, though findings across the broader literature remain partly contradictory (Lopez-Santamarina et al. 2020; Vita et al. 2025). Human cells produce chitinases, enzymes capable of breaking down chitin, suggesting that insect chitin is not simply passed through the gut undigested and that people who consume insects regularly may develop greater chitinolytic capacity over time (Stull and Weir 2023). Insect-based foods may therefore contribute not only to nutritional adequacy but also to functional health outcomes, a dimension that conventional protein supplements do not offer.

**Human-food BSF production requires clean, traceable substrates, unlike some feed and fertilizer pathways.** Substrate strategy bifurcates with end use. BSF reared on mixed urban waste, manure, or food waste of uncertain provenance can produce safe feed or fertilizer products under appropriate downstream controls. BSF reared for human food applications, operates under a stricter regime. Substrates are restricted to clean, food-grade side streams of known provenance, such as brewery spent grain or food-industry by-products with documented composition. The two production pathways share a species and a process, but they are different products with different safety pathways and should not be conflated.

### Cultural familiarity and the novelty question

**African food cultures often include insects, but farm-raised BSF larvae remain new and may need education or familiar food forms.** Cultural familiarity provides a foundation for adding insects to the diet, including BSFL. In the Global North, consumer acceptance of insects as food remains limited, especially for BSF larvae. Many African food cultures already incorporate insects, sometimes at strikingly high rates. In rural Madagascar, for example, insect consumption is deeply woven into childhood practices. Surveys reveal that roughly 35% of children's games involve insects, and in 71% of those cases the activity culminates in consumption. Children reported eating insects during play about three times per week (Andrianome et al. 2026). This indicates that insect consumption is not only culturally familiar but behaviorally routine, though whether this familiarity extends to species not traditionally consumed, such as BSFL, remains uncertain (Tan et al. 2015; Florença et al. 2022). Insect traditions across Africa are built around wild harvesting rather than farming, so the mass rearing of insects for food is novel even where eating them is normalized (Raheem 2019). Education and sensitization have been shown to shift reluctant children toward acceptance of farmed insects not traditionally consumed, with a five-minute session on cricket-based dish preparation persuading 86% of initially reluctant children to try (Rakotondrasoa et al. 2024).

**Children in southern Madagascar accepted unfamiliar insect-based crackers and often chose them over conventional crackers.** Parker et al. (2026) conducted an acceptability study of crackers formulated with a blend of cricket powder, BSF larval powder, rice, and corn in southern Madagascar. In this area, insects are widely consumed but not BSF larvae or this species of cricket. Nearly 80% of children consumed at least 80% of their cracker portions, signaling strong acceptance. When given a choice between insect-based and conventional crackers, 89% of participants selected one of the insect options. This preference suggests that insect-enriched foods can move beyond novelty to become preferred components of children's diets.

### Evidence from human trials

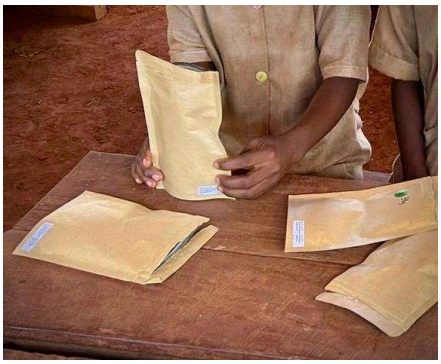
**Human trials using crickets and mealworms show mixed effects on child growth, while evidence on BSFL in children is still pending.** The more pressing policy question is whether insect-fortified foods measurably improve child health outcomes. Most published human feeding trials with edible insects use crickets or mealworms rather than BSF. These studies are relevant but not directly transferable to BSF, since cricket and mealworm rearing diets are typically grain-based and do not raise the same substrate-strategy questions that complicate BSF food applications. BSF-specific human trial evidence is thinner, so the evidence below applies non-BSF findings by analogy. The non-BSF evidence is promising but mixed. Adding yellow mealworm to corn porridge improved linear growth and protein intake in children aged 6–9 compared with corn porridge alone (Boit et al. 2026). In another trial, cricket-fortified porridge improved length-for-age z-scores compared with fortified corn-soy blend (CSB+), though absolute height gain was similar across groups (Okeyo et al. 2026). Across most studies, however, insect-fortified foods do not show a clear advantage over CSB (Boit et al. 2024; Okeyo et al. 2026). Comparable performance is still important, particularly where the comparator itself is a proven intervention. Stunting prevalence often increases across all treatment groups, suggesting that no single ingredient resolves the structural drivers of undernutrition (Okeyo et al. 2026). A 14-week cluster-randomized trial of BSFL-fortified crackers in rural Madagascar, launched in 2026, will provide the first RCT-level evidence on BSFL as a direct human food in children (Box 1.2).

**Insect foods may improve everyday dietary diversity in food-insecure households.** The picture may look different outside the acute malnutrition context. Some food-insecure households have diets that are chronically low in animal-source foods, even when acute malnutrition is not the primary concern. In those settings, insect-based foods offer a different use case: adding dietary diversity and improving micronutrient adequacy at low cost, particularly for children and women of reproductive age. This may be where locally produced edible insects, reared at household or community scale, have their clearest and most direct impact. Insect-fortified foods are nutritionally competitive, culturally acceptable, and safe (Boit et al. 2024). More longitudinal evidence is needed, both in therapeutic feeding contexts and in broader food-insecure populations, to establish whether insect-based interventions translate into sustained improvements in growth, dietary quality, and wellbeing.

**Madagascar has created a regulatory pathway to authorize insect foods through product approvals and a BSF production standard.** Scaling such interventions requires regulatory clearance and integration into aid systems. In Madagascar, this process has advanced. BSF and cricket powders received a government-issued Certificate of Consumption in 2023, followed by approval of insect-fortified crackers in 2024. These certifications signal official recognition of safety and suitability, enabling commercial sales

and integration into national nutrition programs. In 2025, Madagascar went further, establishing through its national standards body the world's first national production standard for dried BSF larvae and larval powder for direct human consumption. Together, product approvals and production standard create an unusually complete regulatory foundation for human food applications, one that most countries promoting BSF have not yet approached.

**Box 1.2: Beyond Feed — A Cluster-Randomized Trial of BSF Larvae-Fortified Crackers for Schoolchildren in Madagascar**



A 2026 Madagascar school trial is testing whether daily insect-fortified crackers improve child health. A multidisciplinary team from Cornell University, PATH, Colorado State University, and the Institut Pasteur de Madagascar launched the 14-week cluster-randomized controlled trial across six rural primary schools in Antsirabe II, in the Vakinankaratra region. The trial is the first RCT to test BSFL as a direct human food in children.

Madagascar is a relevant test setting because child undernutrition, anemia, and poor gut health overlap. About 40% of children under five are chronically malnourished, 8% are wasted, and 46% are anemic. Conventional fortification, including iron-fortified staple foods, can underperform when chronic pathogen exposure inflames the gut and limits micronutrient absorption. The trial tests whether insect-fortified foods can address both nutrient deficiency and the inflammatory barriers to nutrient absorption by combining high-quality nutrients with chitin-derived fiber.

The crackers were co-developed with EXA, a Madagascar-based insect farm and food-tech company. EXA rears the BSFL on brewery spent grain and local bran under food-grade conditions and processes them to meet food-safety standards. A prior acceptability study (Parker et al., 2026) found the crackers safe across 25 biological and heavy-metal hazards, with low allergy risk; nearly 90% of Malagasy children in the study preferred the BSFL-fortified cracker over an unfortified control in blinded taste tests. A 50 g serving provides 183 kcal, 10.7 g protein, 1.8 g dietary fiber, including more than 1 g of insect-sourced chitin, 39–54% of the iron RDA, and about 20% of the zinc RDA for children aged 9–13.

The RCT enrolled 441 students and compared fortified crackers with an unfortified version. The treatment group receives a daily 50 g ration of fortified crackers alongside the standard school meal, while the control group receives the unfortified cracker. Researchers collect stool, blood, growth measurements, and caregiver survey data at baseline, six weeks, and fourteen weeks. The primary outcomes are hemoglobin and ferritin, while secondary outcomes cover gut microbiome composition, intestinal and systemic inflammation, growth Z-scores, and morbidity. The trial therefore tests a question distinct from the broader cases for BSFL as animal feed or general-purpose food protein: whether BSFL produced under human-food conditions can improve child nutrition while addressing gut-health barriers that limit nutrient absorption.

*Source: Valerie J. Stull and Megan Parker, PATH.*

**Local insect protein could reduce food-aid imports while supporting child nutrition and domestic food production.** This pathway extends beyond nutrition. Humanitarian organizations already prefer food aid products containing local ingredients over imports such as peanuts, soy, and milk powder. Sourcing insect protein locally could reduce delivery costs, shorten supply chains, and build domestic productive

capacity. For development funders, the appeal is that the same intervention could address child malnutrition, stimulate local agriculture, create smallholder and enterprise income, and reduce foreign exchange dependency without the environmental strain of some conventional animal-source proteins. In contexts where food aid is a recurring rather than an emergency need, locally produced, nutritionally dense ingredients could improve aid efficiency by shifting part of the supply chain from imports to domestic production. The Madagascar case (Box 1.3) shows how this alignment plays out concretely: where traditional protein sources are environmentally unsustainable, insect farming can address conservation pressure and nutritional deficits at the same time.

**Box 1.3: Wildlife reliance and anemia in Madagascar**

Wildlife consumption helps prevent anemia in northeast Madagascar, but current harvest rates make that nutrition source unsustainable**.** In the northeast, wildlife provides a critical source of bioavailable iron for children, a nutrient derived largely from animal-source foods and the most prevalent deficiency worldwide. This includes lemur species, the majority of which are now threatened with extinction. A longitudinal study of 77 children found that wildlife consumption was directly and significantly associated with hemoglobin concentrations. The study modelled that removing access to wildlife would increase childhood anemia prevalence by nearly 30% overall and triple anemia cases among children in the poorest households (Golden et al. 2011). The cognitive consequences compound the nutritional ones: a reduction in hemoglobin of just 1.0 g/dL has been associated with a population-level decline of 1.75 IQ points (Lozoff et al. 2006) and an increased risk of mild or moderate intellectual disability in early childhood (Hurtado et al. 1999). Because current wildlife harvest rates are already unsustainable, the nutritional safety net that wildlife provides is collapsing. Insect farming offers an alternative that addresses both conservation and public health goals.

### Allergenicity risks and regulatory gaps

**BSFL may cause allergic reactions because some larval proteins resemble shellfish and dust-mite allergens.** Large-scale deployment requires confronting a risk that the current evidence base has not yet resolved: allergenicity. One concern is a class of proteins known as pan-allergens. These proteins are structurally conserved across arthropods, so sensitization to one species can trigger reactions to another. Tropomyosin is the most clinically significant example. It is a structural muscle protein shared across insects, crustaceans, and house dust mites. A person who has developed sensitivity to shrimp or dust mite exposure may therefore react to insect consumption on first exposure, with no prior warning. Arginine kinase, another conserved arthropod muscle enzyme, carries the same cross-reactivity risk. The presence of these proteins in BSFL raises questions about cross-reactivity that cannot be dismissed because a population has no prior history of eating insects (Ribeiro et al. 2018; Leni et al. 2020). Cross-reactivity is not the only concern. Primary sensitization, an immune response triggered directly by insect-specific proteins without prior exposure to shellfish or mites, is also documented (Ribeiro et al. 2018). Novel allergens with no established clinical history are a further unknown (Leni et al. 2020).

**Processing can reduce BSF allergenicity, but residual allergens and limited allergy data leave safeguards incomplete.** Processing reduces but does not eliminate allergenicity risks. Enzymatic hydrolysis reduced but did not eliminate IgE reactivity in BSF protein hydrolysates, and some protein fragments responsible for allergic reactions survived simulated digestion intact (Leni et al. 2020; Delfino et al. 2024). Well-designed nutrition interventions include screening and monitoring protocols, but most

target countries lack the baseline epidemiological data on shellfish-related allergies in child populations that such protocols require. This gap is especially relevant in warm, humid urban environments, where high house dust mite exposure can prime cross-reactive IgE responses to insect proteins before any insect is consumed (González-Pérez et al. 2025). Allergenicity is manageable, but safeguarding against it requires prospective clinical data and regulatory frameworks that do not yet exist in most target countries.

**Assembled into a single pathway, the human-food case reaches nutrition outcomes the feed pathway cannot deliver directly.** A local, food-grade BSF larval product is nutritionally dense, and the acceptance evidence suggests it can be culturally accepted where it has been tried. When combined with the import-substitution and local-production benefits set out above, a single intervention can address child malnutrition, local agricultural income, and foreign-exchange dependence at once. What the evidence cannot yet show is durability at scale. Acceptance measured in trials has to survive real purchasing decisions, food-grade processing has to hold beyond a single producer, and regulatory approval has to translate into market access rather than standards on paper. Madagascar is the one place where all three are being tested at once rather than argued in principle. Its result will be an early signal of whether BSF larvae, eaten directly as human food, can move from promise to practice, a use that would complement the larvae's established role in animal feed rather than replace it.

## The Frass Co-product

### Agronomic properties and the challenge of consistent quality

**Frass is a by-product of BSF production used as organic fertilizer or soil amendment, and its nutrient value depends on the substrate.** Frass is the solid residue separated from larvae at the end of bioconversion: a mixture of larval excreta, shed exoskeletons, and unconsumed feedstock. It is the complement of larval biomass in the nutrient partitioning process: the fraction of the substrate that does not end up in the larvae ends up in the frass, and the same substrate-driven logic that shapes larval fat content and mineral load also determines what the frass contains. Nitrogen ranges from around 1.8% to 5.1% across substrates, phosphorus from 0.3% to 5.2%, and potassium from 0.2% to 4.1% (Lopes et al. 2022). This variation is large enough to determine whether a given frass batch functions as a nutrient-dense fertilizer or a soil amendment of modest agronomic value. A controlled comparison across five East African waste streams shows how this variation tracks substrate type (Ogello et al. 2025): vegetable waste produced frass with the highest organic matter content, at 75.4%, while frass from poultry and fish substrates was richest in nitrogen and phosphorus and had the lowest C:N ratios, indicating faster mineralization and nutrient release. Fresh frass moisture content varies widely with substrate and rearing conditions, and frass must be dried before storage and handling.

**Dried frass offers high organic matter and balanced nutrients, but most nitrogen is released slowly.** Once dried, frass has properties that distinguish it from most organic amendments. Organic matter content is typically high, and pH averages around 7.5, slightly alkaline and compatible with most crop soils (Gärttling and Schulz 2022). Nitrogen, phosphorus, and potassium are present in roughly equal proportions on average, which is unusual among organic fertilizers, where nitrogen typically dominates (Gärttling and Schulz 2022). Only around 16% of total nitrogen is in ammonium form, the fraction immediately available to plants. The remainder is organically bound and releases slowly, such that net nitrogen immobilization

has been observed throughout the active growth stages of maize before mineralization catches up later in the season (Beesigamukama et al. 2020b; Gärttling and Schulz 2022).

**The chitin in BSF frass and the soil microbes it stimulates can help plants resist pests and disease.** Frass has biostimulatory properties beyond its nutrient content. Rich in organic matter, plant nutrients, and chitin, it primes plant immune responses so that plants respond faster and more strongly when attacked, rather than activating costly defenses pre-emptively. The mechanism runs largely through the soil microbiome: frass chitin stimulates chitin-degrading bacteria, which both antagonize fungal pathogens and induce systemic resistance in the plant (Barragán-Fonseca et al. 2022; Elissen et al. 2023). Beyond priming, frass amendment has been shown to suppress specific diseases: in inoculated trials it reduced the severity of Fusarium wilt in tomato (Arabzadeh et al. 2024), and chitin-fortified frass suppressed root-knot nematodes in potato while raising tuber yield above a conventional fertilizer-and-nematicide treatment (Anedo et al. 2025). These effects distinguish frass from mineral fertilizer, which supplies nutrients but none of this biological activity, though they remain under study and depend on frass quality and soil conditions.

**Fresh, unprocessed frass can harm crops if it still contains undecomposed feedstock or reactive compounds.** Realizing this potential consistently has proven more difficult than the nutritional profile alone would suggest. Several mechanisms of phytotoxicity — salinity, ammonium-nitrogen, and low-pH organic acids — have emerged as recurring failure modes (Bohm et al. 2023; Elissen et al. 2023). Standard chemical indicators do not always capture the biological immaturity of fresh frass, which may retain undigested organic material and dead insect parts that compromise its agronomic value (Lopes et al. 2022, 2024). Composting addresses several of these failure modes, including volatile fatty acids, ammonium loading, and anaerobic conditions, by driving further decomposition and stabilizing nutrients. Salinity, where present, persists as a substrate-derived issue. Composting also adds time, cost, and logistical complexity that many smallholder and emerging operations cannot easily absorb. Without this step, crops may experience nutritional imbalances despite the apparent nutrient richness of the amendment (Bernal et al. 2009; Lopes et al. 2022). Producing consistently high-quality frass without relying on post-processing infrastructure is therefore one of the central practical constraints on realizing its agronomic potential.

### Field evidence: Madagascar

**Air-dried BSF frass raised maize and soybean yields and stayed cost-competitive with mineral fertilizer.** Ramiadantsoa et al. (2026) applied air-dried BSF frass from EXA Feed's operation in Antsiranana, produced from larvae reared on STAR brewery spent grain, to maize and soybean in a large-scale field trial in northern Madagascar. The trial tested twelve dose rates from 0 to 30 t $ha^{-1}$. For both crops, dry grain yield increased with fertilizer rate across the whole range, including the intentionally excessive rates, with diminishing returns. The authors found no rate that maximized yield. Instead, yields approached asymptotic maxima of 8.6 t $ha^{-1}$ for maize and 4.1 t $ha^{-1}$ for soybean, corresponding to approximately 12.0- and 1.7-fold increases relative to unfertilized controls, respectively. These asymptotic yields work out to roughly 4.6 and 6.7 times current national average yields. Madagascar's national averages reflect a degraded baseline of low-input smallholder cultivation, so these multipliers show what frass can enable in nutrient-limited conditions rather than how it compares with high-performance agriculture. Germination held up well. Maize declined only modestly, from 93 percent in unfertilized plots to 85 percent at the highest 30 t $ha^{-1}$ rate, staying below the threshold considered agronomically relevant, while soybean

germination was unaffected. Because the study measured a saturating dose-response rather than an optimum, its economic analysis used the marginal value-cost ratio to bound viable frass pricing instead of fixing a single application rate. At FAO crop prices, frass was profitable to highly attractive at retail prices between US$13.87 and 52.59 $t^{-1}$, equivalent to about US$0.4 to 1.5 per kilogram of nitrogen. That is a small fraction, roughly 2 to 8 percent, of the retail cost of the same nitrogen from mineral NPK fertilizer.

**Fresh frass reduced maize germination and killed seedlings at high doses, while composting removed those harms at the same nitrogen level.** Solofondranohatra et al. (2025a) compared fresh frass (sun-dried but uncomposted) against composted frass directly on maize at 43 kg N $ha^{-1}$, both forms produced from the same operation. Fresh frass caused severe germination failure, with fewer than a quarter of seeds emerging. Five weeks of heap composting resolved the problem and produced grain yields 38 percent higher than cattle manure at one-third of the regional recommended nitrogen dose. The unfertilized control produced no harvestable grain despite forming cobs, underscoring how acute nutrient limitation is in these soils. A nursery study using fresh frass from the same source extended the pattern to native tree seedlings (Solofondranohatra et al. 2025b). Low doses produced 95 percent survival and roughly doubled height and diameter growth relative to cattle manure and NPK in the pioneer tree *Dodonaea madagascariensis*, but the highest fresh-frass dose, at twofold nitrogen equivalence, killed every seedling. A later field trial established that composting removes this phytotoxicity rather than merely diluting it (Andriambelo et al. 2026). Survival in *D. madagascariensis* stayed near 100 percent across four sites in the Central Highlands even at the same twofold nitrogen dose that had been lethal in fresh form, with growth responses comparable to cattle manure at equivalent nitrogen input.

**Composting is what reliably converts frass into a safe amendment.** Ramiadantsoa et al. (2026) found uncomposted frass left maize germination high, with only a modest dip at excessive doses, while Solofondranohatra et al. (2025a) found that uncomposted frass caused severe germination failure on the same crop. Five weeks of heap composting removed the penalty entirely, and a composted-frass field trial in tree seedlings (Andriambelo et al. 2026) found no phytotoxicity even at the nitrogen dose that had been lethal in uncomposted form. All of these studies used spent-grain-based frass, but drew it from different operations rather than a single source, so the substrate was not identical across them, and the reasons uncomposted frass performs as variably as it does, ranging from a mild germination dip to outright failure, are not yet established. What the evidence does establish is that composting is the most reliable lever for converting frass into a predictable nitrogen source in nutrient-limited Malagasy soils.

### Field evidence: Kenya

**Kenyan maize trials found composted BSF frass delivered more yield per kilogram of nitrogen than urea.** Kenyan field trials add a more consistent picture. Beesigamukama et al. (2020a) found that composted BSF frass more than double the maize yield per kilogram of nitrogen that urea achieved at an equivalent 30 kg N $ha^{-1}$ rate (frass agronomic nitrogen use efficiency was 116 percent higher than urea's), and outperformed a commercial organic fertilizer made from chicken manure, biochar, and rock phosphate by 27 percent at the same rate. Frass nitrogen was also better synchronized with crop uptake than conventional organic inputs. At the lowest application rate tested, 2.5 t $ha^{-1}$, maize used frass nitrogen 2.4 times more efficiently than nitrogen from the commercial organic fertilizer at the same rate. The authors attribute this to higher mineral nitrogen availability and faster mineralization.

**Farmers growing maize with composted BSF frass earned higher net incomes and reached yield targets more reliably.** Beesigamukama et al. (2022) extended the analysis from agronomy to economics. Maize grown with composted BSF frass yielded 29–44% higher net income than maize grown with commercial organic fertilizer and performed comparably to urea on grain yield, a notable result given urea's entrenched position in smallholder cropping systems. The authors note that in a well-functioning market, frass should command a higher price than commercial organic fertilizer because it produced more reliably, though current market conditions rarely reflect this. Frass-treated plots were also more dependable. At any given yield target, frass plots were more likely to reach it than plots receiving either urea or commercial organic fertilizer. This reliability is particularly relevant for risk-averse smallholders who prioritize dependable yields over higher average performance. The study also found that the economically optimum nitrogen application rate for frass, 79 kg N $ha^{-1}$, was lower than for urea, at 100 kg N $ha^{-1}$, and commercial organic fertilizer, at 120 kg N $ha^{-1}$. Frass therefore reached its agronomic ceiling at lower fertilizer cost.

**Combining BSF frass with NPK fertilizer raised yields and income across vegetable and maize trials more than the component inputs or conventional alternatives.** Companion studies extend the picture across crops and management regimes. Anyega et al. (2021) tested combined BSF frass and NPK against either input alone across tomato, kale, and French bean under greenhouse and open-field conditions over two seasons. The combined treatment consistently outperformed sole NPK by roughly 20–135% on yield across the three crops, and improved nutritional quality. Tanga et al. (2022) found a parallel pattern for maize under greenhouse conditions, where combining BSF frass with NPK produced higher net income than the alternatives: a modest 2% over sole NPK 163% over a brewers' spent grain compost-plus-NPK mixture and 173% over frass applied on its own. Together, these findings suggest frass's most practical role may be as a complement to mineral fertilizer rather than a substitute for it.

**Kenyan studies found more consistent frass benefits than Madagascar studies, partly because they all tested composted frass.** The Kenya evidence is internally more consistent than the Madagascar evidence, and one variable separates the two bodies of work. Every Kenya study cited above used composted frass, while the Madagascar trials varied frass form and processing. Composting consistently emerges as the most reliable lever for unlocking frass value, even if it is not the only one that matters.

### Frass recirculation

**Recirculating frass into restaurant-waste substrate raised larval yield per unit of waste and produced drier, more decomposed frass.** Lopes et al. (2024) tested whether frass from restaurant food waste could be mixed back into the larval feed substrate. The aim was to stabilize the frass faster than composting while converting residual organic matter into additional larval biomass. Larval yield per ton of food waste rose from 207 kg with no frass inclusion to 360–403 kg at 40% inclusion, a near doubling with the same output achievable using up to 56% less food waste. Larvae reared on diets with frass inclusion diets also shifted composition toward protein: at the highest inclusion diets also shifted composition toward protein: at the highest inclusion levels tested, crude protein rose 41% and fat fell 32% relative to a frass-free diet, a useful trade-off in protein-limited contexts. The recirculated frass was more decomposed than fresh frass, and because it is a dry material, the authors suggest it could help condition wet substrates when reintroduced into production. The main concern was sodium accumulation in recirculated frass from restaurant waste, attributable to salt added during cooking. This is not a generic feature of food-waste frass (other food-waste

composts have reported roughly half that salt level), but it requires management through substrate selection or post-processing.

**Repeated frass recirculation maintained larval yields with some substrates, but spent grains reduced conversion efficiency.** Subsequent work tested whether these gains hold across substrates and repeated cycles. Lopes et al. (submitted) found that frass from larvae fed expired chicken feed could be recirculated at 25% inclusion for five to six cycles without reducing bioconversion efficiency or larval yields. Repeated recirculation also increased the $NH_4^+/NO_3^-$ ratio, indicating a higher share of plant-available nitrogen. Consistent with this, greater recirculation improved growth of horticultural crops, including pak choi and tomato. The pattern held with fruit waste and pig manure but not with spent grains, where bioconversion efficiency declined. The authors attribute the decline to higher fiber content. It remains unresolved whether frass recirculation produces a better fertilizer than composting, or reduces greenhouse gas emissions relative to conventional post-processing.

### Evidence gaps and the nitrogen fate question

**Frass research still lacks the comparable field evidence needed to predict crop response and nitrogen losses.** The gaps in the global evidence base are concrete. A recent rapid evidence assessment commissioned by the UK Department for Environment, Food and Rural Affairs reviewed 50 papers on BSF frass as fertilizer and identified three priority research needs: standardizing nutrient composition across feedstocks, optimizing application rates through field-scale trials, and quantifying environmental fate, including nitrogen fate and greenhouse gas emissions (Crotty and Rock 2024). Nitrogen fate refers to what happens to applied nitrogen after frass reaches the soil, including crop uptake, soil retention, leaching, and atmospheric loss. The review's substantive conclusion was that frass nutrient content and agronomic benefits are comparable to other organic amendments, though a critical application rate may exist beyond which frass becomes detrimental to crops, and that the evidence is not yet strong enough for life-cycle-assessment-grade environmental quantification. The African trials cited in this section contribute field-scale, multi-site, multi-crop data on application rates and yield response, giving partial progress on application-rate optimization. Feedstock standardization is just as open in the African literature as in the European literature: each study has used its own substrate, and the cross-study comparability the review calls for has not yet been built.

**Fresh, unstabilized frass can release nitrogen as nitrous oxide, and field evidence has not yet shown which practices reduce those emissions.** The nitrogen fate question is genuinely open and warrants closer attention. In a 40-day soil incubation experiment using fresh, unstabilized frass on German arable soil with no growing plants, Rummel et al. (2021) found that 5.5–9.3% of the nitrogen applied as carbohydrate-derived BSF frass was lost to the atmosphere as nitrous oxide, a potent greenhouse gas. Frass from a protein-rich diet lost less, around 3.3–3.4%, but both ranges sit well above the 1% global default that the IPCC uses for fertilizers in greenhouse gas accounting. The authors identified two principal ways to reduce these losses: applying frass as a nutrient source to growing plants rather than during the fallow period before sowing, and mixing frass with carbon-rich material to immobilize nitrogen and reduce volatilization losses. These approaches align with practices already established in the African operations cited above: Beesigamukama et al. (2021)'s carbon-to-nitrogen adjustment with sawdust in Kenya, Solofondranohatra et al. (2025)'s and Andriambelo et al. (2026)'s heap composting protocols in Madagascar, and Lopes et al. (2024)'s frass recirculation in Sweden. Whether these practices reduce field-scale nitrous oxide emissions

to acceptable levels in African smallholder contexts has not been measured directly and remains a priority for empirical work.

### Frass as a feed ingredient

**Catfish trials suggest BSF frass can improve fish intake and growth, but African substrates and aquaculture species remain untested.** Early trials in the United States found that adding BSF frass to channel catfish (*Ictalurus punctatus*) diets at 100 g/kg significantly increased feed intake and weight gain, likely through improved palatability. The authors also hypothesized that frass may have immunostimulatory properties warranting further investigation, with beneficial microbes in the frass as the suggested mechanism (Yildirim-Aksoy et al. 2020). Feed and protein efficiencies declined at inclusion levels of 200 g/kg and above, placing the practical ceiling around 100 g/kg the highest level the authors found free of any efficiency penalty. The frass tested came from larvae fed distillers' dried grains with solubles, a corn-based agro-industrial co-product not typical of substrates available to African smallholders. Whether these results transfer to African contexts depends on the fish species and the substrate used to produce the frass. Frass from substrates more commonly used in African farming systems has not been tested for feed suitability, and inclusion responses have not been characterized in African aquaculture species such as *Clarias gariepinus* or tilapia. Closing this gap would require characterizing frass composition across substrate types actually available in African farming systems and testing inclusion in locally relevant species. That evidence would sharpen the economics of BSF integration by showing whether frass can provide a second revenue stream beyond its agronomic value.

### Chitin extraction and biocontrol

**Adding BSF-derived chitin to soil can support crop growth and suppress some pests and pathogens.** Frass can be used as a whole product, but value can also be extracted from specific components, most notably chitin, the structural polysaccharide previously discussed for its prebiotic properties when consumed as food. In agricultural use, chitin recovered from pupal exoskeletons or dead adults can function as a soil amendment that supports plant growth and suppresses certain pests and pathogens.

**Kenyan trials found BSF chitin products reduced crop pests and disease while improving plant growth and yields.** Recent Kenya trials provide concrete evidence. Kisaakye et al. (2024) tested chitin-fortified BSF frass extracts on spinach challenged with the root-knot nematode *Meloidogyne incognita*. The extracts achieved nematode juvenile mortality of 95%, comparable to commercial nematicide at 96%, while increasing spinach root biomass by 54–74% and shoot biomass by 39–58% relative to plants treated with commercial nematicide alone. Anedo et al. (2025) tested the same approach on potatoes, testing BSF frass amended with 5% chitin against the potato cyst nematode. The chitin-amended frass produced 9–28% more tubers per plant than other treatments and more than 26% higher tuber yield than NPK fertilizer plus commercial nematicide, while reducing nematode cyst counts by 5–35% more than the NPK-plus-nematicide and organic-fertilizer treatments did. Kemboi et al. (2022) turned to bacterial pathogens, finding that soil amendment with BSF-derived chitin and chitosan reduced bacterial wilt incidence in tomato, caused by *Ralstonia solanacearum*, by 30% and 35%, respectively, compared with inoculated untreated controls. Chitosan is a processed derivative of chitin. BSF-derived chitosan showed antibacterial activity comparable to commercial chitosan, suggesting that the BSF-derived product can match the industry standard. Across these three trials, chitin-based BSF products showed biocontrol activity against root-knot nematodes, cyst-forming nematodes, and a bacterial wilt pathogen.

**Adding BSF-derived chitin to soil appears to stimulate microbes that attack some crop pests and pathogens.** The proposed mechanism is microbial. Chitin amendments stimulate chitin-degrading soil microbes, which can then attack the chitin-containing structures of pathogenic fungi and nematodes. Insect exuviae, the shed skins present in frass as a minor component, appear to stimulate a distinct chitin-degrading microbial community dominated by *Bacilli* with known biocontrol properties. This response differs from the response to purified chitin, suggesting that the biological activity of frass may come partly from its insect-specific origin rather than from chitin content alone (Barragán-Fonseca et al. 2022). Together, these results indicate that chitin-fortified frass can combine nutrient supply with biocontrol, though the evidence base remains thin and concentrated in Kenyan trials.

### Beyond agronomic uses

**BSF frass is mainly valued for crop and soil uses, but some operations can also turn it into cooking fuel.** BSF frass and its derivatives are a family of outputs, each with distinct uses and research needs. Most of these uses are agronomic: fertilizer, soil improvement, and biocontrol. But the family extends further. Briquette du Kivu in eastern DRC (Box 1.4) pyrolyzes frass into charcoal briquettes for cooking fuel, using BSF digestion as a moisture-reduction step before carbonization. The result is a substitute for wood charcoal in a region facing acute deforestation pressure and energy poverty. The agronomic frass evidence base remains the primary case for the co-product's value, but operations in places where fertilizer markets are constrained or alternative fuels are in strong demand may find non-agronomic uses worth pursuing alongside.

### Competitive positioning and adoption sequencing

**In waste-management settings, BSF competes with composting by processing waste faster and producing higher-priced frass.** The agronomic and economic evidence does not fully capture BSF's competitive position. BSF competes with mineral fertilizer and potentially fishmeal on the product side, but it also competes with conventional composting as an organic waste management practice. On that comparison, BSF economics appear more favorable because it has faster throughput, more production cycles per year, and a much higher frass market price than compost (Mugendi et al. 2025). In places where waste management is the primary problem rather than feed cost, municipal and private waste stakeholders may find the BSF case clearer than the feed-substitution argument alone.

**Frass can introduce farmers to BSF without requiring acceptance of insect-fed livestock.** The second dimension is adoption sequencing. In contexts in which cultural resistance to insect-based livestock feed is a genuine barrier, frass may be a more accessible entry point than larvae. Frass competes against expensive imported mineral fertilizers on straightforward economic terms and does not require cultural negotiation about insects in food chains. A 2023 feasibility study in Ethiopia framed frass as a foot-in-the-door product, building farmer familiarity with BSF operations before introducing the more culturally sensitive proposition of insect-fed livestock (Chaix-Bar et al. 2023). A larvae-first sequence may solve the wrong problem first when acceptance is uncertain. In much of sub-Saharan Africa, high fertilizer costs and accessible frass markets may make a frass-first sequence more durable than trying to build frass and larvae markets at the same time.

**Box 1.4: Farming black soldier fly larvae on urban waste to produce clean-burning charcoal in the DRC**

Briquette du Kivu (BdK) uses BSF digestion to turn wet urban market waste into charcoal briquettes for cooking fuel. BdK operates in Bukavu, in eastern Democratic Republic of Congo, where energy shortages, food insecurity, conflict-driven degradation, and demand for wood charcoal place pressure on nearby forests. The DRC loses approximately 590,000 hectares of primary rainforest annually (Global Forest Watch 2026). Food waste is too wet to carbonize directly, so BdK first uses BSF larvae to bioconvert it into frass, reducing moisture and volume before carbonization.

BdK collects roughly 30 metric tons of organic waste each month. BSF digestion reduces the waste volume by 70–80%; 92% of the resulting frass goes to charcoal production and 8% to BdK's nursery. BdK then carbonizes the frass in modified oil-drum kilns, mixes it with clay binder and corn porridge to support continuous flames, and extrudes it into briquettes for sale. Pyrolysis reduces volume by another 60%, yielding 3.3 tons of briquettes per month, sold locally at 1,000 Congolese francs, or US$0.40, per kilogram.

The system produces fuel, feed, trees, and local income from the same waste stream. Annual briquette production displaces about 39.6 tons of wood charcoal, saving roughly 1,650 trees, or 6–7 hectares of rainforest under conservative estimates. BdK also produces 500–700 kg per month of protein-rich larvae, sold as livestock feed at US$1.00 per kilogram, and 2,500 grafted fruit trees per month, sold for US$1.00 each to individuals, businesses, NGOs, and government agencies. Surplus fruit supports household food security and supplemental income for buyers, while the full operation supports 32 contracted workers. The model shows how a small circular bioeconomy system can address waste, cooking fuel, livestock feed, reforestation, and livelihoods at the same time.

BdK's experience also shows the constraints facing isolated BSF operators in fragile settings. Without reliable electricity, the company depends on manual labor and diesel-powered machinery and cannot control environmental conditions to optimize larval development. BdK has built its own peer network and learned many practices through trial and error, though the BSFAfrica initiative led by Africa Circular now connects the company to a wider network through a moderated WhatsApp group. Public and government support for BSF-based waste valorization remains thin in the DRC, limiting access to local financing. BdK's main lessons for future BSF farmers are to secure contracts for waste access, build peer networks for technical learning, and start small while adapting the system.

*Source: Murhula Zigabe Guido, Briquette du Kivu, Panzi, Bukavu; Charles Nwokoro and Antoine de Clipelle, RUNRES, ETH Zurich; Thomas Klammsteiner, University of Innsbruck; and Noah B. Lemke, KU Leuven Campus Geel Research Group for Insect Processing and Production.*

**Frass can create value inside farms even when it is not sold as a commercial co-product.** Living Soils in Côte d'Ivoire (Box 1.5) applies a related principle. In its integrated farming model, BSF is treated as a tool for on-farm soil regeneration and feed substitution rather than as a commercial product, with frass and larvae reintegrated directly into the farms that produced them. The model represents a different end-state from the frass-first commercial adoption sequence because BSF outputs need not enter a market at all. It shares the underlying observation that frass deserves attention as value retained within the operation, not only as a co-product to be sold. A baseline survey from South Sudan documents the same pattern: among host community participants in Jamjang, fertilizer production was the most commonly expected benefit, cited by 80% of respondents, or 4 of 5, ahead of both feed and income (Verner et al. 2022). This reflected the settled-farmer population's prior orientation toward soil amendment rather than any program framing.

This orientation toward soil amendment preceded any program framing, indicating that demand for frass can precede the projects built around it.

**Box 1.5: Living Soils: using BSF inside farm systems in Côte d'Ivoire and beyond**



Living Soils uses BSF farming as a tool within integrated agricultural systems rather than as a standalone product business. The model produces fresh larvae and frass, but these outputs are mainly used on-site as animal feed and for soil regeneration. The initiative began in 2021 and operates in Côte d'Ivoire, Congo-Brazzaville, and remotely in Benin, with an increasing focus on soil health and the role of frass in farm resilience.

Living Soils works with smallholder farmers and local entrepreneurs through a decentralized support model. Training and follow-up are delivered largely through YouTube, WhatsApp calls, and voice messages, making the model accessible beyond sites with permanent technical staff. In Côte d'Ivoire alone, Living Soils has supported more than 1,500 beneficiaries. Partner farms typically process 80–500 kg of organic waste per day, producing larvae and frass that are reintegrated directly into local farming systems.

The integrated model reduces dependence on purchased feed and fertilizer while improving waste management and soil quality. It also simplifies access to key farm inputs and strengthens farmer autonomy across the value chain. Living Soils has deliberately simplified BSF cultivation so farmers can operate the system with limited equipment and recover from mistakes without losing the production cycle.

The main challenge is not waste access but farmer confidence in biological processes. Reducing reliance on chemical inputs requires education, demonstration, and long-term support that shows visible results in soils and productivity. The model's main lesson is that BSF works best when treated as part of a farming system rather than as a standalone product business. Farmers are more likely to adopt and replicate BSF when it solves immediate problems: input costs, soil health, waste management, and farm autonomy.

*Source: Arthur de Dinechin, Living Soils.*

**Frass markets depend on local fertilizer demand, while insect protein must compete with cheaper global soy.** Frass and insect protein face structurally different markets, and that difference affects project economics. Frass enters local fertilizer markets, where demand is driven by the cost of synthetic alternatives, the productivity gains for farmers, and the agronomic value of organic matter. Insect protein, by contrast, must compete with commodity protein prices. Industry experience reinforces this distinction. Kotch (2026), co-founder of Flybox, argues that the protein-first business model that drove roughly £2 billion of venture capital into Western insect farming over the past decade has structurally failed: insect protein at €3,000–4,000 per ton could not compete with soy meal at €500 per ton, and the temporary "green premium" buyers paid was never a durable market. Kotch argues for repositioning insect operations around waste management services, with protein and frass treated as byproducts of a contracted waste-processing

business rather than as primary revenue lines. The argument is partial because Kotch represents a particular industry position with commercial interests in the model he describes, but it points to a real asymmetry in risk profiles. Frass revenue depends on local market depth and farmer awareness, conditions that vary by site and can be designed for. Insect protein revenue depends on global commodity competition that African operations cannot influence. Programs that lead with frass therefore stand on firmer economic ground than those that lead with insect protein. The case for frass-led adoption sequencing, already supported by evidence from Ethiopia and South Sudan above, is reinforced by this industry-side perspective.

## Works Cited


Abro, Zewdu, Menale Kassie, Chrysantus Tanga, Dennis Beesigamukama, and Gracious Diiro. 2020. "Socio-Economic and Environmental Implications of Replacing Conventional Poultry Feed with Insect-Based Feed in Kenya." *Journal of Cleaner Production* 265 (August): 121871. https://doi.org/10.1016/j.jclepro.2020.121871.

Adams, Daniel, and Elizabeth Koutsos. 2026. "The Impact of Whole Dried Black Soldier Fly Larvae on Broiler Health and Growth During a Necrotic Enteritis Challenge." *Poultry* 5 (3): 33. https://doi.org/10.3390/poultry5030033.

African Market Observatory. 2024. *AMO Price Tracker, Issue 33, May 2024.* Centre for Competition, Regulation and Economic Development.

Agbohessou, Pamphile S., Syaghalirwa N. M. Mandiki, Armel Gougbédji, et al. 2021. "Total Replacement of Fish Meal by Enriched-Fatty Acid *Hermetia illucens* Meal Did Not Substantially Affect Growth Parameters or Innate Immune Status and Improved Whole Body Biochemical Quality of Nile Tilapia Juveniles." *Aquaculture Nutrition* 27 (3): 880–96. https://doi.org/10.1111/anu.13232.

Andriambelo, Fitahiana Fenosoa Hariniaina, Cédrique L. Solofondranohatra, Tanjona Ramiadantsoa, and Brian L. Fisher. 2026. "Field Evaluation of Composted Black Soldier Fly Frass as a Soil Amendment for Restoration of Dodonaea Madagascariensis (Sapindaceae) in Madagascar." *Sustainability* 18 (9): 4449. https://doi.org/10.3390/su18094449.

Andrianome, Tojo, Danielle Rakoto, Brian L. Fisher, and Sylvain Hugel. 2026. "Beyond Household Meals: A Game-Based Approach to Unveiling the Role of Insects in Malagasy Children's Diets." *Journal of Ethnobiology and Ethnomedicine* 22 (1): 16. https://doi.org/10.1186/s13002-026-00854-z.

Anedo, Emmanuel O., Dennis Beesigamukama, Benson Mochoge, et al. 2025. "Unpacking the Benefits of Black Soldier Fly Frass Fertilizer towards Nematode Suppression and Potato Production." *Frontiers in Plant Science* 16 (February): 1509643. https://doi.org/10.3389/fpls.2025.1509643.

Anyega, Abel O., Nicholas K. Korir, Dennis Beesigamukama, et al. 2021. "Black Soldier Fly-Composted Organic Fertilizer Enhances Growth, Yield, and Nutrient Quality of Three Key Vegetable Crops in Sub-Saharan Africa." *Frontiers in Plant Science* 12 (June). https://doi.org/10.3389/fpls.2021.680312.

Arabzadeh, Ghazaleh, Maxime Delisle-Houde, Grant W. Vandenberg, et al. 2024. "Suppressive Effect of Black Soldier Fly Larvae Frass on Fusarium Wilt Disease in Tomato Plants." *Insects* 15 (8): 613. https://doi.org/10.3390/insects15080613.

Association of Kenya Feed Manufacturers. 2024. "Kenyan Feed Millers Face Soybean Shortage as Prices Surge by over KSh15." *Animal Feed Middle East & Africa Magazine,* August 6. https://www.animalfeedmea.com/2024/08/06/kenyan-feed-millers-face-soybean-shortage-as-prices-surge-by-over-ksh15/.

Barragán-Fonseca, K. B., Julián Cortés-Urquijo, Julián Pineda-Mejía, Diego Lagos-Sierra, and Marcel Dicke. 2023. "Small-Scale Black Soldier Fly-Fish Farming: A Model with Socioeconomic Benefits." *Animal Frontiers* 13 (4): 91–101. https://doi.org/10.1093/af/vfad030.

Barragán-Fonseca, K. B., D. Gómez, C. H. Lalander, D. Dzepe, and S. Y. Chia. 2025. "Review – Insect Farming for Food and Feed in the Global South: Focus on Black Soldier Fly Production." *Animal* 19 (August): 101397. https://doi.org/10.1016/j.animal.2024.101397.

Barragán-Fonseca, K. B., Azkia Nurfikari, Els M. van de Zande, et al. 2022. "Insect Frass and Exuviae to Promote Plant Growth and Health." *Trends in Plant Science* 27 (7): 646–54. https://doi.org/10.1016/j.tplants.2022.01.007.

Barragán-Fonseca K.Y., Katherine Y., Karol Barragán-Fonseca, Gerard Verschoor, Joop J. A. van Loon, and Marcel Dicke. 2020. "Insects for Peace." *Current Opinion in Insect Science* 40 (August): 85–93. https://doi.org/10.1016/j.cois.2020.05.011.

Beesigamukama, D., B. Mochoge, N. Korir, et al. 2022. "Economic and Ecological Values of Frass Fertiliser from Black Soldier Fly Agro-Industrial Waste Processing." *Journal of Insects as Food and Feed* 8 (3): 245–254. https://doi.org/10.3920/JIFF2021.0013.

Beesigamukama, Dennis, Benson Mochoge, Nicholas Korir, et al. 2020b. "Nitrogen Fertilizer Equivalence of Black Soldier Fly Frass Fertilizer and Synchrony of Nitrogen Mineralization for Maize Production." *Agronomy* 10 (9): 1395. https://doi.org/10.3390/agronomy10091395.

Beesigamukama, Dennis, Benson Mochoge, Nicholas K. Korir, et al. 2021. "Low-Cost Technology for Recycling Agro-Industrial Waste into Nutrient-Rich Organic Fertilizer Using Black Soldier Fly." *Waste Management* 119 (January): 183–94. https://doi.org/10.1016/j.wasman.2020.09.043.

Beesigamukama, Dennis, Benson Mochoge, Nicholas K. Korir, et al. 2020a. "Exploring Black Soldier Fly Frass as Novel Fertilizer for Improved Growth, Yield, and Nitrogen Use Efficiency of Maize Under Field Conditions." *Frontiers in Plant Science* 11. https://doi.org/10.3389/fpls.2020.574592.Beesigamukama, Dennis, Benson Mochoge, Nicholas K. Korir, et al. 2020c. "Biochar and Gypsum Amendment of Agro-Industrial Waste for Enhanced Black Soldier Fly Larval Biomass and Quality Frass Fertilizer." *PLoS ONE* 15 (8): e0238154. https://doi.org/10.1371/journal.pone.0238154.

Belluco, Simone, Carmen Losasso, Michela Maggioletti, et al. 2013. "Edible Insects in a Food Safety and Nutritional Perspective: A Critical Review." *Comprehensive Reviews in Food Science and Food Safety* 12 (3): 296–313. https://doi.org/10.1111/1541-4337.12014.

Bernal, M. P., J. A. Alburquerque, and R. Moral. 2009. "Composting of Animal Manures and Chemical Criteria for Compost Maturity Assessment. A Review." *Bioresource Technology* 100 (22): 5444–53. https://doi.org/10.1016/j.biortech.2008.11.027.

Berners-Lee, M., C. Kennelly, R. Watson, and C. N. Hewitt. 2018. "Current Global Food Production Is Sufficient to Meet Human Nutritional Needs in 2050 Provided There Is Radical Societal Adaptation." *Elementa: Science of the Anthropocene* 6 (July): 52. https://doi.org/10.1525/elementa.310.

Bessa, Leah W., Elsje Pieterse, Jeannine Marais, et al. 2021. "Food Safety of Consuming Black Soldier Fly (*Hermetia illucens*) Larvae: Microbial, Heavy Metal and Cross-Reactive Allergen Risks." *Foods* 10 (8): 1934. https://doi.org/10.3390/foods10081934.

Biteau, Corentin, Tom Bry-Chevalier, Dustin Crummett, et al. 2026. "Have the Environmental Benefits of Insect Farming Been Overstated? A Critical Review." *Biological Reviews* 101 (1): 163–94. https://doi.org/10.1111/brv.70076.

Biteau, Corentin, Tom Bry-Chevalier, Dustin Crummett, Ren Ryba, and Michael St. Jules. 2025. "Bugs in the System: The Logic of Insect Farming Research Is Flawed by Unfounded Assumptions." *Npj Sustainable Agriculture* 3 (1): 9. https://doi.org/10.1038/s44264-024-00042-0.

Black, Robert E., Cesar G. Victora, Susan P. Walker, et al. 2013. "Maternal and Child Undernutrition and Overweight in Low-Income and Middle-Income Countries." *The Lancet* 382 (9890): 427–51. https://doi.org/10.1016/S0140-6736(13)60937-X.

Bohm, Kristin, Gregory A. Hatley, Brett H. Robinson, and María J. Gutiérrez-Ginés. 2023. "Analysis of Chemical and Phytotoxic Properties of Frass Derived from Black Soldier Fly-Based Bioconversion of Biosolids." *Sustainability* 15 (15): 11526. https://doi.org/10.3390/su151511526.

Boit, Gwokyalya, D. Nakimbugwe, B. Grenov, E. Mupere, and N. Roos. 2026. "The Effect of Yellow Mealworm-Enriched Maize Porridge on Growth of School-Going Children in Western Uganda." Paper presented at Insects to Feed the World. June.

Boit, Tele Chepkoros, Alida Melse-Boonstra, Kim F. Michaelsen, and Nanna Roos. 2024. "Should We Provide Edible Insects in Children's Diets?" *Current Opinion in Clinical Nutrition & Metabolic Care* 27 (3): 275–82. https://doi.org/10.1097/MCO.0000000000001029.

Bondari, K., and D. C. Sheppard. 1981. "Soldier Fly Larvae as Feed in Commercial Fish Production." *Aquaculture* 24: 103–9. https://doi.org/10.1016/0044-8486(81)90047-8.

Bondari, K., and D. C. Sheppard. 1987. "Soldier Fly, *Hermetia illucens* L., Larvae as Feed for Channel Catfish, *Ictalurus punctatus* (Rafinesque), and Blue Tilapia, *Oreochromis aureus* (Steindachner)." *Aquaculture Research* 18 (3): 209–20. https://doi.org/10.1111/j.1365-2109.1987.tb00141.x.

Bosch, G., H. Fels-Klerx, Theo Rijk, and Dennis Oonincx. 2017. "Aflatoxin B1 Tolerance and Accumulation in Black Soldier Fly Larvae (*Hermetia illucens*) and Yellow Mealworms (Tenebrio Molitor)." *Toxins* 9 (6): 185. https://doi.org/10.3390/toxins9060185.

Bosch, G., and K. S. Swanson. 2021. "Effect of Using Insects as Feed on Animals: Pet Dogs and Cats." *Journal of Insects as Food and Feed* 7 (5): 795–805. https://doi.org/10.3920/JIFF2020.0084.

Bothma, M., G. M. Teke, E. Pieterse, et al. 2024. "Enhancing Black Soldier Fly Larval Production from Sugarcane Bagasse through Hydrothermal, Enzymatic, and Microbial Treatment." *Journal of Insects as Food and Feed* 11 (5): 937–951. https://doi.org/10.1163/23524588-00001186.

Bureau de Normes de Madagascar. 2025. "Larves séchées de Black Soldier Fly (Hermetia illucens) et leur poudre — Spécifications." Norme Nationale Malagasy NMG 132-13 (Antananarivo, Madagascar). https://www.bnm.mg/processus-delaboration-de-la-norme-malagasy-pour-la-farine-de-larves-de-bsf-en-collaboration-avec-le-groupe-exa-a-antsiranana-mars-2025/.

Caimi, Christian, Manuela Renna, Carola Lussiana, et al. 2020. "First Insights on Black Soldier Fly (*Hermetia illucens* L.) Larvae Meal Dietary Administration in Siberian Sturgeon (Acipenser Baerii Brandt) Juveniles." *Aquaculture* 515 (January): 734539. https://doi.org/10.1016/j.aquaculture.2019.734539.

Camenzuli, Louise, Ruud Van Dam, Theo De Rijk, et al. 2018. "Tolerance and Excretion of the Mycotoxins Aflatoxin B1, Zearalenone, Deoxynivalenol, and Ochratoxin A by Alphitobius Diaperinus and *Hermetia illucens* from Contaminated Substrates." *Toxins* 10 (2): 91. https://doi.org/10.3390/toxins10020091.

Carvalho, Nelson Mota de, Francisco Teixeira, Sara Silva, Ana Raquel Madureira, and Manuela Estevez Pintado. 2019. "Potential Prebiotic Activity of Tenebrio Molitor Insect Flour Using an Optimized in Vitro Gut Microbiota Model." *Food & Function* 10 (7): 3909–22. https://doi.org/10.1039/c8fo01536h.

Chaix-Bar, Mathieu, Asaah Ndambi, and Somaya Naser El Deen. 2023. *Feasibility Study: Black Soldier Fly Production for Animal Feed in Ethiopia.* SWRE-RAISE-FS-23-012. RAISE-FS Manual 2. TRAIDE Foundation & Stichting Wageningen Research. https://edepot.wur.nl/637480.

Chia, Shaphan Y., John Macharia, Gracious M. Diiro, et al. 2020. "Smallholder Farmers' Knowledge and Willingness to Pay for Insect-Based Feeds in Kenya." *PLOS ONE* 15 (3): e0230552. https://doi.org/10.1371/journal.pone.0230552.

Chilaka, Cynthia Adaku, and Angela Mally. 2020. "Mycotoxin Occurrence, Exposure and Health Implications in Infants and Young Children in Sub-Saharan Africa: A Review." *Foods* 9 (11): 1585. https://doi.org/10.3390/foods9111585.

Chilaka, Cynthia Adaku, Jude Ejikeme Obidiegwu, Augusta Chinenye Chilaka, Olusegun Oladimeji Atanda, and Angela Mally. 2022. "Mycotoxin Regulatory Status in Africa: A Decade of Weak Institutional Efforts." *Toxins* 14 (7): 442. https://doi.org/10.3390/toxins14070442.

Climate and Clean Air Coalition. 2025. *Creating Opportunities for Black Soldier Fly (BSF) Waste Processing: A Policy Guide for Governmental Actors.* Climate and Clean Air Coalition. https://www.eawag.ch/fileadmin/Domain1/Abteilungen/sandec/schwerpunkte/swm/BUGS_Africa/bsf_policy_guide_public_sector.pdf.

Competition Authority of Kenya. 2024. *Animal Feed Market Inquiry Report, 2024: Non-Confidential Version.* Competition Authority of Kenya.

Crotty, Felicity, and Liam Rock. 2024. *Research Gap Analysis on Using Black Soldier Fly Larvae Frass as Fertiliser.* Report for Department for Environment, Food & Rural Affairs (Defra). Ricardo Energy & Environment. https://sciencesearch.defra.gov.uk/ProjectDetails?ProjectId=21021.

Delfino, Danila, Barbara Prandi, Erminia Ridolo, et al. 2024. "Allergenicity of Tropomyosin Variants Identified in the Edible Insect *Hermetia illucens* (Black Soldier Fly)." *Food Chemistry* 437 (March): 137849. https://doi.org/10.1016/j.foodchem.2023.137849.

Desiere, Sam, Yung Hung, Wim Verbeke, and Marijke D'Haese. 2018. "Assessing Current and Future Meat and Fish Consumption in Sub-Sahara Africa: Learnings from FAO Food Balance Sheets and LSMS Household Survey Data." *Global Food Security* 16 (March): 116–26. https://doi.org/10.1016/j.gfs.2017.12.004.

Diener, S., C. Zurbrügg, and K. Tockner. 2015. "Bioaccumulation of Heavy Metals in the Black Soldier Fly, *Hermetia illucens* and Effects on Its Life Cycle." *Journal of Insects as Food and Feed* 1 (4): 261–270. https://doi.org/10.3920/JIFF2015.0030.

Diener, Stefan, and Chris Storey. 2025. *Transforming Organic Waste with Black Soldier Flies: A Guide for Decision-Makers, Entrepreneurs, and Implementers to Unlock the Organic Waste Potential of Black Soldier Fly Systems.* CCAC/UNEP. https://www.ccacoalition.org/resources/transforming-organic-waste-black-soldier-flies-guide-decision-makers-entrepreneurs-and-implementers-unlock-organic-waste-potential-black-soldier-fly-systems.

Do, Sungho, Liz Koutsos, Pamela L. Utterback, et al. 2020. "Nutrient and AA Digestibility of Black Soldier Fly Larvae Differing in Age Using the Precision-Fed Cecectomized Rooster Assay." *Journal of Animal Science* 98 (1): skz363. https://doi.org/10.1093/jas/skz363.

Dzepe, Daniel, Michael Y. Osae, Janet O. Asabre, et al. 2024. "Adoption Potential of Black Soldier Fly (*Hermetia illucens* (L.), Diptera: Stratiomyidae) Larvae Composting Technology among Smallholder Farmers in Greater Ahafo-Ano, Ashanti Region of Ghana." *Green Technologies and Sustainability* 2 (3): 100112. https://doi.org/10.1016/j.grets.2024.100112.

Elissen, Hellen, Rommie van der Weide, and Luuk Gollenbeek. 2023. *Effects of Black Soldier Fly Frass on Plant and Soil Characteristics: A Literature Overview.* Wageningen Plant Research. https://doi.org/10.18174/587213.

Erickson, Marilyn C., Mahbub Islam, Craig Sheppard, Jean Liao, and Michael P. Doyle. 2004. "Reduction of Escherichia Coli O157:H7 and Salmonella Enterica Serovar Enteritidis in Chicken Manure by Larvae of the Black Soldier Fly." *Journal of Food Protection* 67 (4): 685–90. https://doi.org/10.4315/0362-028x-67.4.685.

Ezekiel, Chibundu N., Alejandro Ortega-Beltran, and Ranajit Bandyopadhyay. 2019. *The Need for Integrated Approaches to Address Food Safety Risk: The Case of Mycotoxins in Africa.* WHO. https://www.who.int/docs/default-source/resources/the-need-for-integrated-approaches-to-address-food-safety-risk---the-case-of-mycotoxins-in-africa-en.pdf.

FAO. 2013. *Food Wastage Footprint: Impacts on Natural Resources. Summary Report.* Rome: FAO. https://www.fao.org/4/i3347e/i3347e.pdf.

FAO, IFAD, UNICEF, WFP, and WHO. 2024. *The State of Food Security and Nutrition in the World 2024. Financing to End Hunger, Food Insecurity and Malnutrition in All Its Forms.* FAO; IFAD; UNICEF; WFP; WHO. https://doi.org/10.4060/cd1254en.

Fels-Klerx, H. J. van der, L. Camenzuli, S. Belluco, N. Meijer, and A. Ricci. 2018. "Food Safety Issues Related to Uses of Insects for Feeds and Foods." *Comprehensive Reviews in Food Science and Food Safety* 17 (5): 1172–83. https://doi.org/10.1111/1541-4337.12385.

Florença, Sofia G., Raquel P. F. Guiné, Fernando J. A. Gonçalves, et al. 2022. "The Motivations for Consumption of Edible Insects: A Systematic Review." *Foods* 11 (22): 3643. https://doi.org/10.3390/foods11223643.

Francis, Aditya, Eric Schmitt, and Sergiy Smetana. 2025. "Making Better Bugs: Improving Black Soldier Fly Production for a More Sustainable Future." *Journal of Cleaner Production* 521 (August): 146240. https://doi.org/10.1016/j.jclepro.2025.146240.

Gärttling, Daniel, and Hannes Schulz. 2022. "Compilation of Black Soldier Fly Frass Analyses." *Journal of Soil Science and Plant Nutrition* 22 (1): 937–43. https://doi.org/10.1007/s42729-021-00703-w.

Gebiola, Marco, Michael V. Rodriguez, Alexandro Garcia, et al. 2023a. "Bokashi Fermentation of Brewery's Spent Grains Positively Affects Larval Performance of the Black Soldier Fly *Hermetia illucens* While Reducing Gaseous Nitrogen Losses." *Waste Management* 171 (November): 411–20. https://doi.org/10.1016/j.wasman.2023.09.033.

Gebiola, Marco, Andrea Garnica, Deborah Pagliaccia, et al. 2023b. "Impact of Bokashi Fermentation on Life-History Traits of Black Soldier Fly *Hermetia illucens* (Diptera: Stratiomyidae) Larvae at an Industrial Scale." *Journal of Insects as Food and Feed* 9 (9): 1159–64. https://doi.org/10.3920/JIFF2022.0173.

Gilani, G. S., Chao Wu Xiao, and Kevin A. Cockell. 2012. "Impact of Antinutritional Factors in Food Proteins on the Digestibility of Protein and the Bioavailability of Amino Acids and on Protein Quality." *The British Journal of Nutrition* 108 Suppl 2 (August): S315–332. https://doi.org/10.1017/S0007114512002371.

Global Forest Watch. 2026. "Democratic Republic of the Congo Deforestation Rates & Statistics." Global Forest Watch, World Resources Institute. https://www.globalforestwatch.org/dashboards/country/COD/.

Gold, Moritz, Jeffery K. Tomberlin, Stefan Diener, Christian Zurbrügg, and Alexander Mathys. 2018. "Decomposition of Biowaste Macronutrients, Microbes, and Chemicals in Black Soldier Fly Larval Treatment: A Review." *Waste Management* 82 (December): 302–318. https://doi.org/10.1016/j.wasman.2018.10.022.

Gold, M., K. Niermans, F. Jooste, et al. 2023. "Conversion of Mycotoxin-Contaminated Maize by Black Soldier Fly Larvae into Feed and Fertilizer." *Journal of Insects as Food and Feed* 10 (5): 757–70. https://doi.org/10.1163/23524588-00001006.

Golden, Christopher D., Lia C. H. Fernald, Justin S. Brashares, B. J. Rodolph Rasolofoniaina, and Claire Kremen. 2011. "Benefits of Wildlife Consumption to Child Nutrition in a Biodiversity Hotspot." *Proceedings of the National Academy of Sciences of the United States of America* 108 (49): 19653–56. https://doi.org/10.1073/pnas.1112586108.

González-Pérez, Ruperto, Paloma Poza-Guedes, Manuel Alberto Figueiras-Rincón, Mónica Colque-Bayona, and Inmaculada Sánchez-Machín. 2025. "The Allergy Crossroads of Subtropical Regions: Mites, Crustaceans, and the Rise of Edible Insects." *Nutrients* 17 (9): 1405. https://doi.org/10.3390/nu17091405.

Gulsunoglu, Zehra, Smitha Aravind, Yuchen Bai, Lipu Wang, H. Randy Kutcher, and Takuji Tanaka. 2019. "Deoxynivalenol (DON) Accumulation and Nutrient Recovery in Black Soldier Fly Larvae (*Hermetia illucens*) Fed Wheat Infected with Fusarium Spp." *Fermentation* 5 (3): 83. https://doi.org/10.3390/fermentation5030083.

Gustavsson, Jenny, Christel Cederberg, Ulf Sonesson, Robert van Otterdijk, and Alexandre Meybeck. 2011. *Global Food Losses and Food Waste: Extent, Causes and Prevention.* Rome: FAO.

Hale, O. M. 1973. "Dried *Hermetia illucens* Larvae (Diptera: Stratiomyidae) as a Feed Additive for Poultry." *Journal of the Georgia Entomological Society* 8: 16–20.

Havelaar, Arie H., Martyn D. Kirk, Paul R. Torgerson, et al. 2015. "World Health Organization Global Estimates and Regional Comparisons of the Burden of Foodborne Disease in 2010." *PLOS Medicine* 12 (12): e1001923. https://doi.org/10.1371/journal.pmed.1001923.

Headey, Derek, Kalle Hirvonen, and John Hoddinott. 2018. "Animal Sourced Foods and Child Stunting." *American Journal of Agricultural Economics* 100 (5): 1302–19. https://doi.org/10.1093/ajae/aay053.

Hender, Amanda, Muhammad A. B. Siddik, Janet Howieson, and Ravi Fotedar. 2021. "Black Soldier Fly, *Hermetia illucens* as an Alternative to Fishmeal Protein and Fish Oil: Impact on Growth, Immune Response, Mucosal Barrier Status, and Flesh Quality of Juvenile Barramundi, Lates Calcarifer (Bloch, 1790)." *Biology* 10 (6): 505. https://doi.org/10.3390/biology10060505.

Hervé, Mube K., Mekeu D. Calice, Daniel Dzepe, et al. 2025. "Black Soldier Fly (*Hermetia illucens*) Larvae Improve Growth Performance and Flesh Quality of African Catfish (Clarias Gariepinus)." *Discover Animals* 2 (1): 9. https://doi.org/10.1007/s44338-024-00045-8.

Heuel, M., M. Kreuzer, I. D. M. Gangnat, et al. 2023. "Low Transfer of Cadmium, Lead and Aflatoxin B1 to Eggs and Meat of Laying Hens Receiving Diets with Black Soldier Fly Larvae Reared on Contaminated Substrates." *Animal Feed Science and Technology* 304 (October): 115733. https://doi.org/10.1016/j.anifeedsci.2023.115733.

Hilaj, Nikolin, Tele Boit, Pauline Andang'o, et al. 2025. "Zinc Absorption from Maize-Based Meals Enriched with Edible House Crickets: A Randomized Crossover Stable-Isotope Study in Kenyan Pre-School Children." *Nature Communications* 16 (1): 1003. https://doi.org/10.1038/s41467-025-56259-1.

Holeh, Gladys M., Mark A. Opiyo, Carolyn L. Brown, et al. 2022. "Effect of Different Waste Substrates on the Growth, Development and Proximate Composition of Black Soldier Fly (*Hermetia illucens*) Larvae." *Livestock Research for Rural Development* 34 (7). https://www.lrrd.org/lrrd34/7/3457hole.html.

Hopkins, Indee, Lisa P. Newman, Harsharn Gill, and Jessica Danaher. 2021. "The Influence of Food Waste Rearing Substrates on Black Soldier Fly Larvae Protein Composition: A Systematic Review." *Insects* 12 (7): 608. https://doi.org/10.3390/insects12070608.

Huis, Arnold van. 2013. "Potential of Insects as Food and Feed in Assuring Food Security." *Annual Review of Entomology* 58: 563–83. https://doi.org/10.1146/annurev-ento-120811-153704.

Hurtado, E. K., A. H. Claussen, and K. G. Scott. 1999. "Early Childhood Anemia and Mild or Moderate Mental Retardation." *The American Journal of Clinical Nutrition* 69 (1): 115–19. https://doi.org/10.1093/ajcn/69.1.115.

IARC. 2012. *Chemical Agents and Related Occupations.* Vol. 100F. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. International Agency for Research on Cancer. WHO.

https://publications.iarc.who.int/Book-And-Report-Series/Iarc-Monographs-On-The-Identification-Of-Carcinogenic-Hazards-To-Humans/Chemical-Agents-And-Related-Occupations-2012.

Ibengwe, Lilian J. 2023. *Market Survey for Lake Victoria Small Fish.* Regional Technical Report LVFO/C-SRVCS/IFAD/2022-2023/014. LVFO.

Ivanova, Lada, Nada Dhaoui, Feng-Ling Tukun, Eva Byhrø, and Christiane Kruse Fæste. 2026. "Multi-Mycotoxin Method Applicable for the Safety Assessment of Waste-Fed Black Soldier Fly (Hermetia Illuscens) Larvae on the Way to Circular Bioeconomics." *Talanta* 302 (May): 129432. https://doi.org/10.1016/j.talanta.2026.129432.

Janssen, Renske H., Jean-Paul Vincken, Lambertus A. M. van den Broek, Vincenzo Fogliano, and Catriona M. M. Lakemond. 2017. "Nitrogen-to-Protein Conversion Factors for Three Edible Insects: *Tenebrio molitor*, *Alphitobius diaperinus*, and *Hermetia illucens*." *Journal of Agricultural and Food Chemistry* 65 (11): 2275–78.

Javourez, U., L. Tiruta-Barna, M. Pizzol, and L. Hamelin. 2025. "Environmental Mitigation Potential of Waste-to-Nutrition Pathways." *Nature Sustainability* 8 (4): 385–95. https://doi.org/10.1038/s41893-025-01521-z.Kals, Jeroen, Mary A. Opiyo, Eugene Rurangwa, Katrine Soma, Asaah Ndambi, and Adriaan Vernooij. 2024. "Use of Black Soldier Fly Larvae and Freshwater Shrimp to Partly Substitute Commercial Diet for Nile Tilapia Cultured in Smallholder Fish Farms – A Case Study in Busia County, Kenya." *Frontiers in Sustainable Food Systems* 8 (April). https://doi.org/10.3389/fsufs.2024.1298551.

Kamau, Edwin, Patrick Kibuku, and John Kinyuru. 2021. "Introducing Cricket Farming as a Food Security and Livelihood Strategy in Humanitarian Settings: Experience from Kakuma Refugee Camp, Kenya." *International Journal of Tropical Insect Science* 41 (3): 2277–85. https://doi.org/10.1007/s42690-021-00550-3.

Kamika, Ilunga, Pamella Mngqawa, John P. Rheeder, Snow L. Teffo, and David R. Katerere. 2014. "Mycological and Aflatoxin Contamination of Peanuts Sold at Markets in Kinshasa, Democratic Republic of Congo, and Pretoria, South Africa." *Food Additives & Contaminants. Part B, Surveillance* 7 (2): 120–26. https://doi.org/10.1080/19393210.2013.858187.

Kaya, Cengiz, Tomas N. Generalovic, Gunilla Ståhls, et al. 2021. "Global Population Genetic Structure and Demographic Trajectories of the Black Soldier Fly, *Hermetia illucens*." *BMC Biology* 19: 94. https://doi.org/10.1186/s12915-021-01029-w.Kaza, Silpa, Lisa Yao, Perinaz Bhada-Tata, and Frank Van Woerden. 2018. *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050.* Washington, DC: World Bank Publications.

Kemboi, Violah Jepkogei, Carolyne Kipkoech, Moses Njire, et al. 2022. "Biocontrol Potential of Chitin and Chitosan Extracted from Black Soldier Fly Pupal Exuviae against Bacterial Wilt of Tomato." *Microorganisms* 10 (1): 165. https://doi.org/10.3390/microorganisms10010165.

Kim, Do-Hyun, Yilin Wang, Haerin Jung, et al. 2023. "A Type 2 Immune Circuit in the Stomach Controls Mammalian Adaptation to Dietary Chitin." *Science.* https://doi.org/10.1126/science.add5649.

Kipkoech, Carolyne, John N. Kinyuru, Samuel Imathiu, Victor Benno Meyer-Rochow, and Nanna Roos. 2021. "In Vitro Study of Cricket Chitosan's Potential as a Prebiotic and a Promoter of Probiotic Microorganisms to Control Pathogenic Bacteria in the Human Gut." *Foods* 10 (10): 2310. https://doi.org/10.3390/foods10102310.

Kisaakye, James, Dennis Beesigamukama, Solveig Haukeland, et al. 2024. "Chitin-Enriched Insect Frass Fertilizer as a Biorational Alternative for Root-Knot Nematode (Meloidogyne Incognita) Management." *Frontiers in Plant Science* 15 (March): 1361739. https://doi.org/10.3389/fpls.2024.1361739.

Knox, Jerry, Tim Hess, Andre Daccache, and Tim Wheeler. 2012. "Climate Change Impacts on Crop Productivity in Africa and South Asia." *Environmental Research Letters* 7 (3): 034032. https://doi.org/10.1088/1748-9326/7/3/034032.

Konyo, Aziza Athumani, Revocatus Machunda, Liliane Pasape, and Anthony Mshandete. 2023. "The Potential of Valorized Sisal Decorticated Waste in Rearing of Black Soldier Fly." *Recycling* 8 (1): 1. https://doi.org/10.3390/recycling8010001.

Kotch, Larry. 2026. "Insect Farming Business Plan: Why the Protein-First Model Is Dead." *Flybox Blog,* Flybox (Mana Biosystems Limited), March 29. https://flybox.bio/insect-farming-business-plan-protein-first-failure/.

Lalander, C., S. Diener, C. Zurbrügg, and B. Vinnerås. 2019. "Effects of Feedstock on Larval Development and Process Efficiency in Waste Treatment with Black Soldier Fly (*Hermetia illucens*)." *Journal of Cleaner Production* 208 (January): 211–19. https://doi.org/10.1016/j.jclepro.2018.10.017.

Lalander, C., Jørgen Fidjeland, Stefan Diener, Sara Eriksson, and Björn Vinnerås. 2015. "High Waste-to-Biomass Conversion and Efficient Salmonella Spp. Reduction Using Black Soldier Fly for Waste Recycling." *Agronomy for Sustainable Development* 35 (1): 261–71. https://doi.org/10.1007/s13593-014-0235-4.

Lange, Klaus W., and Yukiko Nakamura. 2021. "Edible Insects as Future Food: Chances and Challenges." *Journal of Future Foods* 1 (1): 38–46. https://doi.org/10.1016/j.jfutfo.2021.10.001.

Leinonen, Ilkka, Pietro P. M. Iannetta, Robert M. Rees, Wendy Russell, Christine Watson, and Andrew P. Barnes. 2019. "Lysine Supply Is a Critical Factor in Achieving Sustainable Global Protein Economy." *Frontiers in Sustainable Food Systems* 3 (April). https://doi.org/10.3389/fsufs.2019.00027.

Leni, Giulia, Tullia Tedeschi, Andrea Faccini, et al. 2020. "Shotgun Proteomics, in-Silico Evaluation and Immunoblotting Assays for Allergenicity Assessment of Lesser Mealworm, Black Soldier Fly and Their Protein Hydrolysates." *Scientific Reports* 10 (1): 1228. https://doi.org/10.1038/s41598-020-57863-5.

Limbu, Samwel Mchele, Amon Paul Shoko, Eusebia Ernest Ulotu, et al. 2022. "Black Soldier Fly (*Hermetia illucens*, L.) Larvae Meal Improves Growth Performance, Feed Efficiency and Economic Returns of Nile Tilapia (Oreochromis Niloticus, L.) Fry." *Aquaculture, Fish and Fisheries* 2 (3): 167–78. https://doi.org/10.1002/aff2.48.

Lohri, Christian Riuji, Stefan Diener, Imanol Zabaleta, Adeline Mertenat, and Christian Zurbrügg. 2017. "Treatment Technologies for Urban Solid Biowaste to Create Value Products: A Review with Focus on Low- and Middle-Income Settings." *Reviews in Environmental Science and Bio/Technology* 16 (1): 81–130. https://doi.org/10.1007/s11157-017-9422-5.

Lopes, Ivã Guidini, Viktoria Wiklicky, Björn Vinnerås, Jean Wan Hong Yong, and Cecilia Lalander. 2024. "Recirculating Frass from Food Waste Bioconversion Using Black Soldier Fly Larvae: Impacts on Process Efficiency and Product Quality." *Journal of Environmental Management* 366 (August): 121869. https://doi.org/10.1016/j.jenvman.2024.121869.

Lopes, Ivã Guidini, Jean W. H. Yong, and Cecilia Lalander. 2022. "Frass Derived from Black Soldier Fly Larvae Treatment of Biodegradable Wastes. A Critical Review and Future Perspectives." *Waste Management* 142 (April): 65–76. https://doi.org/10.1016/j.wasman.2022.02.007.

Lopez-Santamarina, Aroa, Alicia del Carmen Mondragon, Alexandre Lamas, Jose Manuel Miranda, Carlos Manuel Franco, and Alberto Cepeda. 2020. "Animal-Origin Prebiotics Based on Chitin: An Alternative for the Future? A Critical Review." *Foods* 9 (6): 782. https://doi.org/10.3390/foods9060782.

Lozoff, Betsy, John Beard, James Connor, Barbara Felt, Michael Georgieff, and Timothy Schallert. 2006. "Long-Lasting Neural and Behavioral Effects of Iron Deficiency in Infancy." *Nutrition Reviews* 64 (5 Pt 2): S34–91. https://doi.org/10.1301/nr.2006.may.S34-S43.

Lundy, Mark E., and Michael P. Parrella. 2015. "Crickets Are Not a Free Lunch: Protein Capture from Scalable Organic Side-Streams via High-Density Populations of *Acheta domesticus*." *PLOS ONE* 10 (4): e0118785. https://doi.org/10.1371/journal.pone.0118785.

Mahuma, Arthur Khomotso, and Namhla Landani. 2025. "High Soybean Prices in Zambia and Malawi May Make Chicken Costly Too: Lack of Competition Is to Blame." *The Conversation,* March 18. https://doi.org/10.64628/AAJ.5t5r3uw3x.

Matumba, Limbikani, Christof Van Poucke, Emmanuel Njumbe Ediage, and Sarah De Saeger. 2017. "Keeping Mycotoxins Away from the Food: Does the Existence of Regulations Have Any Impact in Africa?" *Critical Reviews in Food Science and Nutrition* 57 (8): 1584–92. https://doi.org/10.1080/10408398.2014.993021.

Meerts, A., L. Martinussen, and A. K. Muganga. 2023. *Mapping of the Black Soldier Fly Value Chain in East Africa.* Report prepared by Fair & Sustainable Consulting. FAO.

Meijer, Nathan, Gijs Kleter, Monique de Nijs, Marie-Luise Rau, Ria Derkx, and H. J. van der Fels-Klerx. 2021. "The Aflatoxin Situation in Africa: Systematic Literature Review." *Comprehensive Reviews in Food Science and Food Safety* 20 (3): 2286–304. https://doi.org/10.1111/1541-4337.12731.

Mertenat, Adeline, Stefan Diener, and Christian Zurbrügg. 2019. "Black Soldier Fly Biowaste Treatment – Assessment of Global Warming Potential." *Waste Management* 84 (February): 173–81. https://doi.org/10.1016/j.wasman.2018.11.040.

Moughan, Paul J. 2021. "Population Protein Intakes and Food Sustainability Indices: The Metrics Matter." *Global Food Security* 29 (June): 100548. https://doi.org/10.1016/j.gfs.2021.100548.

Msuya, Neema, and Abraham Temu. 2025. "From Waste to Wealth: Sisal By-Product Opportunities in Tanzania." *Tanzania Journal of Science* 51 (1): 182–95. https://doi.org/10.4314/tjs.v51i1.13.

Mugendi, Perpetual G., Beatrice W. Muriithi, Raphael Gitau, et al. 2025. *Economic Efficiency and Adoption Determinants of Insect-Based Technologies for Organic Waste Recycling into Fertilizer.* Research Square. https://doi.org/10.21203/rs.3.rs-6264404/v1.

Munguti, Jonathan, Mavindu Muthoka, Jimmy B. Mboya, et al. 2025. "Unraveling the Potential of Black Soldier Fly Larvae as a Sustainable Protein Source for Nile Tilapia Production in Diverse Aquaculture Systems." *Aquaculture Nutrition* 2025 (1): 3598843. https://doi.org/10.1155/anu/3598843.

Munthali, Maggie G., Lemekezani Chilora, Mike Goliath, et al. 2023. *The Economic Cost-Benefit Analysis of Black Soldier Fly as an Alternative Animal and Fish Feed Ingredient in Malawi.* Working Paper. AgEcon. https://doi.org/10.22004/ag.econ.338590.

Mutuku, K. V., A. W. Mukhebi, M. A. Orinda, and C. M. Tanga. 2022. "Determinants of Profitability of Black Soldier Fly Farming Enterprise in Kenya." *Journal of Insects as Food and Feed* 8 (6): 693–704. https://doi.org/10.3920/JIFF2021.0066.

Nadeau, Luc, Isaac Nadeau, Frank Franklin, and Florence Dunkel. 2015. "The Potential for Entomophagy to Address Undernutrition." *Ecology of Food and Nutrition* 54 (3): 200–208. https://doi.org/10.1080/03670244.2014.930032.

Ndambi, A. O., K. Soma, A. N. Gitari, B. Obwanga, and E. Rurangwa. 2025. "Awareness, Challenges and Prospects of Using Black Soldier Fly Larvae (BSFL) in Animal Feeding by Smallholders in Nyeri County, Kenya." *Journal of Insects as Food and Feed* 12 (2): 223–238. https://doi.org/10.1163/23524588-bja10267.

Niassy, S., E. R. Omuse, N. Roos, et al. 2022. "Safety, Regulatory and Environmental Issues Related to Breeding and International Trade of Edible Insects in Africa." *Revue Scientifique et Technique (International Office of Epizootics)* 41 (1): 117–31. https://doi.org/10.20506/rst.41.1.3309.

Niermans, K., E. F. Hoek-Van Den Hil, H. J. van Der Fels-Klerx, and J. J. A. Van Loon. 2024a. "The Role of Larvae of Black Soldier Fly and House Fly and of Feed Substrate Microbes in Biotransformation of Aflatoxin B1." *Ecotoxicology and Environmental Safety* 279 (July): 116449. https://doi.org/10.1016/j.ecoenv.2024.116449.

Niermans, K., E. F. Hoek-van den Hil, R. van Dam, H. J. van der Fels-Klerx, and J. J. A. van Loon. 2023. "Effects of the Mycotoxins Aflatoxin B1, Deoxynivalenol and Zearalenone on Survival, Biomass and Toxin Accumulation in Musca Domestica Larvae." *World Mycotoxin Journal* 16 (4): 349–360. https://doi.org/10.1163/18750796-20222826.

Niermans, K., S. P. Salari, J. Carney, E. F. Hoek-van Den Hil, H. J. Van Der Fels-Klerx, and J. J. A. Van Loon. 2024b. "Bioconversion of Aflatoxin-Contaminated Groundnut Press Cake by Larvae of Black Soldier Fly *Hermetia illucens* Results in a Complete Mass Balance for Aflatoxin B1." *Npj Science of Food* 8 (1): 103. https://doi.org/10.1038/s41538-024-00351-1.

Nishimwe, Kizito, Erin Bowers, Jean de Dieu Ayabagabo, Richard Habimana, Samuel Mutiga, and Dirk Maier. 2019. "Assessment of Aflatoxin and Fumonisin Contamination and Associated Risk Factors in Feed and Feed Ingredients in Rwanda." *Toxins* 11 (5): 270. https://doi.org/10.3390/toxins11050270.

Nyamuhirwa, Dieu-Merci Akonkwa, Shiferaw Feleke, Paul-Martin Dontsop Nguezet, et al. 2025. "Perspectives on the Adoption of Black-Soldier Fly Larvae for Animal Feed among Livestock Farmers in Sub-Saharan Africa." *Frontiers in Environmental Economics* 4 (February). https://doi.org/10.3389/frevc.2025.1519767.

Nyamuhirwa, Dieu-Merci Akonkwa, Feleke Shiferaw, Mawufe Komi Agbodzavu, et al. 2026. "Understanding the Role of Institutional Arrangements on Innovation Adoption in Sub-Saharan Africa—a Case Study of Black Soldier Fly Frass." *Q Open* 6 (1): qoag002. https://doi.org/10.1093/qopen/qoag002.

Ogbon, E. A., D. Dzepe, C. Lalander, et al. 2025. "Risk Assessment of Black Soldier Fly (*Hermetia illucens* (L.), Diptera: Stratiomyidae) Larvae Composting for Circular Waste Management in Southern Benin." *Journal of Insects as Food and Feed* 11 (8). https://doi.org/10.1163/23524588-00001344.

Ogello, Erick O., Nicholas O. Outa, Mavindu Muthoka, Fredrick Juma, and Jan Hoinkis. 2025. "Optimizing Black Soldier Fly (*Hermetia illucens*) Production: Effects of Substrate Variation on Biomass, Nutritional Quality, Hatchability, Fecundity, and Frass Quality." *Frontiers in Sustainable Food Systems* 9 (July). https://doi.org/10.3389/fsufs.2025.1621034.

Okeyo, Nicky O., Cecilie E. Wille, Samuel M. Kiiru, et al. 2026. "Effect of Edible Cricket Enriched Complementary Porridge and Nutrition Education on Linear Growth of Children 6–14 Months in Siaya County, Kenya: A Randomized 2 × 2 Factorial Trial." *Maternal & Child Nutrition* 22 (1): e70156. https://doi.org/10.1111/mcn.70156.

Omondi, Elvis, Margret W. Ngigi, and Joel O. Khobondo. 2025. "Technical, Allocative, and Economic Efficiency and Profitability of Black Soldier Fly Farming Among Smallholder Farmers in Selected Counties in Kenya." *Journal of Agricultural Science* 17 (10): p79. https://doi.org/10.5539/jas.v17n10p79.

Onsongo, V. O., I. M. Osuga, C. K. Gachuiri, et al. 2018. "Insects for Income Generation Through Animal Feed: Effect of Dietary Replacement of Soybean and Fish Meal With Black Soldier Fly Meal on Broiler Growth and Economic Performance." *Journal of Economic Entomology* 111 (4): 1966–73. https://doi.org/10.1093/jee/toy118.

Opare, L. O., S. Holm, and T. Esperk. 2024. "Interaction Effects of Substrate Fermentation and Larval Density on Black Soldier Fly Life-History Traits." *Journal of Insects as Food and Feed* 10 (12): 2047–2058. https://doi.org/10.1163/23524588-00001188.

Ouma, Emily, Ben Lukuyu, and Julius Githinji. 2025. *Platform for Alternative Feed Ingredients Evaluation (PAFIE) - Black Soldier Fly Larvae (BSFL) in Kenya. Inception Workshop Report.* ILRI.

Peguero, Daniela A., Moritz Gold, Laura Velasquez, Mutian Niu, Christian Zurbrügg, and Alexander Mathys. 2024. "Physical Pretreatment of Three Biowastes to Improve Black Soldier Fly Larvae Bioconversion Efficiency." *Waste Management* 178 (April): 280–91. https://doi.org/10.1016/j.wasman.2024.02.012.

Purschke, Benedict, Rafaela Scheibelberger, Sonja Axmann, Andreas Adler, and Henry Jäger. 2017. "Impact of Substrate Contamination with Mycotoxins, Heavy Metals and Pesticides on the Growth Performance and Composition of Black Soldier Fly Larvae (*Hermetia illucens*) for Use in the Feed and Food Value Chain." *Food Additives & Contaminants: Part A* 34 (8): 1410–20. https://doi.org/10.1080/19440049.2017.1299946.

Raheem, Dele, Conrado Carrascosa, Oluwatoyin Bolanle Oluwole, et al. 2019. "Traditional Consumption of and Rearing Edible Insects in Africa, Asia and Europe." *Critical Reviews in Food Science and Nutrition* 59 (14): 2169–88. https://doi.org/10.1080/10408398.2018.1440191.

Rakotondrasoa, J. F., T. Ramiadantsoa, L. J. Becker, et al. 2024. "Education: An Efficient Tool to Increase the Willingness of Children to Consume Farmed Crickets in Madagascar." *Journal of Insects as Food and Feed* 11 (3): 455–468. https://doi.org/10.1163/23524588-00001130.

Ramiadantsoa, Tanjona, Anthonely Amady, Marc Philippart, Marcellio Tombozara, Vincent Lucas, and Brian L. Fisher. 2026. "Optimizing Black Soldier Fly Frass Fertilizer Rates for Maize and Soybean Production in Madagascar." *PLOS ONE* 21 (5): e0343378. https://doi.org/10.1371/journal.pone.0343378.

Rawski, Mateusz, Jan Mazurkiewicz, Bartosz Kierończyk, and Damian Józefiak. 2020. "Black Soldier Fly Full-Fat Larvae Meal as an Alternative to Fish Meal and Fish Oil in Siberian Sturgeon Nutrition: The Effects on Physical Properties of the Feed, Animal Growth Performance, and Feed Acceptance and Utilization." *Animals* 10 (11): 2119. https://doi.org/10.3390/ani10112119.

Rebora, Marco, Gianandrea Salerno, Silvana Piersanti, et al. 2023. "The Armoured Cuticle of the Black Soldier Fly *Hermetia illucens*." *Scientific Reports* 13: 22101. https://doi.org/10.1038/s41598-023-49549-5

RefIPro. 2026. *Final Project Evaluation: Refugee Insect Production for Food and Feed (RefIPro).* Internal evaluation report. RAISE, MAMAH, and Bobo Eco Farm.

Rehman, Kashif ur, Clemens Hollah, Karin Wiesotzki, et al. 2023. "Black Soldier Fly, *Hermetia illucens* as a Potential Innovative and Environmentally Friendly Tool for Organic Waste Management: A Mini-Review." *Waste Management & Research* 41 (1): 81–97. https://doi.org/10.1177/0734242X221105441.

Ribeiro, José Carlos, Luís Miguel Cunha, Bernardo Sousa-Pinto, and João Fonseca. 2018. "Allergic Risks of Consuming Edible Insects: A Systematic Review." *Molecular Nutrition & Food Research* 62 (1): 1700030. https://doi.org/10.1002/mnfr.201700030.

Ricardo. 2025. *Life Cycle Assessment of UK Insect Protein Production Processes for Pig and Poultry Feed.* Project Report. UK Department for Environment, Food and Rural Affairs (Defra). https://sciencesearch.defra.gov.uk/ProjectDetails?ProjectId=21021.

Roffeis, Martin, Maureen Elizabeth Wakefield, Joana Almeida, et al. 2018. "Life Cycle Cost Assessment of Insect Based Feed Production in West Africa." *Journal of Cleaner Production* 199 (October): 792–806. https://doi.org/10.1016/j.jclepro.2018.07.179.

Rummel, Pauline Sophie, Lukas Beule, Michael Hemkemeyer, Sanja Annabell Schwalb, and Florian Wichern. 2021. "Black Soldier Fly Diet Impacts Soil Greenhouse Gas Emissions From Frass Applied as Fertilizer." *Frontiers in Sustainable Food Systems* 5 (August). https://doi.org/10.3389/fsufs.2021.709993.

Rumpold, Birgit A., and Oliver K. Schlüter. 2013. "Nutritional Composition and Safety Aspects of Edible Insects." *Molecular Nutrition & Food Research* 57 (5): 802–23. https://doi.org/10.1002/mnfr.201200735.

Samson, William, Jaden Kim, Hewitt Plunkett, et al. 2025. "A Steady-State System for Farming Black Soldier Flies to Convert Agri-Food Waste into Frass and Other Value-Added Products." *Waste Management* 206 (September): 115073. https://doi.org/10.1016/j.wasman.2025.115073.

Schönfeldt, Hettie Carina, and Nicolette Gibson Hall. 2012. "Dietary Protein Quality and Malnutrition in Africa." *The British Journal of Nutrition* 108 Suppl 2 (August): S69–76. https://doi.org/10.1017/S0007114512002553.

Senerwa, D. M., A. J. Sirma, N. Mtimet, et al. 2016b. "Prevalence of Aflatoxin in Feeds and Cow Milk from Five Counties in Kenya." *African Journal of Food, Agriculture, Nutrition and Development* 16 (3): 11004–21. https://doi.org/10.18697/ajfand.75.ILRI04.

Shi, Chaohong, Penghao Xie, Zhexu Ding, et al. 2024. "Inhibition of Pathogenic Microorganisms in Solid Organic Waste via Black Soldier Fly Larvae-Mediated Management." *Science of The Total Environment* 913 (February): 169767. https://doi.org/10.1016/j.scitotenv.2023.169767.

Shumo, Marwa, Isaac M. Osuga, Fathiya M. Khamis, et al. 2019. "The Nutritive Value of Black Soldier Fly Larvae Reared on Common Organic Waste Streams in Kenya." *Scientific Reports* 9 (1): 10110. https://doi.org/10.1038/s41598-019-46603-z.

Siddiqui, Shahida Anusha, Özge Süfer, Gülşah Çalışkan Koç, et al. 2025. "Enhancing the Bioconversion Rate and End Products of Black Soldier Fly (BSF) Treatment: A Comprehensive Review." *Environment, Development and Sustainability* 27: 9673–9741. https://doi.org/10.1007/s10668-023-04306-6.

Sirma, A. J., J. F. Lindahl, K. Makita, et al. 2018. "The Impacts of Aflatoxin Standards on Health and Nutrition in Sub-Saharan Africa: The Case of Kenya." *Global Food Security* 18: 57–61. https://doi.org/10.1016/j.gfs.2018.08.001.

Smith, Matthew R., and Samuel S. Myers. 2018. "Impact of Anthropogenic CO2 Emissions on Global Human Nutrition." *Nature Climate Change* 8 (9): 834–39. https://doi.org/10.1038/s41558-018-0253-3.

Smith, Matthew R., Valerie J. Stull, Jonathan A. Patz, and Samuel S. Myers. 2021. "Nutritional and Environmental Benefits of Increasing Insect Consumption in Africa and Asia." *Environmental Research Letters* 16 (6): 065001. https://doi.org/10.1088/1748-9326/abf06c.

Sogari, G., S. Bellezza Oddon, L. Gasco, A. van Huis, T. Spranghers, and S. Mancini. 2023. "Review: Recent Advances in Insect-Based Feeds: From Animal Farming to the Acceptance of Consumers and Stakeholders." *Animal* 17 (June): 100904. https://doi.org/10.1016/j.animal.2023.100904.

Solofondranohatra, Cédrique L., Clarcky Andrianorosoa Ony, Sakib Burza, and Brian L. Fisher. 2025a. "Preliminary Field Evaluation of Black Soldier Fly Frass as an Organic Fertilizer on Maize (Zea Mays L.) Growth and Yield in Southeastern Madagascar." *Frontiers in Sustainable Food Systems* 9 (October): 1673188. https://doi.org/10.3389/fsufs.2025.1673188.

Solofondranohatra, Cédrique L., Tanjona Ramiadantsoa, Sylvain Hugel, and Brian L. Fisher. 2025b. "Black Soldier Fly Frass Fertilizer Outperforms Traditional Fertilizers in Terms of Plant Growth in Restoration in Madagascar." *Sustainability* 17 (15): 7152. https://doi.org/10.3390/su17157152.

Spranghers, Thomas, Matteo Ottoboni, Cindy Klootwijk, et al. 2017. "Nutritional Composition of Black Soldier Fly (*Hermetia illucens*) Prepupae Reared on Different Organic Waste Substrates." *Journal of the Science of Food and Agriculture* 97 (8): 2594–600. https://doi.org/10.1002/jsfa.8081.

Spranghers, Thomas, Joris Michiels, Joachim Vrancx, et al. 2018. "Gut Antimicrobial Effects and Nutritional Value of Black Soldier Fly (*Hermetia illucens* L.) Prepupae for Weaned Piglets." *Animal Feed Science and Technology* 235: 33–42. https://doi.org/10.1016/j.anifeedsci.2017.08.012.

Stull, Valerie J., Elijah Finer, Rachel S. Bergmans, et al. 2018. "Impact of Edible Cricket Consumption on Gut Microbiota in Healthy Adults, a Double-Blind, Randomized Crossover Trial." *Scientific Reports* 8 (1): 10762. https://doi.org/10.1038/s41598-018-29032-2.

Stull, Valerie J., and Tiffany L. Weir. 2023. "Chitin and Omega-3 Fatty Acids in Edible Insects Have Underexplored Benefits for the Gut Microbiome and Human Health." *Nature Food* 4 (4): 283–87. https://doi.org/10.1038/s43016-023-00728-7.

Suo, Jianghua, Tingting Liang, Haixu Zhang, et al. 2023. "Characteristics of Aflatoxin B1 Degradation by Stenotrophomonas Acidaminiphila and It's Combination with Black Soldier Fly Larvae." *Life* 13 (1): 234. https://doi.org/10.3390/life13010234.

Sustainable Manufacturing and Environmental Pollution Programme. 2024. "Can Cities in East Africa Become Zero-Waste? An Innovative Partnership Model Shows a Route to Achieve This." London and Geneva, November 23. https://smepprogramme.org/can-cities-in-east-africa-become-zero-waste-an-innovative-partnership-model-shows-a-route-to-achieve-this/.

Tambeayuk, Marykathleen Agbornawbi, Olalekan J. Taiwo, and Marc Anselme Kamga. 2025. "The Economic Viability and Social Acceptability of Black Soldier Fly Larvae Frass as a Substitute for Chemical Fertiliser in Agriculture in Cameroon." *African Journal of Environment and Natural Science Research* 8 (1): 216–35. https://doi.org/10.52589/AJENSR-F8PPDQZT.

Tan, Hui Shan Grace, Arnout R. H. Fischer, Patcharaporn Tinchan, Markus Stieger, L. P. A. Steenbekkers, and Hans C. M. van Trijp. 2015. "Insects as Food: Exploring Cultural Exposure and Individual Experience as Determinants of Acceptance." *Food Quality and Preference* 42 (June): 78–89. https://doi.org/10.1016/j.foodqual.2015.01.013.

Tanga, C. M., D. Beesigamukama, M. Kassie, et al. 2022. "Performance of Black Soldier Fly Frass Fertiliser on Maize (Zea Mays L.) Growth, Yield, Nutritional Quality, and Economic Returns." *Journal of Insects as Food and Feed* 8 (2): 185–196. https://doi.org/10.3920/JIFF2021.0012.

Traoré, Ousmane, Paul Alhassan Zaato, Jessica Kukua Baidoo, et al. 2024. "Willingness of West African Consumers to Buy Food Produced Using Black Soldier Fly Larvae and Frass." *Foods* 13 (17): 2825. https://doi.org/10.3390/foods13172825.

Udomkun, Patchimaporn, Alexander Nimo Wiredu, Marcus Nagle, Ranajit Bandyopadhyay, Joachim Müller, and Bernard Vanlauwe. 2017. "Mycotoxins in Sub-Saharan Africa: Present Situation, Socio-Economic Impact, Awareness, and Outlook." *Food Control* 72 (February): 110–22. https://doi.org/10.1016/j.foodcont.2016.07.039.

UNICEF/WHO/World Bank Group. 2025. *Levels and Trends in Child Malnutrition: UNICEF/WHO/World Bank Group Joint Child Malnutrition Estimates: Key Findings of the 2025 Edition.* https://www.who.int/publications/i/item/9789240112308.

United Nations, Department of Economic and Social Affairs. 2024. *World Population Prospects 2024.* United Nations. https://www.un.org/en/global-issues/population.

United Nations Environment Programme. 2024. *Food Waste Index Report 2024: Think Eat Save – Tracking Progress to Halve Global Food Waste.* https://repository.gheli.harvard.edu/repository/13851/.

Valdés, Fabrizzio, Valeria Villanueva, Emerson Durán, et al. 2022. "Insects as Feed for Companion and Exotic Pets: A Current Trend." *Animals* 12 (11): 1450. https://doi.org/10.3390/ani12111450.

Verner, Dorte, Line Kristel Astrom, Maximillian Ashwill, et al. 2022. *Insect Farming to Reduce Hunger Risk in South Sudan: Lessons from Small-Scale Black Soldier Fly Production Pilots.* Washington, DC: World Bank.

Verner, Dorte, Nanna Roos, Afton Halloran, et al. 2021. *Insect and Hydroponic Farming in Africa: The New Circular Food Economy.* Washington, DC: World Bank. https://doi.org/10.1596/978-1-4648-1766-3.

Vernooij, A. G., and T. Veldkamp. 2019. *Insects for Africa: Developing Business Opportunities for Insects in Animal Feed in Eastern Africa.* Wageningen Livestock Research. https://doi.org/10.18174/470617.

Vita, Alexandra Adorno, Shihning Teo, Christine Murphy, et al. 2025. "Safety, Tolerability, and Preliminary Effects of Cricket Chitin for Adults with IBS: A Double-Blind Randomized Crossover Pilot Trial." *Food & Function* 16 (18): 7434–54. https://doi.org/10.1039/D5FO01540E.

Vodounnou, Juste Vital, Victor Dossa, Carmel Djissou, et al. 2024. "Feeding Optimization of Water Hyacinth (Eichhornia Crassipes) Leaves as Rearing Substrate for the Production of Black Soldier Fly (*Hermetia illucens*) Larvae." *Waste and Biomass Valorization* 15 (6): 3569–78. https://doi.org/10.1007/s12649-023-02408-w.

Waithaka, Mwangi K., Isaac M. Osuga, Lucy W. Kabuage, et al. 2022. "Evaluating the Growth and Cost–Benefit Analysis of Feeding Improved Indigenous Chicken with Diets Containing Black Soldier Fly Larva Meal." *Frontiers in Insect Science* 2 (September). https://doi.org/10.3389/finsc.2022.933571.

Yakti, Wael, Simon Schulz, Virginia Marten, et al. 2022. "The Effect of Rearing Scale and Density on the Growth and Nutrient Composition of *Hermetia illucens* (L.) (Diptera: Stratiomyidae) Larvae." *Sustainability* 14 (3): 1772. https://doi.org/10.3390/su14031772.

Yildirim-Aksoy, Mediha, Rashida Eljack, and Benjamin H. Beck. 2020. "Nutritional Value of Frass from Black Soldier Fly Larvae, *Hermetia illucens*, in a Channel Catfish, Ictalurus Punctatus, Diet." *Aquaculture Nutrition* 26 (3): 812–19. https://doi.org/10.1111/anu.13040.

Young, Wayne, Sai Krishna Arojju, Mark R. McNeill, et al. 2020. "Feeding Bugs to Bugs: Edible Insects Modify the Human Gut Microbiome in an in Vitro Fermentation Model." *Frontiers in Microbiology* 11 (July). https://doi.org/10.3389/fmicb.2020.01763.

Zhang, Jie, Xuelian Xu, Chunyan Tang, et al. 2025. "Toxicokinetics and Tissue Dynamics Approaches to Evaluate the Accumulation and Elimination of Cadmium in Black Soldier Fly Larvae." *Ecotoxicology and Environmental Safety* 289: 117481. https://doi.org/10.1016/j.ecoenv.2024.117481.

# Chapter 2. BSF Farming in Practice

**This chapter examines whether the biological and contextual case for BSF farming can be translated into viable operations.** It shifts from what BSF can do to what BSF farms require to work in practice. The chapter assesses the conditions that shape viability: substrate access and cost, labor efficiency, operator capability, market demand, product strategy, infrastructure, climate exposure, financing, regulation, and disciplined learning before scaling. It uses African operational evidence and case studies to compare household, hybrid, and centralized models, with detailed attention to Madagascar because it offers some of the clearest evidence on how different BSF models function under real production conditions.

**The chapter has four main sections, with boxes and case studies supporting each part of the analysis.** Section 2.1, Conditions for Viability, examines the technical, environmental, economic, and management conditions that determine whether BSF operations can work. It focuses on production costs, substrate strategy, operator capability, business planning, labor efficiency, rearing frameworks, and product diversification. Section 2.2, Farming Scenarios, compares household-scale production, hybrid hub-and-spoke systems, and medium- to large-scale centralized facilities. It also examines large-scale failures, environmental evidence, biodiversity and biosecurity risks, financing requirements, and the importance of matching each model to its context. Section 2.3, Black Soldier Fly Production in Madagascar: Two Models, Shared Lessons, presents detailed cases of EXA Feed and BSF Tamatave to show how different models can emerge from different starting conditions. Section 2.4, Pathways Forward, draws lessons across the African evidence base and identifies the shared discipline that successful BSF operations require.

**Overall, the chapter finds that BSF viability in Africa is decided less by biological optimization than by whether the operation is well run and well matched to its context.** Biology is necessary, and a poorly run colony fails on its own terms, but strong biology cannot rescue an operation whose substrate is too costly, whose market is too thin, or whose model does not fit local conditions. The evidence shows that BSF farming can work under African conditions, but only when the production model fits the substrate base, market structure, operator capability, financing horizon, and local climate risks**.** Household systems appear most credible as cost-reduction and farm-integration tools. Hybrid systems can reduce the technical burden on small producers, but depend on reliable hubs, trust, logistics, and a sustainable business model for biological inputs. Centralized systems can reach formal markets and process larger waste streams, but they carry higher capital, infrastructure, and concentration risks. The Madagascar cases show two credible but non-interchangeable pathways: one built around planned industrial scale, secured substrate, off-grid energy, and formal data systems; the other built around frugal entry, local experimentation, partnership, and gradual expansion. The chapter does not present BSF as a single model ready for rollout. It argues that BSF farming can become viable when projects expand what they understand, not what they hope will work, and when model choice follows local conditions rather than external expectations.

## 2.1 Conditions for Viability

**BSF farming viability depends on an understanding of biological, technical, environmental, and economic factors**. Setting up a BSF farm requires careful consideration of several interdependent factors: the biological capability to run production reliably, infrastructure, the local environment, access to low-cost

or free organic feed inputs, and the presence of a viable market for larvae and frass. None of these factors are individually decisive, but a serious weakness in any one of them can undermine an operation that performs well on all the others. How these factors interact across the climatic, infrastructural, and socio-economic conditions of African BSF production remains insufficiently understood. The BUGS Africa project, profiled later in this section (Box 2.3), illustrates one structured approach to navigating these interdependencies through staged feasibility assessment, piloting, and scaling.

## Working biology is necessary but not sufficient

**The most important early question for any BSF operation is: what does local production actually cost, and is there a buyer willing to pay that price?** A pilot phase can help answer that question with locally grounded data, before committing capital to larger infrastructure. Bioconvision Ltd. near Jinja, Uganda, followed this sequence explicitly, running as a research pilot from 2023 before transitioning to commercial-scale operations in October 2025, and is described in Box 2.1.

**Substrate costs determine BSF production's economic viability.** A complete picture of production costs in labor, energy, rent, and consumables alongside substrate — and the relative weight of these cost categories — depends heavily on substrate access. In scenarios where producers must purchase and transport substrate, Beesigamukama et al. (2022) found that the rearing substrate, including its purchase and transport, accounted for 81–90% of total BSF production costs in Kenyan operations. Where substrate is available at low or zero cost — the more typical smallholder situation — labor becomes the dominant constraint. Labor therefore dominates day-to-day operating costs in most smallholder operations, but substrate strategy is what determines whether the enterprise is viable at all. A farm can optimize its labor and still fail if feedstock is unreliable, expensive, or contested.

## Operator capability cannot be assumed

**Reliable BSF production is a skill, not a default, and acquiring it is one of the harder parts of the enterprise.** The biology is well described in published protocols (see Dortmans et al. 2021), but turning those protocols into a colony that performs consistently, through local heat, variable substrate, and disease pressure, takes genuine expertise built over repeated production cycles, and this requirement scales with the operation: a household producer managing a few bins can learn by doing and absorb mistakes cheaply, while a larger facility cannot, because at that scale a colony failure is an existential event rather than a lesson. Underestimating this requirement is itself one of the most common, and most preventable, causes of failure. Where projects work with existing operators rather than building from scratch, technical capacity must therefore be verified at entry and actively sustained throughout implementation. Placing a specialist or delivering training does not guarantee results. Overstated operator capability is a well-documented failure mode in insect farming. Three patterns recur in unsuccessful BSF production: operations that are genuinely new and have not yet closed a single production cycle; farms where prior recognition or funding is mistaken for demonstrated capability, with no data to substantiate results; and external consultants whose own training, whether in business or biology, is inadequate for the specific demands of commercial BSF production. A fourth recurring pattern in BSF projects is the departure of a key technical resource mid-implementation, a specialist whose contract ends, a trained operator who resettles or finds other work, without adequate handover, leaving beneficiaries without guidance precisely when operations are becoming complex enough to require it. What these patterns share is a shortfall in biological command: in each, the

operation lacks someone who can actually run the colony reliably under local conditions. Failure is often read afterward as a management or funding problem, but at its root it is biological.

**Box 2.1: Bioconvision Ltd. — BSF production in Uganda**

Bioconvision (Uganda) Ltd. produces fresh BSF larvae, dried larvae, and insect frass from segregated organic waste streams, supplying livestock farmers and crop producers. The project began as a research and pilot activity in 2023, with a commercial-scale waste treatment facility commissioned in October 2025 near Jinja, Eastern Uganda.

The initiative developed within the Sustainable Waste-based Insect Farming Technologies (SWIFT) project, a transdisciplinary research program funded by the Swiss National Science Foundation and Swiss Development Cooperation. In Uganda, the project combined socio-economic and technical research by Makerere University and Eawag with technical support from Eclose for the construction and operation of the Bioconvision facility.

The facility employs over 40 people across the value chain, including waste collection, processing, and facility operations. It generates additional income for external actors: poultry, pig, and fish farmers, who use larvae as a cost-effective protein source; fishermen harvesting water hyacinth; crop farmers, who apply frass to improve soil fertility; and waste collectors and suppliers, who gain income opportunities through organized organic waste supply chains. By the end of 2025, the facility treated 4–6 tons of organic waste per day, achieving approximately 12% conversion into insect-based feed and 18% conversion into organic fertilizer.

Bioconvision's experience highlights:

- **Start small and scale gradually:** Pilot systems allow technical learning before investing in large-scale infrastructure.
- **Secure reliable raw materials early:** Access to consistent waste streams is essential for stable production.
- **Invest in people:** Skilled and motivated staff are critical to maintaining production quality.
- **Engage customers early:** Demonstration trials and transparent communication help build trust in new products.
- **Adapt technology to local realities:** Robust, practical systems often outperform complex solutions in resource-constrained environments.

The Bioconvision case highlights that successful BSF implementation depends not only on biological performance but on alignment with the enabling environment. The experience suggests that securing reliable substrates, understanding regulatory requirements early, and building strong local partnerships are key for long-term viability.

*Source: Konstantin von Hörner, Bioconvision Ltd., Uganda; Stefan Diener, Eclose GmbH.*

**Launching before fully understanding local conditions is a common project design error, and the conditions most often underestimated are biological.** A related but distinct failure is the assumption that biological production methods are mature and ready to deploy, when in practice they often require substantial site-specific adaptation. Pest pressure, ambient temperature and humidity, locally available feedstocks, and the practicalities of colony management all interact in ways that are difficult to predict from published protocols. Projects that build their logical frameworks around production targets without an explicit research and development phase tend to spend their implementation period working out methods

that the design assumed were already in hand. This is why demonstrated production capability, not just a production plan, should be a condition of financing for larger operations.

**Motivation cannot be assumed or instilled after selection**. Evidence from BSF projects in refugee and smallholder contexts suggests that selecting participants based on vulnerability or need, rather than pre-existing interest in the work itself, consistently produces poor outcomes. In many such cases, beneficiaries expect quick returns, disengage when profits do not materialize, and treat the operation as a transfer rather than a business. Durable operations tend to grow from genuine prior interest, not from assignment.

## The business case

**Success depends on economics, competence, and motivation, all of which converge in a single document: the business case.** Production and retention targets are only as credible as the assumptions about the people meant to deliver them. Projects that enter implementation without a preliminary business case leave beneficiaries with production targets but without other important benchmarks: no defined break-even point, no minimum viable output threshold, and no honest reckoning of how many people a facility can actually support as a profitable business. The first questions to ask of any BSF project are therefore: what does this operation's own production data show, and has it been independently verified? Do the people running it actually want to be there? Does the business case reflect what this facility can realistically produce and support?

**Pricing deserves particular attention among the questions a business case must answer**. Early-stage operations frequently mispriced their products in ways that make the market access problem invisible until capital is committed. A farm-level survey across multiple African countries reported BSF larvae prices averaging around US$1.91 per kilogram dried, with a surveyed range of roughly US$0.60–2.64 (Verner et al. 2021), and field assessments of pilots in refugee settlements in Zimbabwe and Kenya found sundried larvae selling at US$1–2 per kilogram, against a global market average of around US$1.0 per kilogram for dried larvae (see chapter 4). Prices well above this range have been recorded at individual sites, but typically reflect specific institutional buyers rather than a broadly accessible market. Operations entering markets without a preliminary price benchmark — comparing against fishmeal, soybean meal, and the surveyed range for BSF larvae — risk setting prices that make their product commercially nonviable.

## Feed strategy shapes the economics

**The first strategic choice shapes everything that follows: is the operation built around waste or around commodity inputs?** In the first case, insects convert low-value residues — often free, sometimes available for a modest fee — into protein and fertilizer. Economic viability then follows from the gap between input cost and output value. In the second, commodity feedstocks are purchased in the expectation that insects will convert them more efficiently than conventional livestock. The resulting business competes directly against mature livestock and aquaculture industries on conversion efficiency. The environmental case is stronger for the first model, as are the economics for most smallholder and mid-scale operations.

**Starting with agro-industrial or institutional waste reduces preparation burden and improves consistency.** Among waste inputs, source type matters as much as price. A feasibility study across five Ethiopian cities found that waste from hotels, restaurants, and agro-processing facilities — already

separated, available in consistent quantities, and on regular schedules — was substantially cleaner than mixed municipal streams (Chaix-Bar et al. 2023). Mixed municipal waste in the same cities was roughly 70% organic in principle but arrived unsorted, combined with plastics, paper, and other non-organic material.

**Free waste does not always stay free.** For example, ruminant and poultry producers in many markets are purchasing brewery by-products for direct use as animal feed. A BSF operation targeting the same stream would therefore face purchase prices and competition rather than a free input (Chaix-Bar et al. 2023). A free or low-cost waste stream can become a priced input faster than project planners expect, as competing buyers enter the market. Site selection decisions made based on substrate availability at one point in time may need reconsideration as the sector matures. The *Farming Scenarios* section below examines the strategic case for agro-industrial co-location, securing substrate relationships before they become contested.

**Some producers gain revenue from accepting substrate as waste-management providers although this is currently uncommon in Africa.** A further point on the spectrum deserves brief attention. In some markets, primarily the UK, EU, Australia, and parts of the Middle East, organic waste generators pay tipping fees to dispose of their waste, driven by binding landfill diversion regulations and the high cost of conventional alternatives such as anaerobic digestion and incineration. Where such fees exist, BSF operations positioned as waste-management service providers rather than protein producers can collect a per-ton gate fee for accepting waste, making substrate a negative-cost input. This model, described by some commercial operators as Insect Waste Management (Kotch 2026), depends on a regulatory and pricing environment in which waste disposal is expensive enough for the generator that paying a BSF operator to take it is cheaper than the alternatives. That precondition does not currently hold across most African contexts, where organic waste disposal is typically informal, unpriced, or cheaper than any formal alternative. The closest precedents are municipally mandated organic waste separation systems in China (from 2019) and South Korea (volume-based fee system, from 2013), where policy created organized waste streams and the regulated diversion architecture that, over time, can support tipping-fee economics (see chapter 3). Whether comparable arrangements emerge in African cities will depend on the trajectory of waste-management policy and the formalization of organic waste streams, both of which remain at early stages on the continent.

## Labor efficiency must be designed in

**The evidence base on labor costs is small and geographically uneven, but points toward labor as a significant cost.** Profitability and feasibility studies from East Africa include cost estimates, but granular breakdowns of labor as a share of total operating costs from observed commercial operations on the continent remain scarce in the published literature. With that caveat, the available evidence consistently points to labor as a significant cost driver. The most relevant evidence comes from West Africa, where a life cycle cost analysis grounded in real rearing trial data found labor accounting for between 42% and 67% of total operating costs depending on system design (Roffeis et al. 2018), though the analysis modeled production systems ex ante rather than measuring smallholder operations directly. A broader review of the available literature, drawing on pilot facilities in Indonesia and modeled plants in Costa Rica, finds a range of 30% to 65%, with variation driven largely by scale and degree of automation (Joly and Nikiema 2019). Field evidence across 373 BSF farmers in Kenya provides a different angle: average economic efficiency

stood at 40%, indicating that most farmers had substantial room to reduce their production costs by adjusting how they used and combined inputs (Omondi et al. 2025).

**Labor cost estimates should be interpreted with care.** Cross-study labor accounting conventions vary widely across the literature, a problem covered in detail in the *African Setting and Scaling* section above. The figures also assume labor is priced at market rates. Smallholder operations relying on family labor may record no cash labor cost at all, which can make benefit-cost ratios look favorable, but obscures the opportunity cost of household time. The labor pricing assumption in any feasibility assessment is therefore consequential and should be stated outright. Switching from family to hired labor, or properly imputing family labor at its opportunity cost, can shift a viable enterprise into marginal or loss-making territory without any change in biological performance.

**Labor effort devoted to waste preparation is a cost variable.** For example, the effort of sorting incoming waste is routinely underestimated. Where organic waste arrives unsorted — mixed with plastics, packaging, and non-organic material, as is typical when sourced from markets or municipal streams — sorting before feeding can be unavoidable and time-consuming, with mechanization rarely viable at small scale. This cost is rarely accounted for in project budgets or feasibility assessments, and it scales with ambition: the larger the waste volume processed, the larger the sorting burden. Operations that can source pre-sorted waste, negotiate sorting at the point of collection, or situate themselves at waste streams that require minimal preparation — a brewery, a food processing facility, a fish market — carry a structurally lower labor burden than those that cannot, independent of any other efficiency measure. This reinforces the earlier point: substrate strategy is a labor question as much as a feedstock question, and the two must be resolved together in project design. Hydro Victoria's training network in Western Kenya, with over 3,000 active producers sourcing organic waste from local markets, illustrates one operational answer at scale (Box 2.2).

**Waste acquisition is another source of production cost.** Field assessments of BSF pilots in East African refugee settlements document one approach: rotating groups of beneficiaries contracted to collect and deliver organic waste at a fixed price per kilogram, in the Dadaab refugee pilot, KES 16 per kilogram (roughly US$0.12 per kilogram, see chapter 4). Similar arrangements have been used to integrate informal waste pickers into structured supply chains. These arrangements can serve community inclusion and substrate reliability simultaneously. In some contexts, adding labor for waste collection and delivery strengthens access to municipal waste streams by demonstrating local employment benefit (Diener and Storey 2025). Whatever the social value of these arrangements, however, the payment is a production cost. Operations that rely on donor financing to cover waste collection face the same sustainability question as any other subsidized input: whether the business model can absorb it once external support phases out. Free substrate, meanwhile, can carry its own hidden costs. In Jamjang, South Sudan, production groups negotiated directly with municipal waste collectors, local cafeterias, and market vendors to have organic material diverted to the production sites. The arrangement cost no money but required institutional backing and a partner vehicle for collection and transport (Verner et al. 2022). The material itself was free; reliable access to it was not.

**Almost every BSF producer attempts to do every part of the process themselves, presenting market opportunities in some contexts.** Across BSF value chains in East Africa, most producers do it all: managing adult flies, mating, egg collection, nursery rearing, grow-out, drying, and often frass processing

within a single operation — a pattern that drives up labor costs while preventing the specialization that would allow any one function to be done well enough to compete in formal markets (Meerts et al. 2023). In a modeled commercial-scale BSF operation in Malawi, the nursery stages — brood establishment, adult maintenance, egg laying, and hatching — together accounted for roughly 52% of annual operating costs (Munthali et al. 2023). A pilot BSF facility in Indonesia found a comparable figure, with the nursery accounting for 44% of annual operating costs, of which 86% was labor alone (Caruso et al. 2013, as reported in Samson et al. 2025). These early stages of the fly's life cycle are the biological heart of the operation and also its dominant cost center. It is also the stage most dependent on expertise and consistent management attention. A producer purchasing young larvae from a specialist breeder and managing only grow-out would be operating a simpler, cheaper, and more reliable system. The persistence of full-cycle production reflects a market-structure constraint as much as a management preference: where reliable specialist suppliers of eggs or young larvae do not yet exist, producers have little choice. The development of a viable breeder tier is therefore both a labor reduction opportunity for grow-out operations and a sectoral efficiency gain that remains largely unrealized in East African markets. At the household level, full-cycle production is what makes entry possible, since there may be no budget for purchased inputs. The breeder-tier opportunity applies most directly to hybrid and centralized operations aiming to supply formal markets, where specialization yields real efficiency gains (discussed further in the *Farming Scenarios* section below).

**Box 2.2: Youths in Sustainable Aquaculture (YISA) — Black Soldier Fly Larvae production for cottage feed in Kenya**

The YISA project, funded by the Mastercard Foundation in western and coastal Kenya, is implemented by several partners including social enterprise Hydro Victoria

The project produces fresh BSF larvae, solar-dried BSF larvae processed into fish feed, and frass used as organic fertilizer. Since April 2024, Hydro Victoria has trained 4,574 youths (70.8% women, 2% persons with disabilities and internally displaced persons), of whom 3,212 have transitioned into active value chain roles — organic waste collection, BSF production, value addition, and circular cottage feed production — alongside over 3,000 indirect jobs from waste collection through transportation. Average production per farmer per month is 88 kg of wet BSF for on-farm and off-farm feed supplement, with each producer collecting approximately 440 kg of organic waste. Collectively, the project produces about 280 tons of wet BSF larvae and 200 tons of organic fertilizer per month, diverting approximately 1,400 tons of organic waste from dumpsites, landfills, and water ecosystems in the Lake Victoria region.

Project outcomes include increased awareness of BSF farming techniques among youths and the larger community, and the upcycling of significant volumes of organic waste into feed and fertilizer. The project has improved availability of BSF as an alternative protein, saving farmers US$2.9–4.3 per month, and has elicited interest among commercial and cottage feed millers, increasing demand for BSF meal as an alternative ingredient for fish feed. Value-added products include BSF-based super feed for growing tilapia and catfish. BSF-based feed reduces fish feed costs by 26% compared to commercial fish feed dependent on fishmeal and soy meal.

Challenges have included inadequate access and high cost of waste transportation, lack of value-addition equipment such as driers and oil presses, and cultural barriers such as stigma from those who confuse BSF larvae with housefly maggots.

*Source: Fredrick Juma, Hydro Victoria.*

**Producers should apply the principles of labor-efficient design within the constraints of market structure and biology.** The less the insects are handled, the lower the labor cost. Farms should minimize touchpoints wherever the biology allows. Each day and week should follow the same rhythm, with tasks standardized and evenly distributed across the production schedule. Without this discipline, production surges become unsustainable, creating labor spikes that erode the cost advantages BSF integration was meant to deliver. When bottlenecks emerge, anticipating constraints and testing solutions at small scale before they become crises is what allows operations to improve without losing the consistency they have already built.

**Disciplined, attentive management matters more in BSF than in most farming systems.** BSF colonies are not self-managing and their biology moves quickly. The same accelerated development that makes BSF attractive — a complete cycle possible within one month, with larvae doubling in size within days — means that problems scale at the same pace. Moisture imbalance, temperature stress, pest incursion, and substrate failure can develop and compound faster than infrequent monitoring may detect. The window between a manageable problem and a colony-level setback is often narrow.

## Rearing frameworks for smallholder operations

**Two recently published rearing frameworks attempt to reduce both the labor and monitoring burden at small scale.** The common thread across these approaches is that reducing operational complexity is likely to matter more for smallholder viability than optimizing biological yield. A system that produces slightly less but can be managed reliably with the expertise actually available on the ground will outperform a more sophisticated system whose demands exceed its operators' capacity. Both approaches below are, at their core, attempts to embody that principle.

**SIMBA offers full-cycle production and economic viability analysis tools, but its complexity poses trade-offs.** The SIMplified BSF Approach (SIMBA), developed by Eawag and Eclose (Diener et al. 2025a, 2025b), is designed around a two-day-per-week operator schedule. The authors document an operator time requirement of four to six hours per week to operate a paired reproduction and grow-out unit, processing around 250 kg of organic waste per week and producing 30–40 kg of fresh larvae, or 7–10 kg dried. The approach is accompanied by a cost model tool that operators can use to assess financial viability before committing to the system. The attractions are real: low labor hours, modest infrastructure, and modular architecture suited to side-business integration on an existing farm. The simplification is only partial, though. SIMBA still requires the operator to manage the full biological cycle — adult flies, mating, eggs, hatching, neonate handling, and grow-out — to a strict protocol. The challenges are concrete: reduced operator presence amplifies the consequences of poor hygiene; farmers accustomed to experience-based management struggle with the discipline the system demands; seasonal and climatic variation disrupts the protocol and requires active adaptation; and out-growers who attempt to operate their own reproduction facility before gaining adequate experience with the grow-out stage tend to fail.

**A complementary "steady state" design aims for equilibrium, showing success in controlled environments**. Samson et al. (2025) describe a "steady-state" system in which adults, larvae, and pupae coexist continuously in the same bioreactor space, eliminating the dedicated nursery infrastructure that accounts for 73% of initial investment in a conventional pilot facility (Caruso et al. 2013). Loading cycles are required only every four days. The steady-state design raises the possibility that once a biological

equilibrium is established, the system will require less ongoing biological monitoring beyond substrate management than batch systems do. If this holds under field conditions, it would address one of the most persistent barriers to smallholder adoption, the expertise and attention that biological monitoring demands. Two cautions apply: the transition to steady state is itself management-intensive, and the published results come from a controlled university setting in the United States. Field validation in African smallholder contexts is lacking.

**Box 2.3: BUGS Africa**

Biomass Utilization by Insects for Green Solutions in Africa (BUGS Africa) supports governments, municipalities, and entrepreneurs in Africa to enable the practical use of BSF technology to add economic value to organic waste. At present the project focuses on Uganda, Ethiopia, and Côte d'Ivoire, with interventions adapted to local climatic, institutional, economic, and social conditions. The emphasis is on operational feasibility and long-term viability rather than on promoting a single technical model. While individual BSF farms in the three focus countries have benefited from technical advice and tools, BUGS' broader focus is on setting the technical and institutional conditions for BSF to operate effectively at scale.

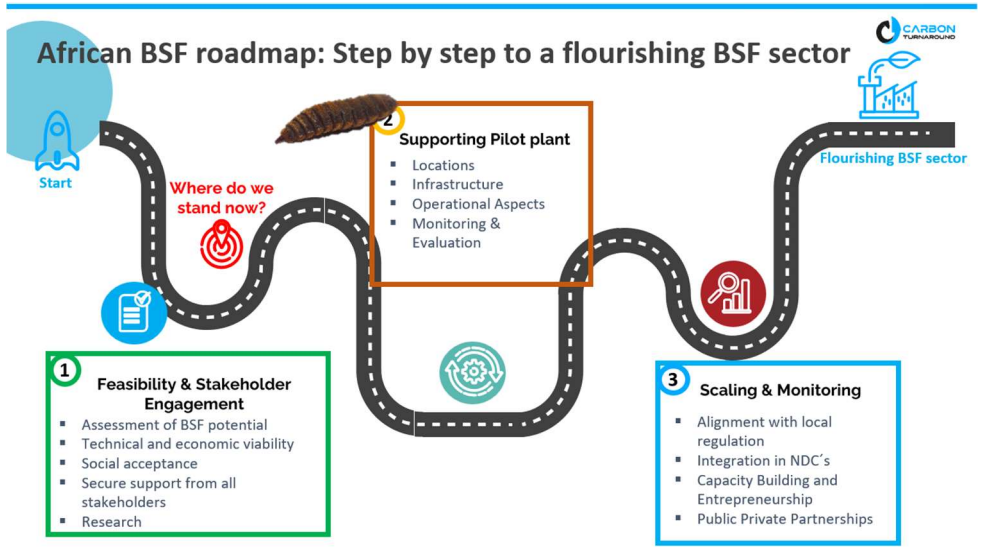
The project was developed by a group of PREVENT Waste Alliance members and is supported through seed funding from GIZ and a grant by the Climate and Clean Air Coalition (CCAC), with a focus on reducing methane emissions through context-appropriate BSF solutions.





BUGS Africa has generated a set of practical, transferable outputs that support both strategic planning and on-the-ground implementation of BSF systems:

- Policy Guide: a planning and decision-support guideline for policymakers and public authorities, outlining how BSF technology can be embedded in waste management and climate strategies.
- Practitioners Toolbox: an operational guideline for entrepreneurs, covering system design, implementation steps, and key operational considerations.
- Rapid Assessment Tool: a structured screening tool to assess local suitability for BSF implementation and identify viable intervention contexts.
- Workshops for policymakers and practitioners: policy workshops engaged ministries, municipalities, relevant agencies, and waste authorities; practitioner trainings involved existing and aspiring BSF farmers.
- WhatsApp-based Community of Practice with dedicated channels in English and French: the CoP enables low-threshold, peer-to-peer exchange among practitioners and experts, supporting continued learning, troubleshooting, and experience sharing beyond formal trainings.






*Source: Piotr Barczak, Africa Circular.*

## Product diversification

**Diversification beyond on-farm feed substitution into commercial production produces more value than wet larvae sales alone**. Bulk frass, pelletized frass, liquid fertilizer, biological starter material (eggs or prepupae), dried larvae, and oil all serve distinct markets with different margins. The gap between what the system produces and what most operations monetize reflects infrastructure constraints as much as market ones. A grow-out specialist selling wet larvae and liquid frass to neighboring farmers is already diversifying meaningfully without any additional capital equipment. Substrate diversity can itself become a product strategy: operations with access to multiple distinct waste streams — brewery grain, market vegetable waste, agro-industrial residues — can produce larval batches and frass grades with different nutritional profiles, opening differentiated markets that a single-substrate operation cannot reach. Diversification opportunities extend what a BSF operation can monetize, but they do not change the starting question: whether the core production system can operate viably at the scale and in the market it faces. Development programs that treat feed as the only end-market are designing for a narrower revenue base than the system could actually support in many cases.

**Wet larvae and frass in their various forms represent a sufficient and commercially viable product range for most smallholder and grow-out operations.** For smaller producers, diversification into processed products is an opportunity rather than a necessity, but one that becomes more relevant as operations scale. The exception worth noting is Kenya, where a documented oversupply of dried larvae has outpaced local demand, leaving producers who invested in drying infrastructure unable to sell at viable prices (Meerts et al. 2023). The oversupply is a caution about sequencing, not about processing itself: product strategy should follow market evidence rather than run ahead of it.

**A further tier of products may become commercially viable where there is processing infrastructure or sufficient scale.** BSF oil is an almost automatic co-product of defatting: any operation producing

defatted meal is also producing oil. The practical question is what market that oil enters. Applications span animal feed, aquafeed, pet food, cosmetics, cooking oil, and biofuel, each with different quality requirements and price points. The value captured depends more on buyer relationships than on production capability. Chitin, by contrast, requires a separate extraction step from pupal casings or larval exoskeletons, with pharmaceutical, cosmetic, and agricultural biopesticide applications (the last discussed in the *Frass Co-product* section above). The chitin pathway is more demanding from a technical standpoint and the market less established in African contexts. Premium frass products — dried, packaged, and quality-tested — access fertilizer markets that bulk commodity frass cannot, completing the processing-tier category alongside oil and chitin.

**Biochar is another example of how processing infrastructure opens new revenue streams.** Chanzi's integrated operation in Tanzania and Kenya pyrolyzes woody and lignocellulosic material that BSF larvae cannot break down, producing biochar that is sold as a standalone agricultural product. Biochar is combined with BSF frass as a premium carbon-sequestering soil amendment, or recirculated into its own bioconversion process as an input (SMEP 2024; the agronomic case for the third use is developed in the *Substrates* section above). The methane and heat generated as pyrolysis by-products are intended to be captured and reused within the facility. For operations managing heterogeneous waste streams with substantial non-digestible fractions, biochar is a logical complementary output, closing a secondary loop the BSF system alone cannot process. The carbon revenue it generates (discussed further in the *Farming Scenarios* section below), along with the premium pricing of frass-biochar compound products, can meaningfully strengthen the economics of waste management-first operations.

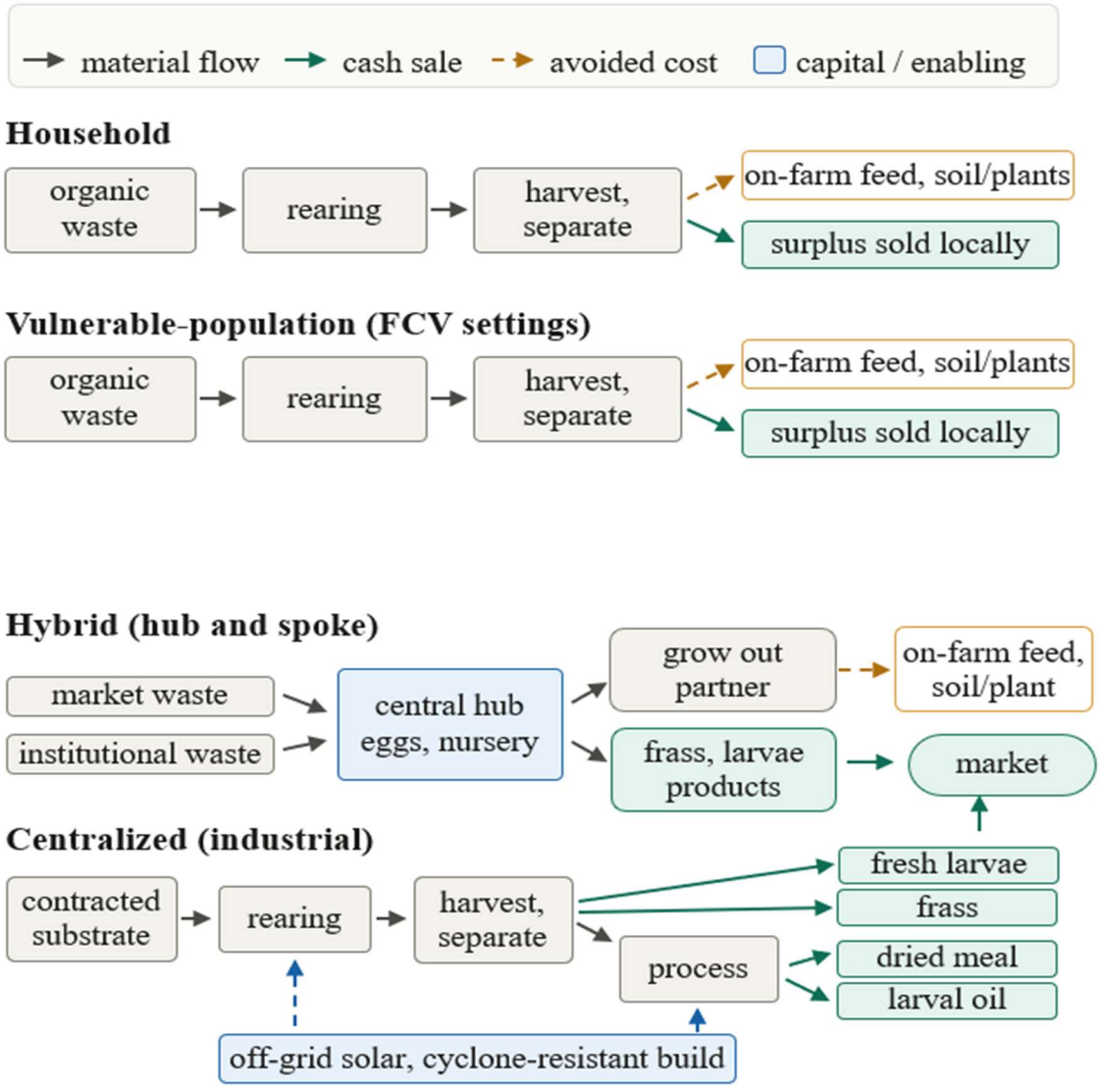
**Liquid frass is another potential revenue source**. Liquid frass is the leachate produced during bioconversion, sometimes fermented into a compost tea. Field evidence from a BSF operation in Malawi documents strong demand for liquid frass fertilizer, with operators reporting that they sold most of their liquid frass production (see chapter 4). Agronomic evidence from tropical field trials in Indonesia finds that liquid BSF frass applied at 5–10 mL/L improved biomass, marketable yield, and quality indicators in shallots and chili peppers (Sopha et al. 2025). Evidence specific to African crops and soils does not yet exist for liquid frass, but the evidence base for solid frass in sub-Saharan Africa is strong: Kenyan field trials document yield gains on maize, tomatoes, kales, and French beans that match or exceed NPK fertilizer performance (Beesigamukama et al. 2020; Anyega et al. 2021). For operations already producing and selling solid frass, liquid frass is an incremental product requiring minimal additional infrastructure, but one whose agronomic positioning for African smallholder markets warrants further field documentation before it is promoted as a primary output.

## 2.2 Farming Scenarios

**Four BSF models recur in Africa: household-scale production, hybrid hub-and-spoke systems, medium- to large-scale centralized facilities, and vulnerable-population production in FCV settings.** Each model has distinct capital requirements, risk profiles, and market access implications. The right choice of production model depends on available capital, the scale of the waste stream to be processed, local labor conditions, and the markets available for larvae and frass. Model choice is consequential, as each model presupposes a different configuration of substrate access, capital, and market depth. The failure mode is to

pick a model first and then look for conditions to fit it, rather than reading the conditions and selecting the model accordingly. The sections below examine each model in turn, present cautionary cases from large-scale African operations, and close with guidance on matching model to context and financing accordingly. Practitioners seeking more granular guidance on system templates should consult Diener and Storey (2025).

**Figure 2.1: The four BSF production models, including cost and revenue**




Source: Authors.

**The four BSF production models, including cost and revenue, are shown in Figure 2.1**. A legend defines five elements: gray boxes are production stages, dark arrows are material flow, green arrows are cash sales, dashed amber arrows are avoided cost, and blue boxes are capital or enabling investment. Avoided-cost (dashed amber arrow) returns are realized on-farm; cash sales (green) enter markets and capital (blue) de-risks the stages it feeds. The household and vulnerable-population models share one chain and may differ in who finances it. The household panel runs kitchen and crop waste into larval rearing, yielding larvae, and frass. Two outputs follow: a dashed amber arrow to on-farm feed and soil for planting,

and a green arrow to surplus sold locally. The vulnerable-population panel repeats that chain, with collected waste, and household food alongside feed as the avoided-cost output. BSF Tamatave illustrates the hybrid model and EXA Feed the centralized model. Both are early-stage Malagasy operations whose long-run viability remains to be demonstrated. The hybrid panel begins with a blue central hub handling eggs and nursery. Three arrows fan out to partner waste streams: a cafeteria, a poultry farm, and market waste. A dashed amber arrow runs from those to grow-out on partners' waste. The centralized panel runs a four-stage chain of substrate, rearing, harvest, and processing. Three green arrows lead from processing to dried meal, larval oil, and frass. A blue box marked off-grid solar and cyclone-resistant build sits beneath, with dashed blue arrows feeding rearing and processing. Read down the figure, returns shift from avoided cost in the upper panels toward cash sales in the lowest.

## Household-scale production

**Household-scale production offers flexibility with minimal capital.** The biology is manageable at small scale, and the circular logic — organic waste from the household or farm converted into larvae and frass, both used on-farm — is immediately intelligible. The entry costs are also low. A case from Madagascar puts a number on how low. One entrepreneur launched her BSF operation with six halved plastic jerrycans, a fabricated love cage, and a total starting outlay under US$60. By her third production cycle she was generating positive net income across five revenue streams simultaneously: wet larvae, eggs, frass, on-farm training sessions, and fabricated equipment sales. All saleable output from every cycle was sold (see chapter 3). The case illustrates what the combination of very low capital requirements and natural product diversification can produce even before any formal market infrastructure exists.

**Household-scale production usually requires that the operator understand and manage the full biological cycle.** This includes the adult fly and egg production stages that are more technically demanding than grow-out alone. The alternative — receiving young larvae from a specialist supplier and managing only grow-out — is not yet broadly available in most African contexts, as discussed in the *Conditions for Viability* section above. Programs supporting household-scale BSF adoption should be clear about whether they are training operators to manage the complete cycle or supplying biological inputs from a central source. The two approaches have very different training and support requirements. Conflating them tends to leave participants unprepared for whichever they end up actually facing.

**Participants should know that small-scale BSF as a stand-alone commercial activity is rarely viable, with its true contribution coming via indirect returns.** The FAO's mapping of BSF value chains in Kenya and Uganda makes the case directly: benefits come primarily in the form of reduced feed and fertilizer expenditure, more reliable nutrition for livestock, and yield improvements in animal and crop production that are absorbed into the household economy rather than transacted in cash markets (Meerts et al. 2023). The Malagasy tilapia farmer discussed in *African Settings and Scaling* illustrates precisely this: no larvae sold, no formal market access, but gross margins of 42–65% on tilapia production, driven entirely by the substitution of on-farm BSF feed for imported commercial pellets (see chapter 3). Living Soils' work in Côte d'Ivoire (see Box 1.5) extends the approach from a single farm to a network of partner operations: BSF is positioned as on-farm infrastructure for soil regeneration and feed substitution rather than as a commercial product. The organization's reported impact is measured in waste valorization capacity and farmer autonomy rather than larvae or frass sales — a deliberate alternative to the commercial-product

framing that household-scale extension programs often default to. Programs that frame it as income generation risk discrediting a genuinely useful intervention when expectations are disappointed.

**In rural settings, substrate availability may cap how far the model can scale even where a buyer is available.** In rural areas, a different constraint applies on the input side: organic waste tends to be already absorbed into existing farm practices — reused as feed, fuel, or fertilizer — leaving less genuine surplus than aggregate waste statistics might suggest. A feasibility study in Ethiopia confirmed this dynamic, finding that rural BSF production was hard to scale beyond modest sub-commercial volumes due to substrate scarcity and the prohibitive cost of sourcing material from further afield **(**Chaix-Bar et al. 2023). Smaller operations may likely be both the most feasible starting *and* endpoint in this context. Programs should set expectations accordingly rather than positioning household BSF as a stepping-stone to larger commercial production in areas where the feedstock simply isn't there.

**A meaningful exception to scale limitations based on substrate availability applies on the output side.** Where an immediate informal market exists — a neighboring farmer willing to buy eggs or starter larvae, a local poultry-keeper absorbing surplus production — even modest sales can meaningfully supplement the cost-saving logic without requiring the infrastructure or consistency that formal off-takers demand.

**An individual refugee case study illustrates what the household model can achieve when conditions support it.** Kanane Bikanyale is a refugee from South Kivu living in Kyaka II settlement in Uganda. Before 2019, he kept around 30 chickens but was chronically constrained by the cost and unreliable supply of commercial feed, including frequent shortages of the silver cyprinid, whose overharvesting from Lake Victoria has driven seasonal fishing bans across the region. After receiving BSF production training through the MAMAH/RAISE program, he began producing larvae on-farm from locally available organic waste (see Box 2.4 on the MAMAH program).

**The results compounded across the refugee's whole farm system**. Poultry grew from 30 birds to between 500 and 800. He diversified into tilapia farming, regularly stocking 6,000 fingerlings. Frass now fertilizes a tomato garden on the banks of his fish pond. His poultry house is built directly over the pond, with chicken droppings supplementing fish feed. He later added mealworm farming for household nutrition. His children are in school and the family is food secure. No purchased substrate, no drying infrastructure, no formal market access — just training, on-farm waste, and management attention.

**The operation has now reached a point where the move to commercial sales is possible, if not yet taken.** Kanane produces larvae reliably enough to supply other farmers, and the biological stock and knowledge to do so are in place. What the transition to a small commercial enterprise requires is not more training or infrastructure — it is a buyer. Whether that buyer emerges through an aggregator, a cooperative, a feed mill, or a neighboring farmer willing to pay for larvae depends entirely on what the local market can support. Kanane's case illustrates a broader pattern: when the household model works, whether it stays small is usually a question of market access rather than any inherent ceiling.

**Two further examples illustrate how institutional support shapes BSF operations**: DanChurchAid's Kakuma program (Box 2.5), which began as a partial-cycle design but was reshaped by farmer preference toward full-cycle production, and Madagascar Biodiversity Center's facilitation network (Box 2.6), which

is structured around peer learning and time-limited institutional anchoring rather than ongoing program delivery.

**Household-scale production works in refugee settlements without becoming a different model.** MAMAH's producers in Kyaka II sell part of each harvest and feed the rest to their own chickens, fish, ducks, and pigs (Box 2.4). DanChurchAid's farmers in Kakuma pushed past the partial-cycle design that the program began with such as building their own breeding cages from local materials, and cut commercial feed purchases roughly in half (Box 2.5). An NGO helped both groups start, the returns are the farmers' returns, and the direction of travel for the project is toward autonomy. The model in the next section shares this chain but not this ownership.

**Box 2.4: BSF strengthening incomes of refugees in Uganda**



Since 2019, Ugandan organization Mothers Against Malnutrition and Hunger (MAMAH) has been supporting refugees and host community members in the Kyaka II refugee settlement to produce BSF larvae. Kyaka II settlement, located in Kyegegwa District in Western Uganda, is home to 138,394 refugees and asylum-seekers, mainly from DR Congo. Most refugees live in poverty, since WFP has stopped almost all food assistance and there are very few income opportunities. In Uganda, 65 percent of refugees now lack sufficient food and levels of malnutrition are high. With funding from the Danish Civil Society Fund and Novo Nordisk Foundation, through the Danish NGO Research & Action for Income Security, MAMAH and its local and international partners have trained 965 individuals organized in 61 groups to produce BSF larvae.

Currently, about 480 individuals are actively involved in production, producing a total of 1.8 tons of fresh larvae per month, with a local market value of approximately 11 million Uganda Shillings (US$3,000). While this translates to about US$6.50 per person per month in direct income, the broader economic impact is significantly higher, especially in a context where most people have few other sources of income.

In practice, most BSF producers sell part of their harvest while retaining some for use as feed for their own chickens, fish, ducks or pigs. Refugees boost their production of livestock, which can in turn improve their income much more than selling the BSF larvae directly. Importantly, these producers are organized into farmer cooperatives, strengthening collective action, improving access to inputs and markets, and building long-term sustainability.

One of the main challenges for scaling up production has been to obtain sufficient feedstock for the larvae. MAMAH and its partners have strengthened systems for collection of organic waste from markets and households in and around the refugee settlement, as well as experimented with different feedstock combinations of maize bran, cow dung, and market waste to optimize production.

*Source: Mothers Against Malnutrition and Hunger (MAMAH) and Research & Action for Income Security (RAISE).*

**Box 2.5: Testing BSF production to support poultry production at household level in Kakuma, Kenya**



Since June 2025, DanChurchAid has supported household-level BSF farming in Kakuma as a low-cost poultry feed supplement, with frass as organic fertilizer for kitchen gardens. Though initially designed as a partial life cycle system, strong farmer demand drove widespread adoption of full life cycle BSF, with farmers independently building their own breeding cages using locally available materials. 30 trained poultry farmers — 16 refugees and 14 from the host community — have begun sharing larvae, training neighbors, and demonstrating kit designs, creating an organic growth in community-level adoption.

Production stands at approximately 6 kg of fresh larvae per farmer per month, with the top 5 averaging 19.4 kg. By project end, 26 of 30 participants had invested in or planned their own on-farm breeding cages. The impact is immediate: one farmer cut commercial feeding sessions from three times daily to once, with a 50-kg bag now lasting nearly twice as long. Farmers also report faster growth, better egg production, and growing interest in kitchen gardening using frass as fertilizer. A key challenge is that as BSF grew in visibility, vendors began hoarding organic waste. Farmers adapted by sourcing from neighbors and bartering frass for feedstock. Kakuma's harsh, hot climate was a second hurdle, met with climate-adapted kit design and coaching on moisture management.

The project's implementers advise embracing full life cycle systems from the outset due to farmers' preference for breeding autonomy. They cited the importance of leading with the economic case (feed savings, faster growth), planning early for organic waste competition, investing in household coaching, and use of simple record-keeping tools to help farmers track savings.

*Photo: Raphael Akumae, project participant (DCA).*

*Source: Dorothy Nyangena, Project Officer, Novel Foods, DanChurchAid (DCA).*

**Box 2.6: MBC Small Farm Program — Facilitated Household-Scale BSF in Madagascar**



The Madagascar Biodiversity Center (MBC), a Malagasy NGO, has established 266 active BSF micro farms across four regions of Madagascar (as of 2026), often in remote settings (see photo). The program is structured around facilitation rather than prescription: MBC provides initial training and biological inputs, then creates conditions for peer exchange and local experimentation to take over. The micro farms are designed as cost-reduction tools rather than as commercial operations: larvae feed directly to poultry and tilapia, and frass goes to kitchen gardens and crop plots. Formal market access is not part of the project, though some participating farmers have begun selling biological inputs and outputs informally within and beyond the network.MBC facilitates peer learning

sessions in which experienced farmers demonstrate solutions for newer farmers. One participating farmer, Mrs. Fanja, developed a system of natural attractants and integrated frass composting with banana stems, with qualitative reports of improved larval yield and fertilizer quality. Participants reported that learning from peers is more accessible and motivating than learning from outside experts (SIANI 2026).

Reported outcomes across program sites include production of 5–25 kg of fresh larvae and 25–95 kg of frass per cycle per micro farm, a 75% increase in selling price for BSF-fed chickens (from MGA 20,000 to MGA 35,000), and a doubling of egg production among participating households to roughly 20 eggs per cycle (SIANI 2026). MBC has also extended BSF integration to human consumption in five villages where eating insects is part of existing tradition, with cooking classes introducing BSF-based recipes (MBC 2025).

The model depends on an institutional anchor willing to absorb training and support costs that participating farmers cannot themselves sustain. The program is structured to reduce dependency over time: as peer-to-peer exchange takes hold and experienced farmers become the primary source of technical knowledge, MBC's facilitating role diminishes. Unlike a hub-and-spoke arrangement where the central node is permanent infrastructure, MBC's design makes the institutional anchor transitional, intended to seed a self-sustaining knowledge network rather than to persist. MBC also conducts field research on BSF agronomy, ecosystem applications, and human nutrition that informs the Madagascar-specific evidence cited elsewhere in this report.

*Source: Hans Kelstrup, Madagascar Biodiversity Center.*

## The vulnerable-population model

**The vulnerable-population model runs the production chain under donor or development financing in FCV settings.** Implementing partners select participants from refugees, displaced, or other vulnerable populations. Substrate comes from beneficiary collection, sometimes paid, or from formal supply contracts. Integrated poultry and crop production absorb much of the output. Figure 2.1 places the chain next to the household models, and they are the same: waste in, rearing, larvae and frass out, most of it used on farm with a small surplus sold locally. Development and other donor finances mostly cover the setup and training phase. The four-country pilot program in Kenya, Malawi, Zimbabwe, and South Sudan illustrates the model, and chapter 4 examines it in detail.

**The financing changes what a missing buyer costs.** A household operator who finds no buyer keeps a smaller operation than hoped for, and can wait. A donor-financed operation that finds no buyer before the implementing partner leaves has failed, because cost avoidance was never the target it was funded against. Both face the same unmet condition. Only one faces it on a deadline set by someone else.

**The distinctive risk is the funding cliff.** Operations reach technical viability before commercial viability, and the gap between the two is where implementing partners exit. Handover succeeds when business-model development starts early enough to close it. At Tongogara, the January 2026 handover from UNHCR to the Government of Zimbabwe placed all livelihoods projects under one agriculture staff member (see chapter 4).

**Programs should select operators on motivation, not on vulnerability alone.** The South Sudan pilots show why. Jamjang had almost no poultry production, and commercial feed could not reliably reach a camp served only by humanitarian airlift, so larvae were the only feed participants could produce locally. They applied their training with high retention despite low levels of formal education. Yei had weaker community buy-in and less thorough consultation, and production there was slower to establish and less consistent. Motivation was the binding variable, not climate or resources (Verner et al. 2022; see chapter 1).

## The hybrid model

**A hybrid model sits between small household production and larger centralized options**. The more technically demanding stages — adult fly management, mating, egg production, and early nursery rearing — are handled by a central operation, while households or small farms receive young larvae and raise them to harvest weight using locally available organic waste. The intent is to combine centralized expertise with distributed engagement: satellite producers operate at a lower technical threshold than full-cycle operations require, while economic benefit is spread more widely than a fully centralized facility could achieve. The central operation in this model functions as both a biological supplier and a knowledge hub, maintaining genetic stock, providing quality-control for the larvae it distributes, and providing technical support to satellite producers.

**One concrete example illustrates the model at semi-industrial scale.** In 2025, BSF Tamatave supplied five-day-old larvae to a commercial operator managing 100,000 chickens across 300 cages, pricing the larvae at MGA 20,000 per kilogram (about US$4.55). Larvae placed beneath cages consumed chicken manure and grew into roughly 10 kg of harvestable biomass per cage within ten days, generating a net economic gain of roughly US$4.50 per cage per cycle after offsetting the cost of the larval input. Repeated three times monthly across 300 cages, the projected monthly benefit reached approximately US$4,100, while simultaneously reducing the farm's purchased feed expenditure by approximately 30% and eliminating a waste management burden, with no additional land, feed crops, or imported inputs required (see chapter 3). Once delivered, the substrate never moves, grown larvae never travel further than the cage they emerged from, and the nutrient loop closes entirely on-site.

**The key logistical constraint of this model is transportation.** The distance between the central operation and satellite producers introduces risks — temperature stress, mortality, delivery timing — that must be planned for from the outset. The central facility's location must therefore be factored into network design, and transport protocols established and actively monitored.

**The central operation must provide biological reliability and resilience to shocks**. Satellite producers taking on grow-out cannot troubleshoot egg quality, hatch rates, or juvenile mortality. The model’s premise is that downstream producers are managing a simpler process precisely because the harder problems have been solved upstream. This means the central operation's primary obligation is not volume but consistency: a regular supply of young larvae of known quality, at a predictable time, at a price that leaves the satellite producer a viable margin. When Cyclone Gezani destroyed BSF Tamatave's infrastructure in February 2026, the satellite operations that depended on it for biological inputs all lost their supply at the same moment. Downstream producers’ lean infrastructure, which had enabled entry into the market, proved acutely exposed to a single point of failure. The central node of a hub-and-spoke biological supply system requires a level of infrastructure resilience that household or small-scale producers do not.

**FAO findings from Kenya and Uganda show how rarely the hybrid model's preconditions are currently in place** (Meerts et al. 2023). Almost all BSF producers currently operate full-cycle, managing breeding, grow-out, and often processing within a single operation. The specialized breeders that a hub-and-spoke system depends on for reliable biological supply barely exist as a distinct actor in either country. If the hub has not yet demonstrated biological reliability, or if substrate shortages and climate variability cause its output to fluctuate, as the FAO documents is common, the satellites absorb a risk they were not designed to manage. There is also a coordination challenge that goes beyond logistics: the FAO found widespread mistrust and competitiveness between BSF producers in Kenya, which actively impedes the kind of knowledge-sharing and division of roles the hybrid model requires. None of this means the model cannot work, but it does suggest that a hybrid system has to build the trust and specialization it depends on rather than presume them.

**Satellite producers' willingness to remain dependent on a hub for biological inputs cannot be assumed.** The DanChurchAid program in Kakuma (Box 2.6) was designed as a partial-cycle system but participating farmers pushed toward full-cycle, with farmers building their own breeding cages from locally available materials and 26 of 30 participants investing in or planning their own breeding capacity. In refugee-context household settings at least, breeding autonomy may be the binding preference rather than a secondary consideration.

**Donor-funded versions of this model often fail by treating the central operation as project infrastructure rather than as a business.** In these cases, central biological outputs — eggs, neonates, or young larvae — are distributed to satellite producers free of charge. The arrangement is well-intentioned and lowers the barrier to participation, but it inverts the economics of the model it is trying to build. An evaluation of one such project in Uganda found that distributing neonates free of charge produced effectively unlimited demand that the breeding centers could not keep pace with, while the centers' profitability remained hypothetical because the product was never sold (RefIPro 2026, internal evaluation). Maintaining genetic stock, controlling juvenile quality, and supplying larvae on a predictable schedule are where most of the technical costs in a hybrid system actually resides. Treating the hub's output as costless to its users leaves the hub perpetually under-resourced relative to demand and removes any path to commercial sustainability when donor funding ends. A breeding operation that has never charged for its outputs has neither price discovery nor customer relationships to fall back on.

**Programs designing hub-and-spoke systems should plan from the outset for how the central node will sustain itself.** Options for sustainability include nominal payment, cooperative ownership, integration into a broader commercial operation, or a defined transition timetable. Whatever the choice, it should be part of initial design rather than something to be addressed after the project closes. Flybox in Kenya and Uganda represents a working version of this model: centralized breeding for paying customers, with biological outputs supplied to satellite producers across East Africa, and a commercial structure that does not depend on continued donor funding (see Box 2.7).

**Box 2.7: Flybox: Building a scalable supply BSF chain across East & West Africa**

Since beginning operations in Kenya in May 2022 and expanding into Budongo, Uganda, in 2025, Flybox has focused on two things: 1) Developing low-cost BSF technology specifically tailored for the African environment. 2) excellence in African BSF colony management for the efficient production of BSF eggs, five-day-old larvae (5DOL).

To date, Flybox has helped 11 farmers in Africa get started with BSF waste management using low tech solutions. They have produced over 250 kg of BSF eggs and converted tens of thousands of tons of waste into valuable protein and fertilizer. Monthly production averages approximately 12 kg of eggs, which equates to roughly 650 million neonates.

The program's success lies in a centralized breeding model combined with distributed farming. By supplying eggs and 5DOL directly to partners, Flybox allows them to bypass the high technical complexity and infrastructure requirements of BSF breeding, enabling them to focus strictly on waste conversion and larval production. This approach supports a network of over 30 partner companies and farmer groups across East Africa, ranging from smallholders and SMEs to waste management companies. Flybox currently assists one new farmer per month in setting up operations across East Africa, Senegal, Ivory Coast, and Nigeria.

Despite this growth, the project faces significant hurdles, particularly regarding the diversity of waste streams and the need for continuous technical support for small-scale farmers. Flybox implementers see funders prioritize "vanity metrics," such as the total number of smallholder farmers trained, while noting that many of those farmers lack the resources or entomological skills to maintain consistent, compliant outputs. Those farmers often abandon BSF farming within a year.

To realize the true potential of BSF in Africa and ensure long-term impact and job creation, Flybox advocates a move away from centralized training programs and toward large-scale infrastructure and decentralized business models. Following successful models observed in China, they advocate a specialized supply chain where companies focus on one of three distinct areas: breeding, waste management, or processing and ingredient sales. Splitting the supply chain into these specialized parts is the most viable path to scaling the industry and moving beyond "feel-good" exercises toward sustainable, industrial-scale waste conversion.

*Source: Larry Kotch, Flybox.*

**A different version of the hybrid model, in which decentralization happens within a single company rather than across independent operators, is emerging in West Africa**. NeoFarm, in Senegal, operates two centralized industrial units that produce juvenile larvae for three modular decentralized greenhouses positioned at waste sources, all under unified management (Box 2.8). This structure preserves logistical advantages — proximity to substrate sources, dispersed climate risk, employment in multiple communities — while avoiding the coordination problems that arise across independent producers without shared incentives. It also requires the capital base of a centralized operation, which positions this version of the model closer to the medium-scale category discussed below.

**Box 2.8: Scaling BSF Production in Senegal through Circular & Decentralized Models**



NeoFarm is a Senegalese biotechnology company developing BSF production systems to convert organic waste into high-value agricultural inputs. Since 2021, NeoFarm has operated a BSF pilot production unit producing organic fertilizer (frass) for farmers and dried larvae for poultry and fish feed. The company has developed BSF production systems adapted to the local context and the available sources of waste: a modular decentralized BSF transformation unit operating directly at the waste source, capable of upcycling up to 10 tons of organic waste per day into organic fertilizer, and a centralized, full-cycle BSF industrial unit capable of upcycling tens of tons of organic waste per day into dried BSF larvae and organic fertilizer.

NeoFarm has recently commissioned a new BSF greenhouse in the region of Dakar with a processing capacity of approximately 4 tons of organic waste per day (~120 tons/month), generating around 30 tons of organic fertilizer per month. This new greenhouse helps bring up to 1,000 hectares of land under more sustainable management practices yearly, improving crop yields by up to 50% and increasing farmers' revenues while reducing carbon emissions by 5,300 tons $CO_2$eq with 1,440 tons of waste upcycled yearly (climate impact forecast validated by EIT Climate-KIC).The project currently supports 10 direct jobs, with projections of 30+ jobs as operations scale, alongside additional employment in waste collection and local logistics.By using low-cost infrastructure such as greenhouses and local equipment, and by positioning units close to waste sources, the company ensures operational efficiency and scalability. The system contributes to reducing organic waste and methane emissions, while improving soil fertility and reducing dependency on imported agricultural inputs.

Key challenges have included access to financing for infrastructure, evolving regulatory frameworks, and the need to adapt BSF systems to local conditions. These have been addressed through blended financing approaches, a progressive pilot-to-scale strategy, and continuous optimization of substrates and rearing conditions, supported by strong local partnerships. NeoFarm's experience highlights several important lessons for emerging BSF initiatives: start with simple, locally adapted systems; secure consistent feedstock supply; prioritize frass valorization for early revenue generation; design modular systems for scalability; and build strong partnerships across the value chain.

*Source: Mansour Niang, NeoFarm.*

## Medium and large-scale centralized production

**Medium- and large-scale centralized production offers advantages that compound at scale.** Concentrated production allows specialization in labor and expertise, drives down per-unit costs through economies of scale, and consolidates pest control and quality management in ways that distributed operations cannot match. Consistent environmental conditions are easier to maintain in a single facility, and the data infrastructure needed to manage biological performance systematically becomes economically justifiable at this scale.

**However, centralized systems require higher levels of capital and pose technical risks.** Centralized systems typically require significant upfront investment, and adapting infrastructure to local environmental and logistical conditions takes time. They also carry a concentration risk: a disease outbreak, a substrate supply failure, or an extreme weather event can affect the entire operation simultaneously (Verner et al. 2021). Capital requirements at this scale typically exceed what self-financing can support, requiring equity investment, grants, or blended finance instruments. The financing horizon must be long enough to accommodate the learning phase that precedes reliable production.

### Processing and scale economies

**A further advantage of centralized systems is greater consistency and processing capacity.** Drying larvae to the specification required by feed millers — consistent moisture content, stable shelf life, de-fatted where required — demands infrastructure that is capital-intensive, technically demanding to operate reliably, and difficult to justify at small scale. The concentration of production and processing in a single facility eliminates the logistical chain of collection, transport, aggregation, and drying that fragments and degrades product quality when handled separately by small operators. For a feed miller purchasing at volume, a single centralized supplier offering consistent product is often not just more convenient than aggregating from dozens of small producers but the only practically viable source. This processing advantage does not automatically justify the capital cost of centralized production, but it does mean that large-scale operations compete in a market that small-scale producers, absent shared infrastructure, largely cannot access at all.

**Case studies illustrate different approaches to success in centralized BSF production.** JKUATES in Nairobi (Box 2.9) is a commercial spinoff of a national agricultural university, producing dried larvae for branded feed manufacturing, fresh larvae, and biofertilizer. JKUATES also includes a developing out-grower program intended to expand substrate intake beyond what the central facility can source directly. Entomo Farm Zambia (Box 2.10) operates the same integrated structure at a smaller scale and bypasses the feed-miller market entirely, selling fresh larvae, dried larvae, and frass directly to gardeners and smallholder chicken, duck, and fish farmers. Entomo's 6 tons of fresh larvae per month support a 4–6-person operation with a different end-market profile than the volume-driven dried-product model. The centralized form scales down as well as up, with the choice of customer base shaping the operation's economics as much as its physical scale.

**Box 2.9: JKUATES — Black soldier fly production and processing in Kenya**



The JKUATES BSF production facility produces fresh larvae, frass/biofertilizer, and manufactures animal feeds using dried BSF larvae. The project is 5 years old and based in Nairobi, Kenya. It started as a technology-scaling venture after years of BSF research at Jomo Kenyatta University of Agriculture and Technology (JKUAT). JKUATES became the commercial partner to scale the technology after successful research trials.

The program employs over 15 technical staff who run the facility's operations. Over 1,000 livestock farmers have benefited from its high-quality animal feed and biofertilizer. The net effect is improved livestock productivity and soil health.

On average, the program produces 900 kg of dried BSF larvae, 2,700 kg of wet larvae, and 10,000 kg of biofertilizer every month. The dried larvae are mainly used for animal feed manufacturing. The eggs from BSF are all incubated to develop new colonies and sustain existing ones.

For 5 years the program has seen commercial introduction of sustainable alternative proteins in animal feed manufacture, creating a network of distributors and end users in the country. Farmers who have used JKUATES biofertilizer reported enhanced soil health and crop productivity, especially green leafy vegetables. Over 3,000 farmers have been trained at the program with the aim of having them as BSF out-growers who can supply the feed manufacturing facility at JKUATES. The out-grower onboarding program is still taking shape, with the first supply expected by start of the third quarter of 2026. JKUATES is mobilizing funds for granulation and liquefaction of biofertilizer as an additional revenue stream.

Larva production containers posed the biggest challenge. Initially the program used plastic crates, which proved incompatible with the region's hot weather. Concrete multi-story feeding units saw productivity increase two-fold.

JKUATES urges BSF producers to innovate technologies applicable to regional conditions rather than copy from other regions or companies. Their advice is "adopt but adapt" to the local situation.

*Source: Meshack Kimondo, JKUAT Enterprises.*

**Box 2.10: BSF Farming as a Catalyst for Inclusive Green Growth — Entomo Farm Zambia**



Entomo Farm Zambia was born from a practical pain point: the crippling cost of chicken feed. When founder Priscilla Musenge discovered black soldier fly larvae as an alternative protein source, she realized the opportunity ran deeper than feed costs alone. BSF could simultaneously address Zambia's organic waste challenge and provide affordable, high-quality nutrition for livestock. One solution, two problems solved. The idea took root between 2018 and 2019, and the company was formally registered in 2020. What followed is one

of Zambia's most instructive early-stage BSF enterprises, honest about its challenges, clear-eyed about its potential, and deeply committed to building an industry, not just a business.

Entomo Farm produces fresh larvae, dried larvae, and frass (organic fertilizer), with a current capacity of up to 6 tons of fresh larvae and 1.6–1.8 tons of dried larvae per month, alongside approximately 7–8 tons of frass at full capacity. These products reach smallholder chicken, duck, and fish farmers, as well as gardeners and vegetable growers, the majority of whom are women. The farm sells directly to individual farmers, keeping supply chains short and benefits local.

Perhaps the most striking evidence of Entomo Farm's impact comes from its fish feed trials. When a larvae-based feed formula was introduced at the fry stage, fish reached 0.8 grams in 21 days, compared to 0.6 grams on conventional feed over the same period. For smallholder fish farmers operating on razor-thin margins, that difference is not a statistic; it is the difference between a viable and an nonviable enterprise. The farm has created 4 to 6 direct jobs, with benefits flowing predominantly to women. Its potential has been recognized internationally: Entomo Farm was a Top 10 winner in the inaugural USADF grant cohort in 2020, a UNDP Waste Management Call awardee in 2021, and placed 2nd globally in the Climate LaunchPad competition that same year. In 2024, its founder was honored with the Zee Women in Banking, Women in Sustainability Award. Entomo's recognition reflects both personal leadership and the broader significance of its results.

Scaling a BSF operation in an emerging market is not without friction. Access to appropriate financing remains the single greatest structural barrier. The absence of capital instruments suited to an industry that does not yet fit neatly into conventional lending categories is a challenge. Alongside financing, the farm has had to invest in market sensitization, educating farmers, gardeners, and potential partners about what BSF products are, what they do, and why they matter. This is the invisible labor of pioneering a new industry. Entomo Farm has responded by leaning into partnerships with government departments, technical experts, and fellow practitioners to collectively lower the cost of building market awareness and share hard-won knowledge across the sector.

Entomo Farm's founder offers this to anyone entering the BSF space: *"Success in BSF farming isn't built in isolation; it's grown through radical collaboration. Because many of us are pioneering niche markets, we must move away from the 'competitor' mindset and embrace being co-creators. Seek out every practitioner in your space, share your failures as openly as your successes, and view every fellow farmer as an ally. We are not just building individual farms; we are building an entire industry from the ground up. If you want to go fast, go alone; but in BSF, if you want to go far, we must go together."* Entomo Farm Zambia is proof that BSF production in Zambia is not a future possibility. It is a present reality.

*Source: Priscilla Musenge, Entomo Farm Zambia.*

### Substrate strategy

**Larger-scale centralized production offers broader pathways to substrate access.** The strategic question of waste-vs-commodity inputs and the dynamics of contested substrate streams are examined in the *Conditions for Viability* section above. The agro-industrial co-location strategy that follows from those dynamics is developed below. A specific nuance of the centralized model is that facilities operating at scale can take on counterparties whose waste volumes match their intake requirements, such as large institutional waste generators, agro-processors, and public-sector authorities. These are possibilities and relationships that smaller operations cannot service even where the contractual will exist. The Ghana-based operation at the Biotechnology and Nuclear Agriculture Research Institute (BNARI), running since 2012 and producing 2 tons of fresh larvae, 850 kg of dried larvae, and 1.6 tons of frass per month (Box 2.11), illustrates one

version: BNARI has secured its substrate flow through formal MOUs with juicing companies, schools, and a slaughterhouse. A second version applies where facilities can take on formal sorting and disposal functions for public markets or municipal waste streams, opening access to public-private partnerships or tipping fees that offset processing costs and reduce dependence on any single substrate supplier, a revenue structure not available to smaller operations.

**Box 2.11: BSF farming in Ghana at BNARI**



The Biotechnology and Nuclear Agriculture Research Institute (BNARI), within the Ghana Atomic Energy Commission, has operated a black soldier fly production facility since 2012, producing fresh larvae, dried larvae, and frass for livestock, aquaculture, and crop and vegetable farmers. Average monthly production is approximately 2 tons of fresh larvae, 850 kg of dried larvae, and 1.6 tons of frass.

BNARI has signed memoranda of understanding with juicing companies, schools, and a slaughterhouse, securing a steady flow of fruit peels, food waste, and slaughterhouse blood, feedstocks that would otherwise become a disposal problem and now serve as inputs to BSF production. This contractual approach has been the operation's principal answer to substrate variability, which is one of the two challenges the operation identifies as most consequential. The other is access to financing for equipment repair and replacement, which the operation manages through a regular maintenance plan funded by production revenues. The fresh and dried larvae supplied to livestock and aquaculture farmers reportedly reduced dependency on soybean and fishmeal by 8 percent while increasing farmer profit margins.

BNARI's experience points to three lessons for new BSF entrants: invest in waste mapping to identify reliable and clean organic waste streams, develop human resource capacity in BSF management, and secure alternative funding sources to stabilize the business through periods of equipment downtime or revenue fluctuation.

*Source: Dr. Enoch Selorm Kofi Ofori, Biotechnology and Nuclear Agriculture Research Institute, Ghana Atomic Energy Commission, and the IITA-led BBEST Project.*

**Private sector cases illustrate potential to reduce waste and sidestep competition for substrate**. Food processing companies — oil processors, breweries, canneries — typically generate large, consistent volumes of organic by-product waste that existing value chains do not absorb, and for which disposal represents a cost rather than a revenue opportunity. A feasibility study in Ethiopia documented two representative cases: a large avocado oil processor generating nearly 9,500 tons of residues per year, much of it pomace and seed waste with limited alternative uses, and a chicken slaughterhouse producing over 50 tons per year of offal and blood by-products going directly to landfill (Chaix-Bar et al. 2023). In both cases, the company faces an active disposal problem. A BSF operation co-located on or adjacent to the facility would address that problem rather than competing for substrate that others already value. This is the structural position the economics favor most clearly: turning a cost into a product, on terms that the waste

generator has reason to support. The Ethiopia study found that both companies had expressed interest in reducing their environmental footprint and improving their business models. However, successful integration would require careful assessment of by-product chemistry. Avocado seeds, for instance, contain antinutritional factors that ruled out their use as a substrate.

**The economic advantages of co-location are clear at any production scale**. A cost analysis from an Indonesian pilot operation modeled an alternative scenario combining co-location of BSF production with a palm oil mill. The arrangement proposed co-location alongside several efficiency improvements, such as a smaller insectarium, reduced manpower, and simplified adult feeding. Together, these changes would cut BSF production costs by approximately 45%, from EUR 0.44 to EUR 0.24 per kg of fresh larvae, and shift BSF meal from 17% more expensive than fishmeal to roughly 33% cheaper (Caruso et al. 2013). The largest single cost in Caruso's accounting is the oversized insectarium, which alone accounts for 44.6% of total production costs; co-location adds further savings by eliminating substrate purchase along with the transport and handling costs that, in Caruso's accounting, were nearly as expensive as the substrate itself. The principle holds at smaller scales too: a Colombian smallholder model integrating BSF production alongside fish farming reported approximately EUR 300 per production cycle in fixed-cost savings versus a structurally identical operation with BSF production in a separate location. Savings in this Colombian case were drawn from avoided land rent, and reduced organic waste transport, marketing overhead, and telephone/internet costs (Barragán-Fonseca et al. 2023). Co-location's cost effect is therefore not a feature unique to industrial scale; it is a feature of the architecture itself, and scales with the size of the overheads it eliminates.

### Revenue mechanisms beyond biological output

**Carbon credits offer an additional potential revenue source**. Where an operation diverts organic material that would otherwise go to landfill, the environmental value of that diversion can be monetized directly through carbon credits. Chanzi's operation in Tanzania and Kenya pioneered a carbon credit scheme tied to its bioconversion process, raising its margin from break-even to profitable (Diener and Storey 2025). The methodology for certifying BSF-related emissions reductions is still being developed. Diener and Storey cite figures of approximately US$135,000 and 2.5 years for the methodology certification work currently underway, costs that fall on the methodology developers rather than on individual operations once the framework is in place. For operations centered on waste management rather than feed production alone, carbon credit revenue is worth incorporating into financial modelling from the outset. Together with agro-industrial co-location, carbon credit access points to a broader principle: the waste management relationship itself — whether with a private processor or a municipal authority — can generate revenue independent of any biological output.

### Contracts and financing

**Physical proximity to a large waste generator or off-taker is not the same as secured access to their output or their sustained purchase of BSF products.** Field assessments of BSF operations in refugee settlement contexts document cases where facilities operated adjacent to substantial organic waste streams for multiple years while still competing unsuccessfully with livestock farmers for the same material. In these cases, waste was secured only when a formal diversion agreement was established as a precondition of a co-located livestock operation (see chapter 4). Contractual commitment is what turns proximity into a reliable operating condition. Medium- and large-scale centralized operations depend on predictable flows

in both directions across multi-year horizons that match their capital recovery periods: substrate coming in at known quantity and cost, and larvae or frass going out to buyers at sustainable prices. On the substrate side, a formal diversion agreement with a market, processor, or municipal authority secures input volume and price against the competition that opportunistic waste access tends to invite. On the output side, a binding agreement with a feed mill, livestock operator, or institutional buyer secures demand at a known price across the capital recovery horizon. Neither arrangement is easy to negotiate, and both require a counterparty willing to commit to a sector still establishing itself. However, centralized operations that enter implementation without binding arrangements on at least one side are betting on market conditions that are variable. For operations seeking external financing at this scale, off-take agreements are increasingly a precondition rather than an enhancement.

**The timing of these agreements requires care.** Off-take and diversion agreements should scale with operational capacity, not preceding it, but a mismatch between agreement and capacity need not be a recipe for failure. EXA Feed's experience illustrates an alternative: in the early stages of scale-up, EXA was unable to process the full amount of spent brewery grain it had agreed to purchase. Rather than absorb a loss, it sold the surplus directly to a local pig farmer, with a further opportunity under discussion to supply surplus spent grain as a feed ingredient to a major Malagasy feed producer (see chapter 3). The off-take obligation that could have become a waste-handling burden instead became a parallel revenue stream. Operations with the flexibility to redirect substrate surplus into adjacent markets can turn a timing mismatch from risk into optionality.

## Cautionary cases: large-scale BSF failure in an African context

**The economic value of BSF inputs such as substrate varies widely according to local context.** The introduction to this report noted that many prominent insect company failures in the Global North, though framed as circular economy operations, were not in fact operating on genuine waste streams. They were purchasing grain-based by-products already in demand by conventional livestock, which drove input costs toward those of conventional feed while their output competed against it on price (Biteau et al. 2024). The criterion is not substrate type but local market depth: a substrate is "genuine waste" when no economically meaningful alternative use absorbs it. In different countries, the same material can sit on different sides of the line dividing waste from resource. A cereal co-product fully absorbed by an integrated livestock industry in one country may have a much shallower alternative-use market in another. Where contractual structures secure substrate flow at prices below alternative-use levels, the input-cost dynamic is held off for the term of the contract. Post-contract economics are a separate question.

**The empirical question of whether a given context offers a genuine cost advantage has to be answered case by case.** The African case studies below should be assessed against their local market circumstances, not against a European context. Biology constrains which substrates work commercially, but where biologically suitable substrates are also commodities, the input-cost dynamic dominates. The South African cases examined below operated on waste. AgriProtein and Inseco both targeted organic waste streams as their primary substrate, yet both still failed. Their failures therefore belong not to a misidentification of the waste status of their substrate inputs, but rather to the execution, infrastructure, and strategic overreach risks that large-scale centralized production carries regardless of input strategy. Box 2.12 sets out an alternative reading: that the broader pattern of capital-intensive insect-farming failures across continents and species is itself the signal.

**AgriProtein grew its operations far faster than its market linkages allowed.** The company targeted food waste as its primary substrate and still entered administration – a status similar to declaring bankruptcy in the United States – in February 2021, after raising US$105 million in 2018. The expansion plan that followed the funding round telegraphed the problem in retrospect: 100 factories worldwide by 2024, another 100 by 2027 — an industrial scale-up timeline that ran years ahead of a market that was still working out what its demand actually was. Krishfield (2023) identifies a fatal combination of factors. COVID-19 disruptions cut off food waste feedstock and exposed the absence of automation. High operating costs from a large headcount and underutilized facility and output-side competition from cheaper soy and fishmeal. AgriProtein's strategic posture prioritized scale over the operational discipline that earlier-stage companies typically build before committing capital at industrial volume. The company reported a US$38.9 million loss in 2019. Its assets were subsequently acquired by Prezero U.S. for US$10 million in June 2021 (Krishfield 2023).

**Inseco lost investor confidence after deferred investment led to lost production.** The company, another Cape Town BSF startup founded in 2018, targeted organic waste streams from food processors and retailers, and ceased operations in 2025 after raising US$5.3 million in 2022 to scale its facility. In an account of the company's collapse, Watson (2025) reports that co-founder Simon Hazell has been candid in print about what went wrong: "We made some bad hires, scaled too quickly, and pivoted too slowly". South Africa's recurring, structured power outages known as "load shedding" disrupted temperature-sensitive biological production cycles and damaged customer relationships and investor confidence. The company had deferred investment in a large backup generator, assuming load shedding would not intensify as it did. Sector-wide investor skepticism, driven by struggles at high-profile international insect protein companies, also dampened follow-on capital availability (Watson 2025).

## The environmental case at scale

**The economic and environmental cases for BSF reduce to a single condition: whether the substrate is genuine waste in its local market.** The economic case for BSF is strongest on genuine waste: substrate with no competing use, ideally co-located with the generator, so that input cost approaches zero and the operation is paid, in effect, to solve a disposal problem. The environmental case is governed by the same condition, though it arrives from the opposite direction. The most damaging critique in the life-cycle literature, that directly feeding a waste stream to livestock outperforms routing it through insects (Javourez et al. 2025), has force only where the substrate is feed-grade to begin with. On a stream that no animal can eat and no market absorbs, there is no direct-feeding alternative to lose to. The insect pathway is then measured not against direct feeding but against composting and anaerobic digestion, a comparison taken up in the environmental section below. The substrate that makes BSF economically sound is therefore also the substrate on which its environmental case is least vulnerable. Genuine waste does not make that case, but it removes the one critique the life-cycle literature presses hardest, leaving the outcome to the processing-energy and scale conditions taken up below. Both arguments rest first on the same discipline: the viability of a BSF operation, on either ground, depends on whether its substrate is genuine waste in its specific local market.

**The largest available life-cycle assessments of the environmental impact of insect protein point in a cautionary direction.** The UK Department for Environment, Food & Rural Affairs (Defra) commissioned

a life cycle assessment (LCA) of insect protein for pig and poultry feed. The study found that BSF larvae fed on restaurant kitchen waste, chicken manure, or wheat-based traditional feed performed worse than soybean meal on 14 of 16 environmental indicators — between 5.7 and 13.5 times the greenhouse gas emissions, depending on substrate — and worse than fishmeal on 10 of 16 indicators (Ricardo 2025). Javourez et al. (2025), simulating 8,820 valorization scenarios for French bio-residues, reached a structurally similar conclusion: directly feeding food and feed-grade waste streams to livestock outperformed the insect pathway on most environmental indicators across all scenarios assessed, including those modeling reduced livestock production and consumption. The studies indicate that adding insects as an intermediate conversion step loses most of the substrate's mass. That is, only 8 to 40 percent of substrate dry weight ends up in the insects; the rest is lost as frass, exoskeletons, respiration, and biological waste. The higher-quality protein that emerges does not compensate for the loss. A life cycle assessment of small-scale BSF meal production in the Western Cape found that on South Africa's coal-heavy national grid, in a Mediterranean climate requiring active energy inputs for temperature control, and at a scale too small to achieve processing efficiency, insect meal carried a higher environmental footprint than fishmeal across most impact categories (Kleyn 2023).

**Most of insect meal's environmental disadvantages come from conditions a well-sited operation can change, with one structural penalty it cannot.** Ricardo's study points to four main drivers. The first is the electricity used to keep rearing facilities warm: larvae need stable, controlled temperatures, and in the United Kingdom that means heating, which accounts for roughly a quarter of the footprint in the two waste-fed systems. The second is the energy used to cook and dry the harvested larvae into a stable meal, a processing step heavy enough to register as a hot spot across every system in the study. The third applies only to the worst-performing system, the one rearing larvae on wheat-based feed: that feed is a grown crop with its own large footprint, and it alone contributes two-thirds of that system's climate impact, which is precisely why feeding larvae a commodity rather than a waste is so costly. The first three drivers are not fixed. They depend on how the electricity is generated, how warm the local climate is, what technology does the drying, and whether the substrate is genuine waste or a grown feed. A tropical operation on low-carbon power, rearing larvae on genuine waste, would face a markedly different version of each. The fourth driver is the one that does not move. Routing material through insects loses most of its mass, since only a fraction of the substrate ends up in the larvae and the rest leaves as frass, exoskeleton, and respiration, and the higher quality of the protein that remains does not fully offset that loss. This is an efficiency penalty inherent to using insects as an intermediate step. Even a well-sited operation on clean energy and genuine waste still carries it, because it comes from the biology rather than from the conditions. The fair reading of Ricardo's result, then, is not that insect meal is inherently high impact. Most of its measured disadvantage reflects conditions a well-sited operation can change. What remains is a smaller penalty built into the biology, which no amount of good geography can remove.

**A second methodological choice swings the result even further; it lowered the insect meal's climate impact, in some cases enough to bring it below fishmeal**. When black soldier fly larvae are reared, the process produces two useful things at once: the insect meal and the leftover frass. The study must divide the total environmental footprint between them, and there are two ways to do it. Ricardo's baseline divides it by value, which puts most of the footprint on the insect meal, since the meal is the valuable product and the frass is worth little by comparison. The alternative divides it by weight instead. Because there is far more frass than meal by weight, this shifts most of the footprint onto the frass and leaves the meal looking

much cleaner. The effect is large. Across all three feeding substrates the study modelled, larvae reared on restaurant food waste, on chicken manure, and on wheat-based feed, switching from the value method to the weight method lowered the insect meal's climate impact by 67 to 82 percent, in some cases enough to bring it below fishmeal. Nothing about the actual farming changed between the two figures. The larvae, the energy, and the emissions are identical. Only the rule for dividing the footprint changed.

**The weight-based result is only as sound as the claim that frass is a real co-product, and on that question the evidence is moving in frass's favor.** Frass already has real value in African smallholder settings, where composted frass has matched or exceeded mineral fertilizer and raised farmers' net income substantially. What has not yet caught up is the standardized, safety-tested frass market that an environmental assessment needs before it can confidently rest a large share of the footprint on frass, especially in temperate studies like Ricardo's, whose frass figures are not drawn from African conditions. The cautious reading for now leads with the value-based result, under which insect meal underperforms its conventional comparators. But the more favorable weight-based result is not a statistical trick; it is a preview of where the numbers move as frass becomes an established, traded co-product. As African frass markets and standards mature, the environmental case for insect meal stands to strengthen with them. Renewable electricity and improved drying methods offer further reductions, smaller than the allocation effect but real, and pointing the same way.

**Beyond these methodological questions, the African evidence base itself is sparse.** Apart from Kleyn's Western Cape study, the only life cycle assessments of insect-based feed production in an African context are the West African studies (Roffeis et al. 2017, 2018, 2020), which modelled housefly and BSF systems at research scale in Mali and Ghana, producing less than 12 kg of insect feed per day. They found that systems run on genuine waste streams generated environmental impacts roughly comparable to fishmeal, but that finding is hard to lean on. The authors themselves flag the limitations: the systems are far smaller than commercial production, and the comparison treats wild fish harvesting as carrying zero environmental burden, which artificially favors fishmeal. Commodity prices in the companion cost analysis (Roffeis et al. 2018) reflect 2017 conditions, before fishmeal prices rose substantially.

**Taken together, the African life cycle assessment evidence base for BSF is thin, geographically narrow, and methodologically constrained.** The existing studies do not cover the conditions that matter most for commercial BSF production in tropical Africa, and they sit outside the parameter space a well-sited operation would occupy. The Western Cape and West African studies neither establish nor rule out favorable performance for such an operation. Ricardo (2025) is built on a temperate European grid, and neither study tests a tropical, low-carbon, waste-fed operation directly — though, as noted above, Javourez's central finding is structural rather than a grid artifact and would not simply vanish under better geography. What the evidence base lacks is the one study that would actually settle the question: a purpose-designed LCA of a tropical African operation, on genuine waste streams and low-carbon energy, before environmental claims for this category of production can be made with confidence.

**Inconsistent comparison methodologies further cloud the environmental evidence base**. Francis et al. (2025) report soymeal at 1.8 kg $CO_2$-equivalent per kg, with 1.27 of that coming from land use change — a footprint consistent with a deforestation-driving soy. The same study reports fishmeal at 1.04 kg $CO_2$-equivalent per kg with virtually no land use change attribution, a footprint consistent with conventional

LCA treatment of wild capture as having minimal upstream environmental cost. The Roffeis studies cited above acknowledged this convention as artificially advantaging fishmeal in BSF-versus-fishmeal comparisons. Among the global LCAs, Ricardo (2025) specifies Cerrado/Goias soy as its comparator, while Javourez et al. (2025) does not name an origin. Soy grown on recently deforested land carries a substantially different environmental footprint from soy grown on long-cultivated land. The implication for African contexts is that the LCA verdict on BSF-versus-soy varies depending on soy land-use assumptions. African-sourced soy has expanded to date primarily on existing agricultural land, and Indian soy is grown on long-cultivated soils. Neither carries the deforestation-linked land use change that dominates the soy footprint in many published LCAs. The forward-looking concern is real, however: conservation analyses have documented an emerging soybean production frontier in Southern African dry forests and savannas, with structural similarities to the South American frontiers where soybean expansion drove deforestation (Gasparri et al. 2016). Whether that frontier is bounded by effective land-use governance will shape the environmental case for the soy comparator over the longer term. A purpose-designed African LCA should specify the soy comparator concretely rather than rely on a generic default. The fishmeal comparator faces a related but distinct problem: there is no settled methodology for attributing environmental impact to wild-capture fisheries, so LCAs apply conservative or near-zero attributions for upstream ecological costs. In African settings, this convention has direct food-security implications. An LCA that treats fishmeal as having near-zero upstream burden misses entirely the consequences of diverting a contested human-food fishery into industrial feed, as the displacement dynamics around silver cyprinid documented earlier in this report illustrate.

## Biodiversity and biosecurity at scale

**The environmental reckoning for BSF extends beyond carbon to the risk that farmed insects escape and affect wild populations.** Invasion biologists have drawn attention to insect farming as a pathway for biological invasion, noting that mass-reared insects escape routinely and that black soldier fly is among the farmed species with the largest areas of climatic suitability for establishment outside its current range. Because even a low per-individual escape rate applied to the very large numbers involved in mass rearing produces repeated introductions to the surrounding environment, the concern is a serious one for the industry as a whole (Manfrini et al. 2025, 2026).

**Its application to sub-Saharan Africa differs from its application to regions where BSF is absent.** BSF is already naturalized across much of the continent, having spread through human activity decades before it was farmed, so in most of the region mass rearing does not introduce a species into an ecosystem that lacks it. The novel-invasion scenario at the center of the global literature is therefore attenuated across much of sub-Saharan Africa, though not everywhere: local ecological conditions and the status of resident populations vary, and site-level assessment remains sensible.

**What naturalization does not remove is a narrower set of genetic and disease risks, governed by strain provenance and containment rather than by facility size.** The first is genetic: escaped larvae can interbreed with locally established wild populations, and where those populations are distinct or locally adapted, repeated introgression could erode that distinctiveness. Strain provenance drives most of this genetic risk. An operation rearing locally sourced BSF releases into a population its escapes largely come from, a substantially lower genetic risk than importing an exotic strain. It does not eliminate the risk, however: strains selected over successive generations for farm traits such as fast reproduction and stress

tolerance can diverge from wild populations, so that even locally derived escapes are not always genetically neutral (Manfrini et al. 2026). Importing exotic domesticated strains from outside Africa compounds both problems: it introduces non-local genetics into established wild populations and can carry pathogens or parasites the local system has not encountered, and unlike escapes of already-naturalized BSF, this risk is not attenuated by the species' established status. A second risk is epidemiological: mass rearing concentrates large numbers of insects, which can amplify and spread pathogens to wild populations if colony health is not managed. Both risks scale with the total number of animals reared and the quality of containment, not with whether production is centralized or distributed. A hub-and-spoke structure, in which a well-managed central node maintains the breeding colony and supplies satellite growers, concentrates strain provenance and the reproductive population where containment can be enforced, and is on these grounds a biosecurity advantage as well as a biological-input one. Where production remains fully distributed, biosecurity guidance delivered through extension and producer associations becomes the practical substitute for that structural control.

**These risks are real but manageable, and have to be weighed against the livelihood, nutrition, and waste-management benefits BSF offers African producers.** BSF farming provides a documented route to income, local protein, and waste valorization, and the genetic and disease risks it carries can be addressed through practices already recommended on other grounds. Much of the invasion-risk concern is calibrated to regions where BSF could become a novel invader. In sub-Saharan Africa, where it is already established, that standard may be stricter than the setting warrants, and applying it uncritically could deny smallholders documented benefits to guard against a risk that is both uncertain and, here, less acute. This attenuation applies to the novel-invasion scenario, not to the residual genetic and disease risks. The consequences of an invasion, once one occurs, are if anything harder to contain in this setting: legislation on biological invasions is often limited across the region (Turbelin et al. 2017), and lower-income nations have scarcer resources to prevent and manage invasions, such that damage costs routinely outstrip management expenditure (Bradshaw et al. 2024). Weaker containment capacity does not raise the probability that already-naturalized BSF becomes a novel invader, but it does raise the stakes of the residual risks that naturalization leaves untouched. That is an argument for the low-cost precautions below, not against them. The proportionate response is neither to dismiss the concern nor to be paralyzed by it, but to manage it with a small set of sensible defaults. The most important is strain provenance: operations should rear locally sourced BSF and avoid importing exotic domesticated strains from outside the continent, which is where the genetic and disease unknowns are greatest and the precaution cheapest. Beyond that, operations should confirm species identity at the outset, since wild-caught starter colonies can include look-alike soldier-fly species; maintain basic containment appropriate to scale; manage colony health to limit pathogen spillover; and deliver this guidance through the extension and producer-association channels that reach the many small operators who make up much of the sector.

**Box 2.12: Reasons for caution on BSF farming in Africa**

Insect farming in Africa has real potential, but the optimistic case for it rests on conditions that have not yet been demonstrated at commercial scale, and on several risks that get little attention. The sector's record also supports a less reassuring reading than the one usually offered. Insect-farming ventures have now failed across many countries, species, and business models. That variety is often taken as reassuring: with no single shared cause, the argument goes, there is no deeper problem with the sector. The opposite reading is at least as plausible. When failure recurs across all those differences, the one constant is insect farming itself, and the pattern may point to a difficulty with the model as a whole rather than to a series of separate mistakes. The sections below set out where the evidence is thin and where the risks remain. One caveat on the research used here: these life cycle and economic critiques were built mainly around operations in the Global North, so we note where they apply to Africa and where they do not.

**Frass as fertilizer: more questions than answers.** Frass is often presented as a valuable co-product, and it does contain plant-available nutrients. However, a research gap analysis commissioned by the UK Department for Environment, Food and Rural Affairs (Defra) concluded that the usefulness and safety of frass spread in large quantities over farmland are not yet established. The review highlights missing field-scale trials, no consensus on application rates, and uncertainty about what happens to nitrogen after application. Several studies have reported that frass-amended soils can release substantial nitrous oxide, especially when the rearing substrate is carbohydrate-rich, alongside elevated $CO_2$ fluxes, though the data come largely from short-term incubations, leaving the net greenhouse-gas balance an open question rather than a settled benefit (Rummel et al. 2021; Crotty & Rock 2024; Ricardo 2025). Recurrent phytotoxicity from ammonium-N, salinity and inadequately stabilized material has also been reported. Excessive frass application has been found to harm crops through mechanisms that are not yet identified. For Africa, where frass is being promoted as an organic fertilizer but where monitoring and regulatory capacity are limited, these gaps matter.

**Safety risks from waste-based substrates.** Converting organic waste into protein through BSF is a central argument for the sector. But the use of waste as substrate raises real food and feed safety concerns. The UK Food Standards Agency has warned that insects can act as disease vectors when reared on waste, and that insect-processed proteins may lead to disease outbreaks (FSA 2023). Contaminants such as pathogens, prions, heavy metals, and mycotoxins can transfer through insects into the food chain (van der Fels-Klerx et al. 2018). In Europe, precisely because of these risks, regulations restrict which waste types can serve as substrates. In much of Africa, waste streams are less regulated and source segregation infrastructure is largely absent, making these concerns particularly relevant. Safe use of waste-based substrates is possible, but requires quality control and regulatory systems that most African countries are still building.

**The meat-substitution assumption is a strong one.** Life cycle assessments tend to find a clear environmental advantage for insect protein only under one condition: that the product replaces meat in human diets, rather than fishmeal or soymeal in animal feed (Javourez et al. 2025). That condition is doubtful. Almost no commercial product today puts insects in place of meat; most farmed-insect output goes to animal feed and pet food, where the favorable comparison does not hold (Biteau et al. 2025). The cultural trend points the other way as well. Even where insects are traditionally eaten, consumption tends to fall as incomes rise and populations move to cities, with meat replacing insects rather than the reverse (Barennes et al. 2015; Hlongwane et al. 2021). Insect products also do not fill the same culinary role as meat, so a direct dietary swap is unlikely even where they are sold. An environmental case that depends on meat substitution therefore relies on a change in eating habits that the evidence does not support, in Africa or anywhere else.

**Risks a tropical climate does not remove.** Warm temperatures, low labor costs, and abundant unmanaged waste are real advantages where they exist, but they do not remove the operational risks. Unreliable grid power disrupts the continuous temperature control that BSF biology needs, and outages have already forced large African operations to close. Daytime maxima in some regions exceed BSF's thermal tolerance, so a tropical setting only helps within a temperature window. Abundant waste is not the same as usable substrate. Collecting dispersed food waste, keeping it fresh, and sorting it to a usable quality is costly and complex, more so than sourcing concentrated agricultural by-products, and the irregularity of supply pushes many operations back toward the grain-based feeds that weaken the model's circular-economy case (Biteau et al. 2024).

**What this means for policy.** BSF farming may find viable African niches, above all in decentralized smallholder waste-to-feed-to-fertilizer systems with low capital intensity and substrate that is genuinely on-farm. The case for industrial-scale BSF as a public-investment priority is weaker. Its environmental claims are not yet backed by African LCA data, its safety depends on regulatory infrastructure most countries do not have, and the model has not yet produced a durable success on the continent. Public money should follow context-specific African evidence rather than projections imported from conditions that have not held elsewhere. Independent life cycle assessments of representative African operations should come before policy promotion, not after.

*Source: Corentin Biteau, (ONEI); Tom Bry-Chevalier (ONEI, AgroParisTech-INRAE, Université de Lorraine).*

## Matching model to context

**BSF farming in Africa is not a single intervention waiting to be rolled out — it is a family of approaches, each viable under different conditions.** Success in BSF requires the appropriate configuration of capital, expertise, and market access. That diversity is a strength: the sector can take root in a refugee settlement in Uganda, operate as a semi-industrial partnership in Madagascar, or run at industrial scale adjacent to a brewery in the north of the same island. In all of these cases, the same underlying biological logic applies, adapted to radically different contexts. The task for development programs is not to pick a winning model but to understand which conditions each model requires and apply the appropriate approach where conditions exist, or build those conditions deliberately where they do not yet exist.

**BSF viability depends on site conditions that continental generalizations cannot capture.** Tropical Africa is not uniformly favorable for BSF: parts of the Sahel exceed BSF's thermal tolerance during peak daytime temperatures and require active cooling rather than ambient temperature management. Grid reliability varies substantially even within a single country. Capital and management depth in much of sub-Saharan Africa are thinner than what AgriProtein and Inseco operated with in South Africa. Cyclone exposure on the East African coast adds an infrastructure cost that landlocked or sheltered sites do not carry. Before model selection, therefore, comes a more fundamental question: which conditions does this specific site offer and which constraints does it actually impose? Programs that assume continental-scale advantages without testing them at the site level likely invite risks they have not budgeted for.

**Climate-resilient infrastructure is one of the facets of BSF where trade-offs are sharpest.** In cyclone-exposed geographies, frugal entry — a low-capital approach that lets operators demonstrate viability before

committing serious investment — concentrates climate risk into the period when the operator is least able to absorb a total loss. Climate-resilient construction, on the other hand, commits substantial capital expenditure to operators whose biological consistency, management capacity, and market access are not yet proven, posing a substantial sunk cost risk on operators who may fail for reasons unrelated to weather. There is no costless resolution. The practical question for program designers is whether investments in climate resilience happen alongside operator validation milestones, become a separate insurance-like investment, or whether adverse climate impacts are accepted as an unavoidable risk during the entry phase. Each path has cost and risk implications that need to be modeled at the project level rather than assumed.

**Substrate safety and related regulatory posture are important structural considerations.** EU and US regulation prohibits BSF rearing on several substrate categories that are routinely available in African settings — manure, mixed urban waste, fecal sludge — reflecting safety concerns that are largely substantive rather than arbitrary. The biological hazards those restrictions address apply across contexts. What differs across contexts is the cost-benefit calculation about acceptable risk thresholds when alternative protein sources are scarce. Operations using these substrate categories therefore carry real responsibility for the safety of their products, and program designs should treat substrate qualification, contamination testing, and end-product monitoring as design requirements rather than as costs to defer. The cost of doing this work properly is not trivial. Testing capacity is itself underdeveloped in most African food-safety regimes. A program that assumes regulatory permissiveness as a comparative advantage without budgeting for the testing and monitoring infrastructure that responsible substrate use requires has substituted one set of risks for another. As food-safety regimes mature in Africa — Madagascar's NMG 132-13 is one early signal of that trajectory — operations whose business cases depend on current regulatory flexibility face the additional risk of compliance retrofitting under tightening standards.

**A quality problem becomes a market problem when buyers cannot tell safe larvae from unsafe ones.** Larvae reared on clean, qualified substrate and larvae reared on contaminated or prohibited material are visually indistinguishable, and at present they command the same price. Without testing, certification, and traceability, the market gives producers little reason to absorb the cost of substrate discipline, and the economic incentive runs toward the cheapest available material and toward maximizing volume over quality. This invites the use of substrates that should be excluded and the skirting of the handling and processing steps that keep products safe. The risk is systemic rather than confined to any single operation: a small number of adulterated or unsafe products can discredit an entire emerging category, and the absence of verification falls hardest on responsible producers, who cannot charge a premium for a safety margin that buyers are unable to see. For a young sector whose credibility with feed millers, food regulators, and consumers is still being established, this is a foundational vulnerability. Quality assurance, contamination testing, and traceability are therefore not refinements to be added once the sector matures but preconditions for it to mature at all, and because testing capacity is scarce and expensive, they are most efficiently built as shared infrastructure rather than left to individual operators to construct alone.

**Typological models are not fixed categories, but stages that operations may pass through over time.** The capital-light pathway may begin at household scale — whatever waste is nearby, whatever labor is available — and transition toward the hybrid model as biological reliability is established and market relationships develop. BSF Tamatave's trajectory illustrates this movement: the operation began with chicken manure and kitchen scraps, built a stable protocol around port-rejected wheat bran and restaurant

waste, and scaled not by expanding its own facility but by embedding larvae into a 100,000-chicken poultry operation and a municipal waste stream. The facility itself remained modest; the system it anchored grew substantially. The dynamic can also run in the opposite direction: a centralized pilot can spawn satellite operations downstream as it trains capable operators, with the pilot facility serving as biological supplier to household kits or small group farms. Beneficiaries and staff identified this decentralization pathway at the Dadaab refugee settlement in Kenya as a valuable complement to the benefits of the central facility (See chapter 4). The capital-intensive pathway often follows a different sequence — site selection precedes infrastructure, infrastructure precedes production, and production precedes market entry. However, the underlying logic is the same: each stage builds only on what the previous stage has demonstrated, not on what it hopes the next stage will deliver. What pathways share, and what any transition between models requires, is a discipline that is easier to state than to maintain: build on what has been demonstrated, not on what is hoped.

**Successful BSF financing adapts to local conditions rather than following simple typologies.** Household operations are typically self-financing through labor and on-farm waste. External capital at the smallholder level risks creating dependency rather than capability. The most useful support to household-level BSF operations is training and market linkage rather than grants or loans. The hybrid model's centralized-provider operation is where external financing becomes genuinely relevant. However, investors must offer patient capital, with a realistic understanding of the learning phase that precedes reliable biological output. A central operation capitalized for production before it achieved biological consistency will scale its problems rather than its productivity. The capital-intensive model requires the longest financing horizon and the most formal risk assessment. Investments like EXA Feed's off-grid solar and cyclone-resistant construction add significantly to upfront costs but eliminate categories of existential risk that would otherwise demand emergency financing at the worst possible moment. Standard financing instruments often fail BSF operators across all three models because they are designed for cash flows that BSF does not generate. Microcredit at roughly 20% annual rates is incompatible with multi-month learning curves and inventory-heavy operations, leading Malagasy producers to explicitly decline it as unworkable (see chapter 3). Blended finance instruments combining concessional development capital with commercial bank participation, with tenors and grace periods aligned to BSF cash flow realities, are what the sector requires to grow beyond informal financing. Development programs that deploy standardized financing instruments across all three models — treating a household producer, a hybrid hub, and an industrial facility as variants of the same investment category — will systematically misallocate support.

**Matching model to context is more important than optimizing within a model**. The conditions that made EXA Feed viable in Madagascar's Diego Suarez — a guaranteed industrial substrate, a climate requiring minimal environmental control, and access to patient capital willing to fund a two-year pilot before committing to full infrastructure — are not replicable by design. Operators had to identify and secure those conditions before choosing the model. Conversely, the capital-light pathway that BSF Tamatave followed — beginning with whatever waste was nearby, generating early revenue from biological inputs rather than processed product, and scaling by embedding in existing systems rather than expanding its own facility — was precisely suited to starting conditions. Tamatave would have been undermined rather than accelerated by early infrastructure investment. Kanane Bikanyale in Kyaka II settlement illustrates the household model's logic at its most direct: no formal market access, no drying infrastructure, no external financing, just on-farm waste, training, and management attention compounding across a whole farm

system. The question a development program should ask before supporting any BSF initiative is therefore not "which model is best?" but "which conditions are present, and which model do they point toward?" That question has an empirical corollary: ground-level evidence from East African value chain research suggests that the household model's returns are most reliably realized as cost savings rather than commercial income. Programs that have conflated the two generated both disappointment among participants and skepticism among off takers (Meerts et al. 2023). Holding that distinction clearly — subsistence integration as a livelihood strategy, hybrid and centralized models as commercial enterprises — is what separates a program that builds durable capacity from one that generates a wave of disappointed adopters.

## 2.3 Black Soldier Fly Production in Madagascar: Two Models, Shared Lessons

The following case studies draw on the experience of two Malagasy BSF enterprises — EXA Feed in Diego Suarez (Antsiranana) and BSF Tamatave on Madagascar's east coast — to illustrate what industrial and hybrid-model insect production can look like in practice, and what conditions make each viable. Both are early-stage operations whose long-run viability remains to be demonstrated. What they offer is detailed operational evidence on how each model navigates the conditions it faces, not proof that either model will succeed at maturity. Together, they offer some of the most concrete and transferable evidence available on BSF development in sub-Saharan Africa.

### EXA Feed– Diego Suarez, Northern Madagascar

EXA's BSF program was initiated in 2023, with a pilot facility in Antananarivo before launching a vertically integrated production facility in Diego Suarez in September 2024. BSF was a deliberate strategy: if larvae could be reared on food-grade waste at sufficient scale, they could supply both a growing animal feed market and — critically for EXA's mission — a low-cost protein ingredient for human nutrition programs targeting malnutrition in Madagascar.

**EXA's model addresses by design the weaknesses that have undermined industrial BSF elsewhere:** feedstock contracted rather than assumed, energy designed to the site rather than assumed from infrastructure, and value-capture extending across multiple output streams.

**Long-term, low-competition contracting for reliable feedstock is a key structural advantage in the EXA case.** EXA Feed identified a large brewery in Diego Suarez producing twenty tons of spent grain per day and secured a ten-year offtake agreement for the substrate at negligible cost. The economics of this arrangement reflect a market structure specific to northern Madagascar. Spent grain from a brewery in a Northern European or established African market typically tracks commodity feed parity, because an integrated livestock industry has organized around the supply over decades. In Africa, Ethiopia is a similar example, where brewery by-products are already purchased by ruminant and poultry producers (Chaix-Bar et al. 2023). Northern Madagascar does not yet have that absorption capacity at scale, and the brewery's daily output had limited established outlets before EXA contracted for it. The ten-year offtake stabilized a market that had not formed at meaningful volume — not a concession against established price, but the building of a market relationship where one had not previously existed. EXA Feed's identification of this opportunity, and its willingness to commit infrastructure to take advantage of it, distinguishes the case from

operations that premised their economics on similar materials in markets where non-BSF buyers were already competing for the same feedstock supply.

**Sales of surplus substrate avoided loss and opened new revenue streams.** The brewery's daily output of spent grains exceeded what EXA's larval rearing could initially absorb. Rather than leaving the surplus unused, EXA Feed invested in sun-drying the excess spent grains and began selling it to pig farmers and other agricultural buyers in the region. Without EXA Feed in the relationship, most of the surplus had no buyer at scale: the pig sector is undeveloped and absorbs only a fraction of the brewery's daily output. The brewery is not in the business of aggregating dispersed small-farm demand. The substrate relationship that had been secured as a cost-reduction measure became an independent revenue stream, one that generated income before a single kilogram of larvae reached a customer. This arrangement reduced EXA's effective substrate cost further by monetizing what the BSF operation could not yet consume. This detail carries significance beyond the EXA Feed case: it illustrates that a well-structured industrial offtake agreement can generate value at both ends of the substrate relationship, and that the economics of substrate security are not simply about minimizing input cost but about understanding what else the waste stream can do.

**Investments in off-grid electricity and climate resilience increased initial costs, but mitigated major risk categories.** Northern Madagascar's stable tropical climate meant that larvae could be reared in passively ventilated structures without the heating and cooling costs that make European BSF operations economically marginal. Land was leased immediately adjacent to the brewery. EXA built a solar-powered facility from the ground up off the municipal grid entirely. The region's unreliable electricity would have otherwise threatened an operation that requires continuous environmental control and capacity for sanitizing, drying, pressing, and grinding the insects. The facility was also designed from the outset to withstand cyclones — a real and recurring risk in Madagascar — with reinforced structures that added to upfront capital costs but eliminated a category of existential production risk that BSF Tamatave (see below) would later experience firsthand.

**The operation was designed for industrial scale and circularity from the outset.** EXA's approach included purpose-built rearing infrastructure, stage-segregated production spaces, hundreds of daily data points feeding a central performance database. The company established a multi-product commercial strategy spanning fresh larvae for local poultry farms, dried BSF meal for aquaculture, BSF powder for human food aid, and frass fertilizer for agriculture. The circular vision EXA is building toward is ambitious: brewery waste feeds larvae, frass fertilizes maize, crop byproducts re-enter the system as larval feed ingredients, and locally produced BSF meal and maize combine to formulate a complete chicken feed in which both protein and energy are sourced entirely from waste streams.

**EXA is treating scale growth as a series of replicable steps rather than a single transformative leap.** EXA Feed has recently entered a new phase of scaling through vertical farming. Drawing on the biological and operational standards developed in earlier rearing systems, the firm sourced specialized trays and equipment and adapted a poultry house-inspired building — fitted with oversized ventilation and evaporative cooling pads — to house pallets of insect rearing trays at density. Crucially, knowledge accumulated from a year of horizontal rearing translated directly into this new format: EXA tested and refined protocols within the building before locking them in for replication. With the vertical system

validated, scaling becomes a question of quantity rather than reinvention, with a target of six metric tons of fresh larvae per day in the near term.

**EXA's multi-product strategy allows operational refinements that single-market operations could not easily implement.** Manganese — a heavy metal that BSF larvae accumulate moderately from substrate (Bessa et al. 2021) — varies enough across food-grade ingredients to matter for products entering the human food market while not mattering for animal feed and frass. Rice bran, a locally abundant carbohydrate ingredient in northern Madagascar, carries substantially more manganese than corn bran. As EXA's monitoring of larval composition through 2024 and 2025 surfaced this variability, the production response was straightforward: corn bran replaced rice bran in the substrate going to human-food larvae, while rice bran continued to be used for substrate going to feed and frass production. The manganese levels in the rice-bran-fed larvae remained within tolerance ranges for animal feed and for adult human consumption. The substitution was a precaution for the human food pathway, where margins narrow for malnourished children whose nutrient absorption is less tightly regulated than in adults. The substitution itself is an ingredient swap rather than an architectural change, and the economics work because the human-food premium absorbs the input cost differential.

## BSF Tamatave – Tamatave, Eastern Madagascar

**BSF Tamatave began with an individual, self-taught woman entrepreneur.** Lamiah was a trader whose distribution business in Tamatave was severely disrupted by Covid. Facing economic uncertainty, she made a deliberate pivot: agriculture and livestock, she reasoned, were the only activities capable of functioning through a crisis. She relaunched a family farm with 500 laying hens, immediately confronting feed costs consuming nearly eighty percent of operating expenses. Searching for alternatives, she noticed BSF larvae in her chickens' droppings and recognized what they were doing. With no commercial strain available in Madagascar, no local expertise, and no external support, she taught herself the biology from a Swiss Federal Institute of Aquatic Science and Technology (EAWAG) manual (Dortmans et al. 2021) and YouTube videos. She began experimenting in a small garage with whatever substrates were available locally, including chicken manure, kitchen scraps, restaurant waste, and agricultural residues.

**Four years of compounding ingenuity in inputs, infrastructure, and communication led to profits and formalization.** Lamiah identified a supply of low-grade, moisture-damaged wheat bran rejected at the port of Tamatave during shipping, a material most would discard. She recognized it as a reliable and cheap moisture regulator and substrate stabilizer, turning one industry's waste into a technical solution for BSF. She fermented restaurant waste to tame its unpredictable water content. Rat infestations led to pragmatic solutions: hard barriers around the highest-value biological stock (eggs and young larvae) and cats for the rest of the site. Horizontal basins gave way to vertically stacked trays when space became a constraint. She shared her progress openly on social media, which attracted customers wanting BSF strains to start their own operations. Those early revenues funded land acquisition and the next round of infrastructure. At every stage, she self-financed the operation's growth. BSF Tamatave was formally registered as a company in January 2024, supported by repayable funding from the USAID-backed Mitsiry program — $5,000 in an initial phase and $15,000 in an acceleration phase — which introduced financial discipline, formal reporting, and a structured business model.

**A series of increasingly large institutional partnerships allowed further growth**. Juvenile larvae from BSF Tamatave were introduced into a 30,000-hen poultry operation to process manure, reducing waste volume and providing a harvestable protein stream that cut feed costs by around thirty percent. Frass from the process fertilized maize crops, closing a complete waste-to-feed-to-fertilizer loop. BSF Tamatave does not operate the poultry farm, but it provides the biological key that makes the whole system work. At Ambatovy, one of Madagascar's largest mining companies, BSF Tamatave is converting five tons of daily cafeteria waste that had previously been burned or buried into approximately one ton of larvae, demonstrating that large industrial actors can become substrate partners and turn a waste liability into an economic input. The "Green Bazaar" project, developed in partnership with the Urban Commune of Tamatave, collects and sorts organic market waste at source — processed by paid dockworkers — and converts it into larvae and frass, reducing landfill costs and creating daily employment.

**BSF Tamatave has also become a key node of BSF knowledge in Madagascar.** The company's founder has trained over 3,000 people in BSF farming across the country — individual farmers, cooperatives, NGOs, and technical institutions — through practical, locally adapted training sessions developed from her own experimentation. This dissemination work took on institutional form through a partnership with the Association Forum du Conseil Agricole, which helped formalize her field experience into a transferable curriculum. A separate program, funded by a $10,000 grant from Conservation International's Adaptation Accelerator, directed this knowledge toward conservation objectives: 42 community members living around Ivoloina Park participated in training on BSF rearing and frass use as a sustainable economic alternative to forest resource extraction. Eighty percent of participants reached a satisfactory proficiency level and 83% now recycle their organic waste. The program demonstrated that BSF can function not only as a production system but as a tool for community-level ecological transition, providing substitute livelihoods that reduce forest-pressure dependence while delivering household-scale benefits in waste management and feed costs.

**Frugal infrastructure can increase vulnerability.** In early 2026, Cyclone Gezani destroyed BSF Tamatave's hangars, equipment, and inventory. The frugal infrastructure that had enabled entry proved acutely vulnerable to extreme weather. The response — a structured cyclone protocol, reinforced storage for biological stock, and a reassessment of what climate-resilient infrastructure actually requires — produced a hard lesson that BSF Tamatave has documented and shared openly.

*"Frugality enables entry, but resilience ensures survival. Climate-proof infrastructure must be integrated from the start. Reconstruction costs far exceed the cost of resilient planning."*
*— Lamiah, BSF Tamatave Founder*

**The two cases above differ in operational architecture, but both respond to local needs and opportunities.** When compared side by side (see Table 2.1), the point is not which model performs better, but how each firm's choices follow from a different starting point and holds together as a coherent system. Each operation's choices are mutually reinforcing within their own logic — EXA's site, capital, and energy decisions form one coherent system; BSF Tamatave's substrate, infrastructure, and capability-transfer choices form another. The two systems are not interchangeable, and neither could have been arrived at by adjusting parameters within the other.

| Table 2.1: A comparison of BSF Tamatave and Exa Feed | | |
|---|---|---|
| | **EXA Feed** | **BSF Tamatave** |
| Founded by | Entrepreneur and scientists | Trader-turned-farmer responding to feed-cost crisis |
| Starting capital | Investor equity + grant funding | Own resources; later repayable donor grants |
| System type (Diener & Storey, 2025) | Centralized Medium Scale Facility (System 5) | Decentralized/waste-management hybrid (System 3 + Waste Management model) |
| Approach | Purpose-built industrial facility | Frugal, community-embedded operation |
| Substrate strategy | Concentrated: Ten-year brewery offtake contract (spent grains) & agro byproduct | Diversified: restaurant waste, manure, market organics, port-rejected bran |
| Energy | Off-grid solar; purpose-built infrastructure | Grid-dependent; low-cost materials |
| Data approach | Hundreds of daily data points; formal KPI system | Observation-first; simple weight and yield records |
| Climate advantage | Site selected for near-ideal BSF climate; | Coastal tropics; managed through substrate and practice |
| Primary markets | Human food, aquaculture meal, poultry, pet food | Fresh larvae (poultry/fish), dried meal, frass, pets, strain sales |
| Knowledge role | Internal R&D; scientific advisory | Trained 3,000+ farmers nationally; formal curriculum; Donor-funded community program |
| Climate resilience | Solar independence; controlled-environment facility; cyclone-resistant construction | Vulnerable; cyclone damage in 2026 drove protocol development |
| Source: Authors. | | |

## 2.4 Pathways Forward

### The three pathways

**Successful BSF operations of all sizes focus on learning for adaptation and growth.** EXA Feed and BSF Tamatave offer two distinct answers to the question of how BSF scales, illustrating the centralized and

hybrid pathways respectively. What is striking is not their difference but their convergence on a single underlying principle: neither operation skipped the learning phase. Both started small, built knowledge systematically from local conditions, and expanded capacity only when biology, substrate supply, and operational protocols were sufficiently understood to justify it. All three pathways share that discipline — more than capital, climate, or technology — and it is what made scaling possible in each case. A third pathway operates at household scale across several African contexts, less commercially structured than EXA's or BSF Tamatave's but shaped by the same underlying discipline.

### The Capital-light Pathway — Starting from a Problem

BSF Tamatave's trajectory illustrates how BSF production can begin with almost no capital and scale through reinvestment, observation, and partnership. Its stages are recognizable and have proven replicable — the organization's founder has trained over 3,000 people in the same approach across Madagascar.

**Stage 1. Start with whatever waste is nearby and observe carefully.**
Lamiah began what became BSF Tamatave with chicken manure, kitchen scraps, and restaurant waste — whatever was available locally — and learned through direct observation what worked and what did not. No laboratory, no consultant, no external funding. A garage, a few trays, and access to organic material were sufficient to begin. The entry point for BSF is genuinely small, and the knowledge gained at small scale is the foundation for all that follows.

**Stage 2. Identify a reliable, cheap substrate and build a stable protocol around it.**
The transition from experimentation to production happened when Lamiah identified a consistent waste stream and developed a repeatable protocol for using it. Low-grade wheat bran from the port — rejected during shipping and available cheaply — became the moisture regulator that made variable restaurant waste manageable. The substrate question was solved before capacity was expanded. In BSF Tamatave, scaling an unstable input would have amplified problems rather than output.

**Stage 3. Let market relationships and knowledge precede infrastructure investment.**
Early revenue came from selling BSF strains — a product requiring almost no processing — to people wanting to start their own operations. Those revenues funded land acquisition. The social media community built around transparent documentation of the process generated customers, credibility, and eventually institutional interest. Infrastructure followed knowledge and market relationships, not the other way around. BSF Tamatave was formally registered as a company only in January 2024, two years after starting in a garage, when there was a real business to structure.

**Stage 4. Scale by embedding in existing systems, not only by expanding the facility.**
BSF Tamatave's most significant scaling step was not expanding its own production space — it was introducing larvae into a 30,000-hen poultry operation, a mining company's waste stream, and a municipal market waste system. In each case, BSF Tamatave provided a biological input that made someone else's system more efficient and more circular. This partnership model allowed the operation to process far more substrate than its own facility could handle, generate revenue from multiple sources, and build institutional relationships that provided both feedstock security and market access, without requiring commensurate capital investment.

**Stage 5. Accept that setbacks are part of the learning process, not the end of it.**

Every BSF operation encounters failures: substrate protocols that don't transfer, biological stock that doesn't perform as expected, infrastructure that proves inadequate under conditions that weren't anticipated at the planning stage. What distinguishes operations that improve from those that collapse is not the absence of setbacks but the presence of enough biological knowledge, operational resilience, and partnership depth to rebuild from them. The learning-first approach is not just a path to scale, it is what makes recovery possible when things go wrong. The knowledge and relationships that made the operation viable in the first place remain intact even when the physical infrastructure does not.

## The Capital-Intensive Pathway — Designing for Industrial Scale

EXA's trajectory is not a larger version of BSF Tamatave's, it is a different model, with different preconditions and a more formally structured learning phase. The decisions associated with an operation co-located from the beginning with an industrial-scale partner are higher-stakes, but the underlying logic is the same: knowledge before capacity.

**Stage 1. Treat substrate security and climate suitability as site selection criteria, not operational variables.**

EXA's founding logic was site selection. The brewery in Diego Suarez provided a guaranteed substrate at negligible cost, and the site itself sat in a climate near-ideal for BSF rearing. These two factors — feedstock security and climate advantage — were treated as non-negotiable prerequisites before any infrastructure commitment. The commercial rationale for the Diego Suarez facility depends directly on both: without the brewery contract and the climate, the economics look substantially worse.

**Stage 2. Use the pilot phase to generate knowledge, not just product.**

EXA Feed operated a pilot facility in Antananarivo for two years before building in Diego Suarez. That pilot was a knowledge-generation exercise as much as a production operation: substrate formulations, nursery protocols, aviary design, environmental control, KPI frameworks, and staff training methods were all developed and tested at pilot scale before transferring to the target site. What moved north from the capital to Diego Suarez was a working production system, not a hypothesis.

**Stage 3. Invest in infrastructure that eliminates existential risks upfront.**

Two of EXA's most consequential infrastructure decisions — going off-grid with solar and cyclone-proofing the facility — share a logic but differ in character. Going off-grid was largely constraint-driven. Grid electricity in Diego Suarez is expensive (roughly twice the Antananarivo tariff and entirely fossil fuel-based), unreliable enough that operations connected to it typically run a generator alongside it, and prone to transient power-quality issues that damage sensitive environmental-control equipment without protective hardware. For a biological operation requiring continuous environmental control, the question was therefore not whether to invest in independent power but how. EXA's choice was to commit capital up front for solar with battery storage rather than carry the cost as a recurring operational expense for grid electricity, generator backup, fuel, and power-quality protection. Once that capital is committed, the marginal cost of producing a kilowatt-hour at EXA Feed runs at roughly one-third of the national grid tariff. That comparison includes operations & maintenance, generator fuel costs, and amortization of solar capital expenditure and batteries (EXA Feed, internal data). The all-in figure is specific to this site: it reflects Diego Suarez's high tariff, low grid reliability, and the avoided cost of power-quality protection that grid-tied operations would

otherwise bear. In a context with a cheaper, more reliable grid, the comparison would look different. Cyclone-proofing was a separate hedge: northern Madagascar sits in an established cyclone corridor. Cyclone Gezani's destruction of BSF Tamatave's facility in early 2026 illustrates the cost of treating climate-resilient construction as optional. Whether EXA's specific construction proves adequate is something a future major cyclone will test directly. What can be said now is that the company identified, costed, and addressed cyclone risk at the design stage rather than absorb it when storm damage materialized.

**Stage 4. Structure the commercial model across multiple value streams from the outset.**
EXA's commercial strategy was always multi-product: fresh larvae, dried meal, BSF powder for human food, frass fertilizer, and oil from processing. This is not opportunism but risk distribution. A single-product operation is exposed to price and demand volatility in one market, while a multi-product operation can absorb shocks to one stream while others generate revenue. EXA factored each product's required processing infrastructure into the facility design, rather than add them later.

**Stage 5. Lock in protocols before replicating.**
When EXA Feed moved to vertical farming — pallet-based rearing in a purpose-adapted building with industrial ventilation and cooling — the team did not assume that horizontal protocols would transfer automatically. They tested and validated within the new format before committing to replication. As a result, each additional rearing unit added to the system is a known quantity: its performance is predictable because it has been demonstrated, not modeled. This is EXA's answer to the common pitfall of scaling before the protocols are ready, an error that has been the undoing of many insect companies.

## The household pathway

**Household operations rarely produce the longitudinal records that commercial enterprises do, but share the learning-and-adaptation first approach of the previous two pathways.** The household pathway runs alongside the two commercial tracks, but the available evidence is different. As a result, this section characterizes the pathway from cross-sectional evidence rather than tracing a single operator's stage-by-stage trajectory. The available evidence — Kanane Bikanyale's farm system in Kyaka II settlement in Uganda, refugee pilot beneficiaries in Kenya, Malawi, and Zimbabwe, and microfarms in the Madagascar Biodiversity Center network — points to a pathway that works differently from the commercial tracks while sharing their underlying discipline.

**Scaling runs through farm-system integration, not facility expansion.**
The household pathway begins where Lamiah's did when building BSF Tamatave: with on-farm waste, no external capital, and learning at small scale before any expansion. What differs from both commercial tracks is the direction of scaling. A household operation that succeeds does not typically grow by expanding production capacity. It grows by integrating BSF more deeply into the surrounding farm system. Kanane's trajectory illustrates this: 30 chickens became 500–800 not through larger BSF infrastructure but because the larvae allowed the poultry operation to absorb the feed cost pressure that had previously capped it. Tilapia farming, frass-fertilized horticulture, and mealworm farming followed in sequence rather than as expansions of the BSF unit itself. The BSF facility remained modest; the farm system around it transformed.

**Returns are realized as cost reductions, not sales revenue.**
The household pathway also differs from the commercial tracks in how it captures value. Most household operations realize their returns as cost reductions — feed and fertilizer not purchased, livestock losses no longer absorbed — rather than as sales revenue (Meerts et al. 2023). Where sales emerge, they emerge informally and opportunistically: a neighboring farmer willing to buy starter larvae, a local poultry keeper absorbing surplus production. The cost-reduction logic also explains why household operations are durable under conditions that would close a commercial enterprise. There is no margin to defend, no buyer to lose, and the operation's value to the household persists whether or not an external market exists.

**The ceiling is set by demand, not supply.**
The same logic that makes household operations durable also binds them. Kanane's farm produces larvae reliably enough to supply other farmers. What is missing is the demand. Whether a household operation transitions to commercial scale depends on whether a market emerges around it, such as formal aggregation, a feed processor willing to absorb dispersed supply, or a local off taker scaled to what household production can actually deliver.

## The shared discipline

**Across all three pathways, the same principle holds: expand what you understand, not what you hope will work.** EXA Feed spent two years in Antananarivo before building in Diego Suarez. Lamiah spent two years in a garage before registering BSF Tamatave. Kanane Bikanyale's farm grew from 30 chickens to 500–800 by integrating BSF before adding tilapia, frass-fertilized horticulture, and mealworms in sequence. All three made mistakes — aviary designs that failed, substrate protocols that did not transfer, infrastructure that proved vulnerable — but all three improved because those mistakes happened at a scale where they could be absorbed. The learning phase is not a delay on the way to scaling. It is what makes scaling possible.

## Shared Lessons for BSF Development Programs

The lessons below draw on EXA Feed and BSF Tamatave in Madagascar, household-pathway evidence from Uganda, Kenya, Malawi, Zimbabwe, and Madagascar, and value chain assessments from Madagascar, Kenya, and Uganda. They are presented thematically rather than by case, because the convergence across scales, contexts, and capital structures is what makes them lessons rather than observations. They have emerged independently across the African evidence base, which suggests they are characteristic of what BSF requires under African conditions rather than artifacts of any single context. They are written for development program designers and implementing partners considering BSF as a tool in agricultural or food-security programming.

**1. Substrate security is a first step that should precede site selection.**
The operations that succeeded across the African evidence base did so in part because they secured substrate before committing to scale. EXA Feed secured a ten-year brewery feedstock agreement and selected its site based on proximity to that source. BSF Tamatave built a diversified portfolio of waste partnerships — poultry farms, mining operations, municipal markets — that gave it feedstock resilience no single source could provide. In Jamjang, South Sudan, refugee-camp production groups began negotiating formal diversion agreements with municipal collectors, local cafeterias, and market vendors when opportunistic substrate access proved insufficient (Verner et al. 2022). In each case, the underlying logic was the same:

without guaranteed, consistent, and affordable substrate, conversion rate targets are meaningless, and production economics cannot stabilize.

**Paying for substrate makes the economics of BSF much more challenging**. Where substrate can account for 81–90% of total BSF production costs, the model becomes punishing: substrate costs crowd out the margin BSF needs to compete with conventional protein sources (Roffeis et al. 2018; Beesigamukama et al. 2022). In a Kenyan smallholder census, substrate volume became the strongest positive predictor of profitability where substrate was obtained at low or no cost, with each additional unit of substrate flowing almost directly to gross margin (Mutuku et al. 2022). Among operations that have established reliable production, the most consequential economic variable is therefore whether substrate is genuinely free or near-free at the farm gate. In conventional livestock farming, feed cost is the binding constraint. For BSF farms drawing on waste streams, the binding constraint is volume, but only when the waste itself is free. Programs that fund BSF training and infrastructure without first establishing what the substrate actually costs, where it actually comes from, and at what volume it can actually be supplied, produce operators who cannot maintain production.

### 2. Climate is an input, not a backdrop.

EXA Feed's commercial rationale depends on a climate advantage: northern Madagascar's stable tropical conditions sharply reduce the environmental-control burden that dominates BSF operations in temperate zones. BSF Tamatave's coastal setting similarly reduced the need for environmental control. Climate can also work against operations. EXA's early aviary suffered from wind disruption, solar heat gain through glass, and seasonal humidity swings, problems that destabilized egg production until the company implemented controlled-environment solutions. BSF Tamatave lost its facility to Cyclone Gezani in early 2026. Site selection for BSF programs must account not only for average conditions but for seasonal extremes and the climate risks specific to the region.

### 3. Consistency is harder than productivity, and more important.

The single most persistent challenge at EXA and BSF Tamatave was variability: in egg production, substrate moisture, larval survival, and juvenile counts. The breakthroughs that mattered most were not the ones that improved peak outputs but rather the ones that eliminated unpredictability. EXA's path to stable egg production illustrates this: shifting to purpose-designed aviary lighting and reformulating oviposition attractants from seasonal market waste to fermented dead adults and frass delivered consistency that productivity gains alone had not. Those changes also retrospectively explained much of the company's early underperformance. BSF Tamatave achieved the same outcome at lower cost through a fermentation protocol for restaurant waste and the use of recycled frass as a substrate stabilizer in place of wheat bran. In both cases, reliability proved more valuable than peak performance. The same dynamic appears at sector scale: value chain assessments in Kenya and Uganda found that consistency in biological performance, not peak output, is what most reliably distinguishes producers who continue operating from those who do not (Meerts et al. 2023). Program design that rewards peak output rather than sustained consistency will misidentify which operations are stabilizing into viability

### 4. Data transforms observation into knowledge — but simplicity matters at entry level.

EXA Feed operated a formal data system: hundreds of daily data points, key performance indicator tracking, staff calibration exercises for insect counting, and protocols that triggered intervention whenever

performance diverged from baselines. This investment was what allowed EXA to improve systematically and to distinguish genuine progress from seasonal noise. BSF Tamatave began with a notebook: egg weight in, larvae at five days, larvae at harvest, substrate consumed. These four numbers were enough to answer the questions that mattered in the early stages: how much does one gram of eggs produce, and is that getting better or worse over time? Both approaches were right for their scale. The lesson is not that all BSF operators need industrial data systems, but that some form of disciplined measurement is indispensable from day one. The simplest useful system of measurement is more accessible than many assume. Programs that emphasize training and infrastructure without equipping operators to measure their own performance leave them unable to learn from their own experience and leave donors unable to tell whether the operations they have funded are working.

**5. Labor efficiency must be engineered, not assumed.**

Several of EXA's most significant operational gains came from logistics rather than biology: consolidating eight small mating cages into two large ones, standardizing neonate dosing with a calibrated scoop, and redesigning nursery trays for direct tray-to-tray transfer, which eliminated manual redistribution of juveniles. BSF Tamatave's shift from horizontal basins to vertical stacked trays addressed the same underlying constraint, producing more from a given footprint without proportionally more labor. In both operations, the efficiency gains that mattered most were structural, built into the design of processes and spaces rather than managed through effort alone. Programs that fund BSF infrastructure without paying attention to its labor implications produce operations whose costs grow proportionally with their output.

**6. Biosecurity is a facility design decision, not a management response.**

EXA's pilot facility had no sanitary airlock between production and the outside environment. As a result, housefly incursions were chronic. Wild fly contamination in rearing trays is not merely a pest problem. It undermines larval performance, corrupts quantitative records, and creates food-safety risk for operations producing for human consumption. BSF Tamatave's response to rat infestations was pragmatic — protect the highest-value biological stock (eggs and young larvae) with hard barriers and deploy cats elsewhere — but it was a workaround for a structural gap. The principle holds across operations: biosecurity features built into facility design are more effective and less costly than the management burden of compensating for their absence. Programs that fund BSF infrastructure without specifying biosecurity at the design stage trade a one-time capital cost for an ongoing operational burden, usually at higher total cost. Biosecurity also runs in the other direction. The same containment that keeps wild flies, pests, and contaminants out of the colony is what keeps farmed larvae from escaping into the surrounding environment, where, at scale, escapes of imported domesticated strains raise genetic and disease risks to wild BSF populations. Designing for containment therefore serves both the operation and the environment around it; the biodiversity and biosecurity risks this addresses are discussed in section 2.2.

**7. The circular economy case is real, but it requires relationships and active integration.**

Several operations in this report moved beyond simple waste-to-larvae conversion toward genuinely circular systems: frass as fertilizer, frass as substrate conditioner, and larvae cycled back into the feed chains that generated the original waste. BSF Tamatave's partnership model shows that the circular loop need not be owned by a single entity. EXA's ambition to produce a complete chicken feed from locally sourced waste streams illustrates a more vertically integrated version of the same logic. At the smallest scale, Kanane Bikanyale's farm in Uganda integrates the loop directly: poultry housed over a fishpond, BSF larvae feeding

both, frass fertilizing a tomato garden, and mealworms supplementing household nutrition — five productive systems closing a single waste stream into successive uses. In all of these cases, circularity required deliberate partnership-building and a willingness to engage waste generators as partners rather than as transactional input suppliers. It did not happen automatically. Chanzi's operation in Tanzania and Kenya extends circularity in a different direction. The operation pyrolyzes the woody material BSF cannot bioconvert, producing biochar that it then sells as a soil amendment, combines with frass into a carbon-sequestering product, or recirculates into bioconversion as a substrate amendment. Programs that fund BSF infrastructure as if circularity were a feature of the technology rather than of the relationships built around it produce operations that fall short of their development case.

**8. Infrastructure investment horizons differ fundamentally between models.**

EXA's off-grid solar facility, purpose-built rearing infrastructure, and controlled-environment production spaces represent a capital commitment that is not accessible to smallholders or most early-stage commercial operators. BSF Tamatave's frugal approach allowed entry at a fraction of that cost, but the deferred resilience investments left the operation vulnerable to climate shocks, as Cyclone Gezani demonstrated. At the household scale, Kanane Bikanyale's farm system extended the range further, with small-scale, locally fabricated structures such as love cages, larval trays, and integrated poultry housing built incrementally as the operation grew, rather than purchased or deployed at the outset. No model is universally applicable. Each is appropriate to a different stage of operator development, a different risk profile, and a different financing context. The three operations together illustrate the range of investment structures that BSF can accommodate, from incrementally built household-scale infrastructure to frugal commercial entry to capital-intensive industrial construction. Programs that promote a single infrastructure model across diverse contexts misallocate capital, either by funding industrial-scale infrastructure that the operator cannot sustain or by funding smallholder-scale tools where commercial volume is achievable.

**9. Human food application is achievable, but the operational pathway is longer than for animal feed.**

EXA's BSF powder and crackers passed quality control testing and confirmed cultural acceptability in field research. These trials were conducted within broader research efforts in Madagascar, including work led by the Madagascar Biodiversity Center, which integrate product development, behavioral research, and school-based feeding interventions. Insect consumption is already part of the diet in many regions of Madagascar, and field research has confirmed acceptance of BSF specifically. Human food also offers BSF producers price premiums over animal feed in many contexts. The human food market does, however, require a pre-harvest fasting protocol, stricter substrate controls, more rigorous quality assurance, and longer regulatory engagement than the animal feed market. In EXA's commercial model, the animal feed market provides near-term revenue while the human food pathway is developed in parallel. Programs that pursue human food applications without a parallel animal feed revenue stream commit operations to extended development periods without operating income.

**10. Demonstrating that BSF works is not the same as making it self-sustaining.**

Pilots across Kenya, Malawi, and Zimbabwe show two distinct categories of difficulty (see chapter 4). The first is to achieve a stable production. Not all pilots that begin operations achieve consistent biological output, and the path from initial training to a functioning colony has often required multiple cycles of beneficiary attrition, technical troubleshooting, and group reorganization before something resembling stable production emerges. The second category — and the one that catches programs most unprepared —

is what happens after demonstrated biological viability. The infrastructure is there, the colonies are productive, the operators are skilled. What is missing is the business architecture: market relationships that generate revenue independent of program subsidy, financial planning that survives the funding cliff when implementing partners exit, and pricing that reflects actual production costs rather than donor-absorbed costs. Programs that treat business development as a follow-on to technical training, rather than as an embedded design element from the outset, leave operators with the technical skills to produce but without the commercial structure to sustain production once the program ends. Program designers must plan for, rather than assume this mindset shift from aid recipient to skilled producer. The most consequential design decision a development program can make is whether business viability is treated as the goal from day one or an aspirational outcome that will eventually emerge on its own following technical success.

### 11. Sector-level institutions matter as much as individual operator capability.

A group, even a large group, of capable individual BSF operators is not yet a functioning sector. Value chain assessments in Madagascar, Kenya, and Uganda all identify a similar gap: BSF entrepreneurs build operations, develop technical expertise, and generate informal knowledge networks, but the institutional architecture that translates individual capability into sector capacity is largely absent. Sector associations exist in name in some countries but lack the membership, governance structure, and operational capacity to advocate to government, structure market relationships with poultry and aquaculture producer associations, or coordinate standards. Training pathways run parallel to existing extension and vocational systems rather than embedded within them, meaning each new operator largely starts from scratch instead of inheriting accumulated sector knowledge. A different model is research-institution-anchored networks like Madagascar Biodiversity Center's 266-farm network, where ongoing monitoring rather than ongoing support is the institutional contribution. Operators decide whether BSF is worth their effort, and the network learns which conditions and operator profiles sustain production. This produces sector knowledge of a different kind — not which operations the institution kept afloat, but which operators chose to continue. Most financial instruments are not designed for BSF cash flows: standard microcredit at roughly 20% annual rates is incompatible with production cycles that require multi-month learning curves and inventory-heavy operations, leading Malagasy producers to explicitly decline microcredit as unworkable (see chapter 3). Where these institutions are absent, what fills the gap is at best informal coordination such as lead farmers training others, knowledge-sharing in WhatsApp groups. At worse, active mistrust emerges, such as regulatory grey zones unaddressed by any sector body and Kenyan producers competing rather than collaborating (Meerts et al. 2023). Development programs that focus on individual operator capability without investing in sector institutions are building structures that hold only as long as the program lasts. Sector institutions — associations, research-institution-anchored networks, integrated training pathways, blended finance instruments aligned to BSF cash flow realities — are what convert individual successes into a sector that can sustain new entrants without external support. Different institutional forms address different aspects of a flourishing sector, from advocacy to monitoring to financing, and most of these functions are absent from the African BSF landscape.

The contrast is sharpest at continental level. North America, Europe, Asia, and Australia each have an industry coalition — NACIA, IPIFF, AFFIA, and IPAA respectively — that consolidates regulatory engagement, develops standards, curates research, and represents the regional sector in global forums (see Box 2.13 for one example of how this work is structured in practice). Africa is the only major insect-farming region without an equivalent body, and African positions in global insect-agriculture discussions are

currently presented by individual researchers, donor-funded projects, or by other regions' coalitions speaking on Africa's behalf. The institutional layer that NACIA performs for North America and IPIFF performs for Europe does not yet exist for Africa, and the gap is most consequential precisely at the moment when the sector is establishing the standards, regulatory frameworks, and market relationships that will shape it for decades.

**Box 2.13**: **Black Soldier Fly Frass — Building the Science and Systems for Adoption**

The North American Coalition for Insect Agriculture (NACIA) serves as the industry convener and advocacy voice for insect agriculture across North America.

The Frass Institute, a program of the NACIA Foundation, operates globally to advance the science, standards, and practical application of insect frass. NACIA focuses on policy, regulatory engagement, and industry coordination. The Frass Institute serves as global connective infrastructure for frass-related research and application by:

- Curating global research on frass and soil health
- Supporting consistent evaluation methods and datasets
- Connecting research with practical agricultural use
- Providing a neutral, science-based resource

Who benefits

- Commercial insect producers
- Farmers evaluating frass
- Researchers and public institutions
- Regulators and policymakers

Interest in frass is growing as a tool to improve soil health, enhance nutrient use efficiency, and recover value from organic materials. Adoption depends on credible, comparable data, which the Frass Institute is working to organize and advance.

Key challenges

- Limited standardized evaluation methods
- Fragmented regulatory pathways
- Need for practical, user-facing guidance

Advice for emerging projects

- Focus on end-market fit early
- Generate data under real-world conditions
- Engage regulatory pathways early

*Source: The Frass Institute (NACIA Foundation).*

## What the African Evidence Tells Us

**Madagascar case study firms did not succeed *despite* their differences in model and scale but rather *because* of how those differences mapped onto context.** EXA Feed and BSF Tamatave each found an approach appropriate to its capital base, its founding knowledge, and its operational realities, and then iterated from there with rigor and discipline. Taken together, the Madagascar experience also shows the

importance of a broader research ecosystem, with institutions such as Madagascar Biodiversity Center helping generate the knowledge base that informs diverse operational pathways without being tied to any single enterprise model.

**The most important conclusion from Madagascar is not that BSF works but that none of its potential outcomes are automatic.** The technology, the circular economy logic, and the food security application are all achievable. They require the right substrate partnerships, the right site, the right infrastructure, and, at every scale, a discipline around data and consistency that distinguishes operations that improve from those that merely persist or those that disappear. The viability of BSF farming is not a question of scale. It is a question of context. and of whether the conditions that make it work have been treated as foundational rather than incidental.

## Works Cited


Barennes, Hubert, Maniphet Phimmasane, and Christian Rajaonarivo. 2015. "Insect Consumption to Address Undernutrition, a National Survey on the Prevalence of Insect Consumption among Adults and Vendors in Laos." *PLOS ONE* 10 (8): e0136458. https://doi.org/10.1371/journal.pone.0136458.

Barragán-Fonseca, K. B., Julián Cortés-Urquijo, Julián Pineda-Mejía, Diego Lagos-Sierra, and Marcel Dicke. 2023. "Small-Scale Black Soldier Fly-Fish Farming: A Model with Socioeconomic Benefits." *Animal Frontiers* 13 (4): 91–101. https://doi.org/10.1093/af/vfad030.

Barragán-Fonseca, K. B., D. Gómez, C. H. Lalander, D. Dzepe, and S. Y. Chia. 2025. "Review – Insect Farming for Food and Feed in the Global South: Focus on Black Soldier Fly Production." *Animal* 19 (August): 101397. https://doi.org/10.1016/j.animal.2024.101397.

Beesigamukama, D., B. Mochoge, N. Korir, et al. 2022. "Economic and Ecological Values of Frass Fertiliser from Black Soldier Fly Agro-Industrial Waste Processing." *Journal of Insects as Food and Feed* 8 (3): 245–254. https://doi.org/10.3920/JIFF2021.0013.

Bessa, Leah W., Elsje Pieterse, Jeannine Marais, Karim Dhanani, and Louwrens C. Hoffman. 2021. "Food Safety of Consuming Black Soldier Fly (*Hermetia illucens*) Larvae: Microbial, Heavy Metal and Cross-Reactive Allergen Risks." *Foods* 10 (8): 1934. https://doi.org/10.3390/foods10081934.

Biteau, Corentin, Tom Bry-Chevalier, Dustin Crummett, Ren Ryba, and Michael St. Jules. 2024. "Is Turning Food Waste into Insect Feed an Uphill Climb? A Review of Persistent Challenges." *Sustainable Production and Consumption* 49 (September): 492–501. https://doi.org/10.1016/j.spc.2024.06.031.

Bradshaw, Corey J. A., Philip E. Hulme, Emma J. Hudgins, Brian Leung, et al. 2024. "Damage Costs from Invasive Species Exceed Management Expenditure in Nations Experiencing Lower Economic Activity." Ecological Economics 220 (February): 108166. https://doi.org/10.1016/j.ecolecon.2024.108166.

Caruso, D., E. Devic, I. W. Subamia, P. Talamond, and E. Baras. 2013. *Technical Handbook of Domestication and Production of Diptera Black Soldier Fly (BSF), Hermetia illucens, Stratiomyidae.* IPB Press.

Chaix-Bar, Mathieu, Asaah Ndambi, and Somaya Naser El Deen. 2023. *Feasibility Study: Black Soldier Fly Production for Animal Feed in Ethiopia.* SWRE-RAISE-FS-23-012. RAISE-FS Manual 2. TRAIDE Foundation & Stichting Wageningen Research. https://edepot.wur.nl/637480.

Diener, Stefan, Bram Dortmans, Daniela Peguero, and Christian Zurbrügg. 2025a. *Simplified Black Soldier Fly Approach (SIMBA) – Grow-Out Unit: Standard Operating Procedure.* Eawag: Swiss Federal Institute of Aquatic Science and Technology. https://www.ccacoalition.org/resources/simplified-black-soldier-fly-approach-simba-grow-out-unit-standard-operating-procedure.

Diener, Stefan, Bram Dortmans, Daniela Peguero, and Christian Zurbrügg. 2025b. *Simplified Black Soldier Fly Approach (SIMBA) – Reproduction Unit: Standard Operating Procedure.* Eawag: Swiss Federal Institute of Aquatic Science and Technology. https://www.ccacoalition.org/resources/simplified-black-soldier-fly-approach-simba-reproduction-unit-standard-operating-procedure.

Diener, Stefan, and Chris Storey. 2025. *Transforming Organic Waste with Black Soldier Flies: A Guide for Decision-Makers, Entrepreneurs, and Implementers to Unlock the Organic Waste Potential of Black Soldier Fly Systems.* CCAC/UNEP. https://www.ccacoalition.org/resources/transforming-organic-waste-black-soldier-flies-guide-decision-makers-entrepreneurs-and-implementers-unlock-organic-waste-potential-black-soldier-fly-systems.

Dortmans, B. M. A., J. Egger, S. Diener, and C. Zurbrügg. 2021. *Black Soldier Fly Biowaste Processing — A Step-by-Step Guide, 2nd Edition.* Dübendorf, Switzerland: Eawag: Swiss Federal Institute of Aquatic Science and Technology.

Fels-Klerx, H. J. van der, L. Camenzuli, S. Belluco, N. Meijer, and A. Ricci. 2018. "Food Safety Issues Related to Uses of Insects for Feeds and Foods." *Comprehensive Reviews in Food Science and Food Safety* 17 (5): 1172–83. https://doi.org/10.1111/1541-4337.12385.

Francis, Aditya, Eric Schmitt, and Sergiy Smetana. 2025. "Making Better Bugs: Improving Black Soldier Fly Production for a More Sustainable Future." *Journal of Cleaner Production* 521 (August): 146240. https://doi.org/10.1016/j.jclepro.2025.146240.

FSA. 2023. *The Future of Animal Feed.* FSA Research Report No. FS900202. Food Standards Agency. https://doi.org/10.46756/sci.fsa.gzi586.

Fuhrmann, Adrian, Benjamin Wilde, Rafaela Feola Conz, et al. 2022. "Residues from Black Soldier Fly (*Hermetia illucens*) Larvae Rearing Influence the Plant-Associated Soil Microbiome in the Short Term." *Frontiers in Microbiology* 13 (September). https://doi.org/10.3389/fmicb.2022.994091.

Gasparri, Nestor Ignacio, Tobias Kuemmerle, Patrick Meyfroidt, Yann le Polain de Waroux, and Holger Kreft. 2016. "The Emerging Soybean Production Frontier in Southern Africa: Conservation Challenges and the Role of South-South Telecouplings." *Conservation Letters* 9 (1): 21–31. https://doi.org/10.1111/conl.12173.

Hlongwane, Zabentungwa T., Rob Slotow, and Thinandavha C. Munyai. 2021. "Indigenous Knowledge about Consumption of Edible Insects in South Africa." *Insects* 12 (1): 22. https://doi.org/10.3390/insects12010022.

Javourez, U., L. Tiruta-Barna, M. Pizzol, and L. Hamelin. 2025. "Environmental Mitigation Potential of Waste-to-Nutrition Pathways." *Nature Sustainability* 8 (4): 385–95. https://doi.org/10.1038/s41893-025-01521-z.

Joly, Gabrielle, and Josiane Nikiema. 2019. *Global Experiences on Waste Processing with Black Soldier Fly (Hermetia illucens): From Technology to Business.* Colombo, Sri Lanka: International Water Management Institute. https://doi.org/10.5337/2019.214.

Kleyn, Ellene. 2023. "The Environmental Impact of Fishmeal and *Hermetia illucens* (Black Soldier Fly) Larvae Meal in Aquaculture Feed, Utilising Life Cycle Assessment under South African Conditions." Master's thesis, Stellenbosch University. http://hdl.handle.net/10019.1/127277.

Kotch, Larry. 2026. "Insect Farming Business Plan: Why the Protein-First Model Is Dead." *Flybox Blog,* Flybox (Mana Biosystems Limited), March 29. https://flybox.bio/insect-farming-business-plan-protein-first-failure/.

Krishfield, Laura. 2023. "What Happened to AgriProtein?" *Lux Research,* July 5. https://luxresearchinc.com/blog/what-happened-to-agriprotein/.

Manfrini, Eléna, Franck Courchamp, Pierre-Olivier Maquart, et al. 2025. "Predicting the Biological Invasion Risks of the Most Farmed Insect for Food and Feed." bioRxiv preprint, posted October 31, 2025. https://doi.org/10.1101/2025.10.30.685499.

Manfrini, Eléna, Åsa Berggren, Franck Courchamp, et al. 2026. "Preventing Biological Invasions from Insect Farming: The Need for Stronger Biosecurity Measures in a Growing Industry." HAL preprint hal-05607879, submitted April 30, 2026. https://hal.science/hal-05607879v1.MBC. 2025. "A New Future for Farmers in Madagascar: BSF Farming Story." YouTube video. https://youtu.be/FCgCN6V_Y8k?si=1IXKKnKxis1WPLHh.

Meerts, A., L. Martinussen, and A. K. Muganga. 2023. *Mapping of the Black Soldier Fly Value Chain in East Africa.* Report prepared by Fair & Sustainable Consulting. FAO.

Munthali, Maggie G., Lemekezani Chilora, Mike Goliath, et al. 2023. *The Economic Cost-Benefit Analysis of Black Soldier Fly as an Alternative Animal and Fish Feed Ingredient in Malawi.* Working Paper. AgEcon. https://doi.org/10.22004/ag.econ.338590.

Omondi, Elvis, Margret W. Ngigi, and Joel O. Khobondo. 2025. "Technical, Allocative, and Economic Efficiency and Profitability of Black Soldier Fly Farming Among Smallholder Farmers in Selected Counties in Kenya." *Journal of Agricultural Science* 17 (10): p79. https://doi.org/10.5539/jas.v17n10p79.

Parker, Megan E., Valerie J. Stull, Chandrakant D. Agme, et al. 2026. "Black Soldier Fly Larvae and Cricket Fortified Crackers Are a Safe, Nutritious, and Acceptable Snack for School Children in Madagascar." *Scientific Reports* 16. https://doi.org/10.1038/s41598-026-52709-y.

RefIPro. 2026. *Final Project Evaluation: Refugee Insect Production for Food and Feed (RefIPro).* Internal evaluation report. RAISE, MAMAH, and Bobo Eco Farm.

Ricardo. 2025. *Life Cycle Assessment of UK Insect Protein Production Processes for Pig and Poultry Feed.* Project Report. UK Department for Environment, Food and Rural Affairs (Defra). https://sciencesearch.defra.gov.uk/ProjectDetails?ProjectId=21021.

Roffeis, Martin, Joana Almeida, Maureen Elizabeth Wakefield, et al. 2017. "Life Cycle Inventory Analysis of Prospective Insect Based Feed Production in West Africa." *Sustainability* 9 (10): 1697. https://doi.org/10.3390/su9101697.

Roffeis, Martin, Elaine C. Fitches, Maureen E. Wakefield, et al. 2020. "Ex-Ante Life Cycle Impact Assessment of Insect Based Feed Production in West Africa." *Agricultural Systems* 178 (February): 102710. https://doi.org/10.1016/j.agsy.2019.102710.

Roffeis, Martin, Maureen Elizabeth Wakefield, Joana Almeida, et al. 2018. "Life Cycle Cost Assessment of Insect Based Feed Production in West Africa." *Journal of Cleaner Production* 199 (October): 792–806. https://doi.org/10.1016/j.jclepro.2018.07.179.

Samson, William, Jaden Kim, Hewitt Plunkett, et al. 2025. "A Steady-State System for Farming Black Soldier Flies to Convert Agri-Food Waste into Frass and Other Value-Added Products." *Waste Management* 206 (September): 115073. https://doi.org/10.1016/j.wasman.2025.115073.

SIANI. 2026. "Farmer-Led Black Soldier Fly Farming Innovations in Madagascar." *SIANI Blog,* Stockholm Environment Institute International Agri-food Network (SIANI), January 15. https://www.siani.se/blog/black-soldier-fly-farming-innovations/.

Sustainable Manufacturing and Environmental Pollution Programme. 2024. *Waste-to-Insect Protein and Fertiliser: A Multi-Technology Industrial Organic Waste Solution.* UK Foreign, Commonwealth and Development Office (FCDO) and United Nations Conference on Trade and Development (UNCTAD). https://smepprogramme.org/project/takataka-solutions-ltd/.

Turbelin, Anna J., Bruce D. Malamud, and Robert A. Francis. 2017. "Mapping the Global State of Invasive Alien Species: Patterns of Invasion and Policy Responses." Global Ecology and Biogeography 26 (1): 78–92. https://doi.org/10.1111/geb.12517.

Verner, Dorte, Line Kristel Astrom, Maximillian Ashwill, et al. 2022. *Insect Farming to Reduce Hunger Risk in South Sudan: Lessons from Small-Scale Black Soldier Fly Production Pilots.* Washington, DC: World Bank.

Verner, Dorte, Nanna Roos, Afton Halloran, et al. 2021. *Insect and Hydroponic Farming in Africa: The New Circular Food Economy.* Washington, DC: World Bank. https://doi.org/10.1596/978-1-4648-1766-3.

Watson, Elaine. 2025. "South African Insect Ag Co Inseco Calls It Quits amid Power Cuts, Pivots: 'We Ran out of Time.'" *AgFunderNews,* October 15. https://agfundernews.com/south-african-insect-ag-co-inseco-calls-it-quits-amid-power-cuts-pivots-we-ran-out-of-time.

# Chapter 3. Madagascar Black Soldier Fly Value Chain Analysis

**This chapter analyzes Madagascar's black soldier fly value chain from sector conditions to farm-level business models.** It examines how BSF farming has developed in Madagascar, what markets it can serve, how producers source inputs and sell outputs, and which institutions shape the sector's growth. The analysis draws on sector mapping, stakeholder consultations, market data, institutional profiles, and five value chain cases covering micro-enterprise, semi-commercial, integrated farm, diversified commercial, and industrial production models.

**The chapter proceeds in three sections.** Section 3.1 profiles Madagascar's BSF sector, including its strengths, development priorities, supply chain, markets and end uses, institutional support structure, and the role of the Ministry of Agriculture and Livestock. Section 3.2 presents five value chain cases across different production models, from a solo micro-enterprise and semi-commercial farm to an integrated aquaculture-BSF system, BSF Tamatave, and EXA Feed. The section closes with a cross-case synthesis on how Malagasy producers capture value, manage substrate, build markets, and face shared constraints. Section 3.3 presents recommendations to strengthen the sector's enabling environment through producer coordination, aquaculture integration, organized waste supply chains, tailored finance, insurance, technical extension, standards dissemination, and market development.

**The chapter finds that Madagascar's black soldier fly sector is a commercially active, institutionally immature market with numerous opportunities for development.** This chapter finds that BSF farming generates positive returns at multiple scales and across multiple revenue streams, including larvae, eggs, frass, training, and equipment sales. The sector benefits from low barriers to entry and from demand alignment with the country's livestock sector. Madagascar is the first country in the world to establish a national standard for dried BSF larvae and larval powder for human consumption, a regulatory milestone that opens additional market opportunities. The analysis also identifies four structural constraints that limit scale: the absence of organized organic waste supply chains, inadequate access to appropriately structured finance, limited technical extension, and weak coordination among producers. The chapter's recommendations address these gaps through eight prioritized interventions, beginning with the establishment of a financially self-sustaining sector association and extending to blended finance instruments, insurance, aquaculture market integration, and sector visibility campaigns.

## 3.1 Sector Overview of Black Soldier Fly Farming in Madagascar

Section 3.1 establishes the foundation for the value chain analysis that follows by documenting the black soldier fly (*Hermetia illucens*) sector's commercial context, structural characteristics, and institutional landscape. It opens with BSF sector strengths and market opportunities, before turning to the sector's development history, which traces the emergence of BSF farming in Madagascar from isolated early experiments to its current state of dispersed but growing commercial activity. The section then examines the supply chain, with particular attention to substrate logistics and market linkages. A detailed market analysis follows, quantifying demand across livestock subsectors in poultry, aquaculture, and pigs. The section closes with profiles of the institutions actively engaged in the sector including government

ministries, research NGOs, international development partners, vocational training networks, and community knowledge platforms.

**Madagascar's black soldier fly farming sector is a remarkable story of entrepreneurial momentum that has moved beyond proof of concept.** In just a few years, driven by grassroots knowledge sharing, peer-to-peer learning, and a growing recognition of BSF larvae as a high-value, locally producible protein source, producers across the country have established commercially viable operations ranging from micro-enterprises launched with repurposed cooking oil containers to an internationally certified industrial facility operating on solar power. The sector has attracted engagement from international development partners, national research institutions, government ministries, and vocational training networks. Madagascar is the first country in the world to establish a national standard for BSF larvae and larvae powder for direct human consumption – a regulatory milestone that positions the country as a global pioneer in the insect sector. This chapter documents that ecosystem in detail: the market opportunity, the institutional landscape, and five in-depth value chain cases showing BSF farming in Madagascar as an already-functioning commercial reality, not only an emerging prospect.

## Sector Strengths, Opportunities, and Development Priorities

**Madagascar's BSF sector has proven models and demand, but realizing potential requires resolving organizational, financial, and regulatory constraints.** Table 3.1 presents a structured overview of the sector's strengths and market opportunities, based on field research and stakeholder consultations. The changes needed to fully realize these opportunities are addressed in the Recommendations section of this chapter.

## Sector Profile: BSF Farming in Madagascar

**Industry structure, market opportunities, and institutional landscape shape the BSF sector.** This section offers a collection of organizations involved in BSF in Madagascar, including public agencies, donor-funded programs, research entities, and producer organizations, with emphasis on their current roles and limitations.

### Sector development and history

**The BSF sector in Madagascar is less than ten years old, but its history is not fully documented.** The earliest documented external initiative to deliberately establish BSF farming in Madagascar was the ProciNut project, funded by the German Federal Ministry of Food and Agriculture (BMEL). ProciNut launched in 2018, with the first BSF training conducted in August 2019 and nine pilot farms established among farmers in Sandrandahy in early 2020. Prior to ProciNut, at least one BSF farming operation – Madagascar Century Food in Antsirabe – reportedly existed, but it ceased operations before 2018 and no longer exists. Attempts by Gasy Insectes Comestibles (GIC) in the early 2020s to obtain Madagascar Century Food's contact information were unsuccessful, leaving little verifiable information about its scale or activities. The longest-established active operation consulted for this study began in early 2022 (BSF Tamatave). Several other BSF farmers interviewed for this analysis indicated that BSF Tamatave was the first producer to effectively promote and demonstrate the benefits of BSF farming at scale. While this claim cannot be independently verified, it is a reasonable characterization given the company's relative success and its role in disseminating sector-related information through online content and public visibility.

| Table 3.1: Madagascar BSF sector strengths, opportunities, and development priorities | | |
|---|---|---|
| **Theme** | **Key finding** | **Significance** |
| Commercial viability across scales | BSF farming generates positive returns across a spectrum of production models – from micro-enterprises producing 12 kg per cycle to operations producing 150 kg per day – with multiple revenue streams including larvae, eggs, frass, training, and equipment sales. | The sector does not require a single optimal scale or business model; entry and growth pathways exist for producers at all resource levels. |
| Exceptionally low barriers to entry | Start-up capital requirements are minimal: a basic BSF micro-farm can be established for under US$60, using repurposed containers, a fabricated love cage, and a small quantity of eggs or pupae. | BSF farming is accessible to smallholders, women, youth, and rural households with limited capital, making it a broadly inclusive livelihood option. |
| Pioneering regulatory achievement | Madagascar is the first country in the world to establish a national standard for dried BSF larvae and larvae powder for direct human consumption (NMG 132-13, BNM, 2025), developed in partnership with EXA's certified production facility. | Legitimizes BSF as a food product, creates a commercial framework for high-value markets, and positions Madagascar as a regulatory trailblazer in the global insect sector. |
| Industrial-scale, standards-compliant production | EXA Feed operates a vertically integrated, solar-powered BSF production facility in Diego Suarez, certified to FSSC 22000 and HACCP food safety standards, with a production cost trajectory targeting US$0.55/kg at full scale. | Demonstrates a pathway toward industrial-scale, standards-compliant BSF production in Madagascar; full-scale commercial performance and international BSF market access remain to be demonstrated. |
| Large and growing domestic feed markets | Madagascar's commercial poultry sector implies a near-term addressable market of approximately 44,700 MT of wet larvae per year. The government's National Action Plan for Fisheries and the Blue Economy targets a 116 percent increase in fish production by 2028, creating direct demand for a domestically produced feed protein alternative. | BSF farming is structurally aligned with Madagascar's largest livestock subsector by headcount and its high-ambition aquaculture development agenda, both of which currently rely heavily on expensive or imported feed inputs. |
| Competitive advantage over imported feed | On-farm BSF-based feed costs 41% less per kilogram than imported commercial fish feed – before inland freight, importer margins, and retail markup – and Madagascar currently imports 93 to 100 percent of its commercial aquaculture feed from a single foreign supplier. | The economic case for BSF as a feed input is compelling and documented; supply reliability and price stability further strengthen the argument for domestic production. |
| Rural food security and livelihood opportunity | Madagascar's 91 percent indigenous scavenging chicken population, raised by smallholder households across the country, faces chick mortality exceeding 40% and adult mortality averaging 31%, both of which are reducible through supplemental BSF larvae produced at household scale from local organic waste. | BSF farming can improve rural household nutrition, income, and flock resilience without requiring cash inputs or formal supply chains. |

| | | |
|---|---|---|
| Circular agriculture value creation | A BSF-poultry integration model in which 5-day-old larvae are placed beneath cages to consume manure and grow into harvestable biomass projects MGA 18,000,000 per month in economic gain across a 300-cage farm, while reducing purchased feed costs by 30% and eliminating a waste management burden. | Demonstrates that BSF farming creates value for the livestock sector beyond the BSF producer alone, with replicable models applicable at any poultry farm scale. |
| Frass as a high-value agricultural input | BSF frass increases maize yields by 38% compared to cattle manure and supports native tree seedling survival rates of up to 95%, outperforming both cattle manure and synthetic NPK fertilizer in field trials. | Frass represents a significant additional revenue stream and a contribution to soil health, reforestation, and reduced reliance on synthetic inputs. |
| Active and diverse institutional ecosystem | Producers engage MINAE, BNM, MBC, GIC, FAMI, Health In Harmony, SIANI, JICA, Conservation International, GIZ/PADM, the Don Bosco vocational network, and a Facebook practitioner community of over 12,000 users. | Institutional engagement is broader and more active than the sector's nascent status suggests; the foundations for coordinated support already exist. |
| Organic waste abundance | Antananarivo alone generates an estimated 500 tons of food waste daily. Industrial sources such as brewery spent grain, market waste, abattoir by-products, and food processing residues are widely available across the country at little or no direct cost. | Substrate, BSF's primary input cost driver, is structurally abundant; the constraint is organization and logistics. |
| Premium downstream market validation | EXA Feed's BSF meal has been incorporated into R&D feeding trials by Acipenser Madagascar, Africa's only caviar producer, with projected annual procurement of 23,000 kg upon full adoption. Acipenser's caviar is sold internationally, providing a potential premium downstream market linkage for a Malagasy BSF ingredient. | Provides validation from a premium Malagasy buyer with international downstream markets; full adoption and export-oriented BSF market access remain to be demonstrated. |
| Source: Authors. | | |

**Early sector dissemination relied on informal knowledge-sharing, with more formal external support playing an important role.** Early mechanisms of BSF learning emphasized peer-to-peer learning, on-farm demonstrations, and adaptation of low-cost production methods – rather than on formal public extension services. The sector has nonetheless benefited from external engagement by donors, NGOs, and research organizations. Notably, the Madagascar Biodiversity Center, an NGO involved in extensive insect research, entered the BSF space around 2023, although not as a commercial farming operation.[1]

**Interest in BSF farming has increased rapidly.** BSF's momentum is increasing due to rising feed costs, environmental pressures, and growing demand for circular agricultural solutions. This has led to a proliferation of pilot initiatives, training activities, and externally supported projects across multiple regions. This growing momentum reflects genuine market pull and entrepreneurial energy. Formalizing coordination and strengthening institutional structures are the next logical steps for a sector that has already demonstrated commercial viability.

[1] Swedish International Agricultural Network Initiative. 2026.

### Sector structure

**Madagascar's BSF sector encompasses a diverse range of production systems and scales.** These include household-level micro-enterprises operated by a single founder to emerging commercial operations with multiple employees and diversified product lines, through to a fully integrated industrial facility with international food safety certification. This diversity is a strength: it reflects the accessibility of BSF farming across income levels and resource endowments, and the multiple pathways for producers to enter and grow within the sector. Production practices, inputs, and outputs are not yet formally standardized across the sector, which represents both an opportunity for quality improvement and a rationale for the extension and association-building activities addressed in Section 3.

### Data availability and registration

**Madagascar's BSF sector is growing, but formal tracking mechanisms fall short.** The number of registered BSF enterprises is not precisely known, for two reasons. First, access to business registration data held by the Economic Development Board of Madagascar (EDBM) – the central authority for business registration – is limited. EDBM did not provide the sector-specific information we requested during field consultations. Second, even if such data were accessible, existing classification systems do not distinguish BSF-related activities from other insect-related agriculture, making it difficult to identify relevant enterprises within broader groupings (e.g., general insect production, including cricket and mealworm production, or animal feed activities). As a result, BSF producers may be registered under multiple or broader categories, limiting the ability to quantify the sector accurately. In practice, the sector includes a mix of formally registered firms and a far more numerous set of informal producers, reflecting both access constraints and classification limitations.

## Supply Chain

**The BSF sector is highly accessible.** The supply chain is straightforward to enter, with low capital requirements and a wide range of locally available organic substrates serving as the primary input. Entry barriers are low, and production can begin with basic equipment and access to live biological inputs (eggs, larvae, or pupae). In practice, most new farmers are introduced through existing producers or training initiatives. The basic set-up for most new producers consists of plastic basins for nursery and grow-out stages, a screen or sieve to suspend eggs above the nursery basin, an adult fly cage ("love cage"), and oviposition supports ("eggies"). At small scale, expansion initially requires little more than additional basins and related equipment, with more specialized infrastructure potentially needed for commercialization.[2]

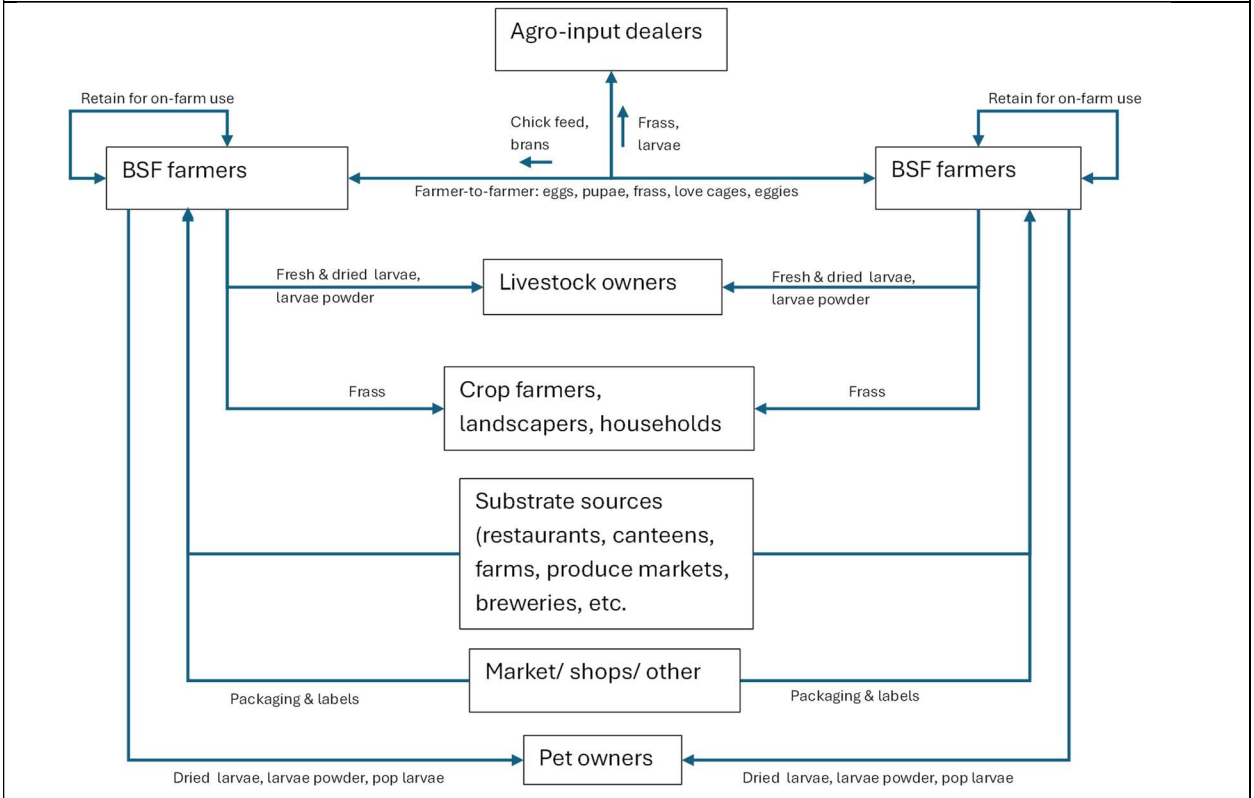
**Substrate drives BSF costs and nascent markets complicate revenue.** Farmers rely on a wide range of locally available substrates, including household and restaurant waste, market waste, farm waste, wheat/rice/maize bran, manure, brewers' spent grain, expired food products, and slaughterhouse by-products. Although some substrates carry little or no direct cost to BSF producers, acquisition is rarely costless in practice, as transport, fuel, and time requirements can be significant. This is particularly the case in Antananarivo, where traffic and fuel costs significantly increase collection costs. In the absence of formal substrate markets, municipal aggregation systems, or organized collection networks, farmers must secure

[2] Information from producers who were supporting smallholder farmers reported donating start-up kits ranging from US$0 to US$60. The kits included the listed items, as well as live biological inputs, eggs, and pupae.

substrates through informal arrangements and personal networks, increasing transaction costs and limiting scale. On the output side, BSF farming produces several marketable products without processing, including eggs and pupae for colony propagation, larvae for animal feed, and frass as an organic fertilizer. At present, these output channels remain weakly structured, and market relationships are typically informal and localized.

**For Madagascar's established producers, the main supply chain challenge lies less in production itself than in securing reliable substrate and linking to stable end markets.** This reinforces the importance of producer coordination, market structuring, and institutional support if the sector is to scale beyond dispersed smallholder activity. At present, the BSF supply chain reflects the organic growth of a sector in its early commercial phase: producers are active, markets are real, and the primary opportunity lies in organizing what already exists – substrate supply, market linkages, and producer coordination – rather than building from scratch. The supply chain illustrated in Figure 3.1 reflects the organic growth of a commercially active sector. Among Madagascar's experienced producers, the technical foundations of production are increasingly well established. The technical foundations of BSF production are well established among Madagascar's producers. The primary opportunity for sector development lies in organizing the input supply and market linkage dimensions that will allow individual commercial successes to scale.

**Figure 3.1: BSF farming supply chain**




Source: Authors.

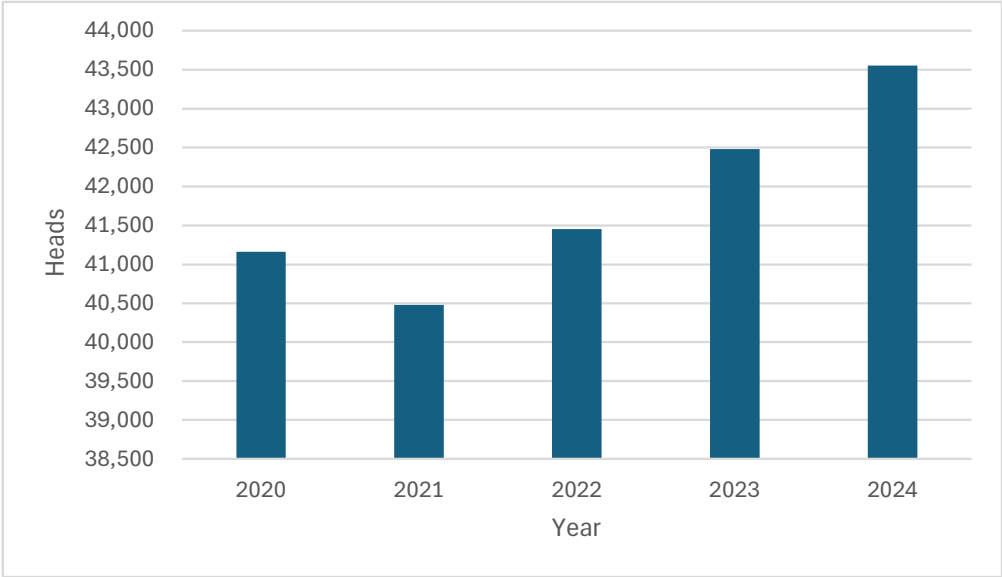
## Markets and End Uses

**BSF products are primarily used as animal feed.** In Madagascar, the particular focus is on poultry and aquaculture, though pigs also benefit from BSF inclusion. Feeding BSF larvae to pigs results in higher growth rates, improved digestive health, and lower feed costs.[3] With aquaculture production on the rise, poultry showing a moderate but steady increase, and pigs requiring a relatively greater amount of feed per head, demand for protein in livestock feed will only grow stronger. Indeed, a representative of AGRIVET, the leading agricultural supplier in Madagascar, which also produces feeds, told the owner of BSF Tamatave that the company needs 700 tons of protein per month.[4]

### The chicken market

**Chicken production is growing.** Figure 3.2 shows Madagascar's estimated chicken population from 2020 to 2024. The production dip from 2020 to 2021 was likely due to the COVID-19 pandemic. The population rebounded after 2021 and continued to grow steadily through 2023, with an average year-on-year increase of 2.5 percent. This coincides with the average 2.5 percent human population growth in Madagascar over the same years.[5] There were more than 43.5 million heads in 2024.

**Figure 3.2: Madagascar chicken population, 2020–2024**




Source: FAOSTAT (estimated values) compiled by Authors.

**Increased chicken production leads to increased opportunities to provide feed protein from BSF larvae.** To calculate the tonnage of wet BSF larvae (BSFL) needed to replace the protein required for chickens, the calculation can be simplified by assuming the daily protein requirement per chicken is approximately 17 grams.[6] This protein requirement is based solely on egg-laying chickens or "layers" as

[3] Hong, J., & Kim, Y. Y. (2022).
[4] Primary fieldwork, 2025. Field notes held by the author. AGRIVET's need for 700 MT of protein per month was established through direct field interviews; not independently verified through published sources.
[5] https://www.macrotrends.net/global-metrics/countries/mdg/madagascar/population-growth-rate.
[6] Thayer, R. H., Hubbell, G., Kasbohm, J., Morrison, R., & Nelson, E. (1974).

opposed to chickens raised for direct human consumption, or "broilers." Broilers live an average of 6 to 7 weeks and consume approximately 1 kilogram of protein, whereas layers consume approximately 680 grams over the same time. Therefore, the calculation will underestimate the actual protein requirement for 43,500,000 chickens. The calculation is as follows:

- 43,500,000 birds * 17 grams protein * 365 days = ~270,000 MT protein/year
- 270,000 MT * 25% = 67,000 MT to come from BSFL

Wet larvae tonnage necessary to replace 25 percent of the chicken's diet with larvae is calculated below for four scenarios of crude protein content:

- At 20% BSFL crude protein: 67,000 / 0.2 = 335,000 MT wet larvae/year
- At 17% BSFL crude protein: 67,000 / 0.17 = 394,100 MT wet larvae/year
- At 15% BSFL crude protein: 67,000 / 0.15 = 446,700 MT wet larvae/year
- At 10% BSFL crude protein: 67,000 / 0.1 = 670,000 MT wet larvae/year

**Even these conservative calculations show large hypothetical markets for BSF larvae in the poultry sector.** The wet larvae required to replace only 25 percent of the protein consumed by Madagascar's chickens, based on 2024 data, would amount to no less than 925 MT of wet larvae per day – assuming a generous BSF crude protein content of 20 percent and an underestimated average daily protein requirement per bird. Keeping in mind that this assessment considers chickens only, if the analysis is extended to include other poultry – ducks, turkeys, and geese – it will add an additional 10 million heads, based on 2024 FAOSTAT data.[7] On a daily basis, all three types of poultry consume more protein than chickens. However, maintaining calculation simplicity by factoring in the birds above at the same rate as chicken protein consumption, and assuming 15 percent crude protein content (thus multiplying the result for 15 % BSFL crude protein by 1.25), yields a daily wet larvae requirement of 446,700 MT wet BSFL * 1.25 = 558,375 MT wet larvae per year, or 1,530 MT per day.

**Only 10 percent of Madagascar's chicken production occurs in commercial facilities.** The calculations above represent a theoretical upper bound on the commercial BSFL market within Madagascar's poultry sector. A village poultry production survey conducted in Madagascar found that indigenous scavenging chickens accounted for approximately 91 percent of the total chicken population, with households averaging just 11 birds that subsisted primarily on foraging rather than commercial feed.[8] Scaling the results above by an estimated 10 percent to reflect the commercially managed share of the flock yields a near-term addressable commercial market of approximately 44,700 MT of wet larvae per year – roughly 122 MT per day – at 15 percent crude protein content. Applied to the combined poultry figure, which included ducks, turkeys, and geese, the comparable commercial-sector estimate is approximately 55,800 MT per year, or 153 MT per day.

**Household-level chicken production is still an important application for BSF production.** The predominance of indigenous chickens in Madagascar's rural landscape nonetheless represents an opportunity for development rather than simply a demand constraint. These birds – raised by smallholder households as a source of protein, income, and household savings – face severe productivity constraints: chick mortality exceeds 40 percent, driven primarily by parasitic infections and nutritional deficiencies

[7] 4,651 ducks; 3,009 geese; 2,484 turkeys

during the scavenging period, with adult mortality averaging an additional 31 percent.[9] Black soldier fly larvae are well-suited to this context. Unlike commercial feed, which requires a cash outlay and reliable supply chains, larvae can be produced at household scale using agricultural waste, kitchen scraps, and animal manure at a cost primarily of labor and knowledge rather than capital. Even modest supplemental larval feeding can reduce chick mortality, improve laying rates, and strengthen flock resilience, with direct benefits for household food security and, potentially, income. The binding constraint is behavioral rather than economic: adoption of an unfamiliar practice requires sustained extension support, demonstration sites, and peer-to-peer knowledge transfer. For BSF enterprises and development programs operating in Madagascar, indigenous chicken keepers represent a large, geographically distributed, and motivated potential client base – one in which the value proposition is livelihood improvement rather than feed cost reduction alone.

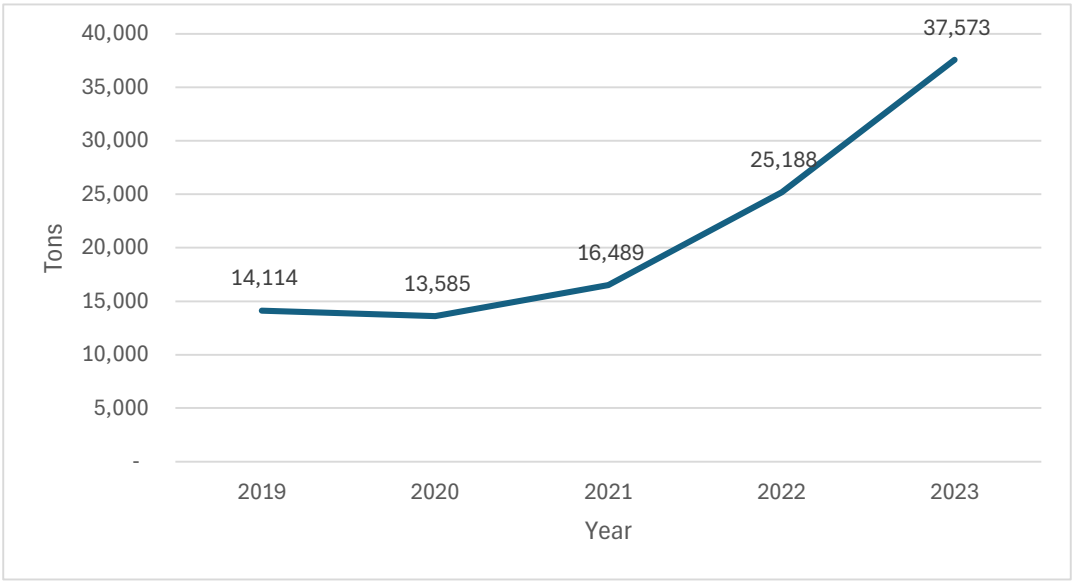
### The freshwater aquaculture market

**Madagascar's aquaculture sector is large but narrow.** The term "aquaculture" comprises a broad range of cultivation of both animals and plants. Total aquaculture production in Madagascar surpassed 30,000 MT in 2023 (Figure 3.3) with seaweed – cultivated along the coastline primarily for export – accounting for approximately 71 percent of total aquaculture output by quantity as recently as 2021. Marine shrimp farming accounted for most of the remainder.[10] Inland freshwater production, the subsector relevant to black soldier fly larvae as a feed input, represented just 8.1 percent of total aquaculture production in 2021 – approximately 1,300 MT – down from a 31.1 percent share in 2000 as seaweed cultivation expanded.[11] Applying this share to the 2023 total suggests that current freshwater finfish production lies between 2,000 and 2,500 MT. This figure carries some uncertainty given that recent growth in total aquaculture output may be concentrated in the marine sector.

**The country's two primary fish-based aquaculture models differ in feed-input requirements.** Freshwater aquaculture in Madagascar is dominated by two species – tilapia (principally Nile tilapia, *Oreochromis niloticus*) and common carp (*Cyprinus carpio*) – farmed under two distinct production systems that differ fundamentally in their feed requirements.[12] The first is the rice-fish system, an extensive model in which fish are stocked directly in paddy fields and subsist on naturally occurring insects, aquatic plants, zooplankton, and the organic matter generated by rice cultivation. This system requires no purchased feed under normal management conditions but currently occurs in only 20 percent of the paddy area in Madagascar considered suitable for the practice.[13] The second is semi-intensive earthen pond culture, in which fish are stocked at higher densities and fed supplementary inputs – typically rice bran, agricultural by-products, and locally produced protein sources – to achieve commercially meaningful yields. Feed cost is the principal determinant of profitability in this system.

[10] FAO. 2023.
[11] FAO. Fishery Country Profile: Madagascar.
[12] Ibid.
[13] NBI Global Resource Centre / GIZ. 2024.

**Figure 3.3: Madagascar aquaculture harvest, 2020–2024**




Source: World Bank Open Data Platform compiled by Authors.

**The feed-input distinction allows assessment of the BSFL market opportunity in aquaculture.** Rice-fish farmers, operating extensive systems dependent on natural food sources, do not purchase supplemental feed and are therefore not an immediate market for BSFL as a feed input. The opportunity in that subsector lies instead in intensification: BSFL can serve as the bridge between extensive management and semi-intensive production by providing a locally producible, waste-derived protein source that eliminates the need for imported commercial feed as the step-up input. For semi-intensive pond farmers, the case for BSF is more direct. Madagascar has no domestic fish feed manufacturing industry, and commercial aquaculture feed is overwhelmingly imported. The principal source of imported fish feed is Mauritius, which supplied nearly 100 percent of all fish feed imports to Madagascar in 2023 and 93 percent in 2024.[14] This near-total dependence on a single foreign supplier creates both price volatility and supply risk, particularly for farmers in remote, rural areas far from port infrastructure. The urgency of addressing this dependency is underscored by the government's National Action Plan for Fisheries and the Blue Economy (2024–2028), which targets a 116 percent increase in total national fish production to 307,000 MT by 2028, placing aquaculture expansion at the center of that ambition.[15]

**Estimates of fish diets and overall scale allow estimates of potential BSF markets in aquaculture subsectors.** To estimate indicative BSFL demand from the semi-intensive pond subsector, the following conservative assumptions are applied: total freshwater finfish production of approximately 2,000 MT annually; a semi-intensive pond share of 60 percent of that total, consistent with the FAO estimate that roughly 40 percent of Madagascar's freshwater fish farmers raise carp in rice paddies;[16] and a feed conversion ratio of 2.0, consistent with tilapia farmed in muddy earthen ponds.[17] Based on these

[14] UN Comtrade.
[15] Oirere, S., (2024).

assumptions, the semi-intensive pond subsector requires approximately 2,400 MT of supplemental feed annually. At a dietary crude protein content of 28 percent, the annual protein requirement is approximately 670 MT. Replacing 25 percent of that protein requirement with BSFL – at a wet larval crude protein content of 15 percent – implies an annual demand of approximately 1,120 MT of fresh larvae, equivalent to roughly 3 MT per day.

**Possible shifts from low-input to semi-intensive fish cultivation models represent opportunities for BSF.** The calculations above exclude the intensification potential of the rice-fish subsector, any growth in semi-intensive pond area, and the sector's ongoing expansion trajectory. They therefore represent a conservative floor to the potential market for BSF larvae in semi-intensive pond cultivation. The GIZ-financed *Projet d'Aquaculture Durable à Madagascar* (PADM), which supported 15,815 fish farms across six regions between 2018 and 2024, and its successor program, which extends to 2028, represent active public investment in precisely this intensification pathway.[18] Each incremental farmer transitioning from extensive rice-fish to semi-intensive pond management represents an additional unquantified unit of BSFL demand. The economic case for on-farm BSFL production as a feed input in the semi-intensive pond system, including a detailed cost comparison with imported commercial feed, is examined through a farm-level value chain analysis presented in Section 0.

### Pigs as an additional demand vector

**Pigs represent a further potential market for BSF larvae as a feed protein source.** Research confirms that inclusion of insect-derived protein in swine diets supports higher growth rates, improved digestive health, and reduced feed costs compared to conventional protein sources.[19] However, any forward-looking assessment of pig-sector demand in Madagascar must be qualified by the persistent presence of African Swine Fever (ASF). The fever has been endemic on the island since at least 1998 and periodically constrains herd sizes and farming continuity.[20] Reliable headcount-based demand projections are therefore difficult to sustain. Additionally, the practical application of BSFL in swine nutrition requires attention to species-specific processing and life-stage considerations, as the nutritional profile and digestibility of insect products vary with larval preparation method and the pig's age and production phase.[21] As ASF management improves and Madagascar's pig sector stabilizes and recovers, pigs represent meaningful incremental BSFL demand beyond the estimates presented above for poultry and aquaculture, and warrant closer analysis as the sector develops.

## Institutional Support Structure

**Strong institutional support is a requirement for BSF sector growth.** Realizing even a fraction of the market potential described above depends critically on the institutional environment shaping producer capacity, coordination, and regulatory clarity. Madagascar's BSF sector benefits from an institutional support landscape that is more active and diverse than its nascent status might suggest. Government bodies, research institutions, international development partners, private enterprises, vocational training providers, and community networks are all engaged. In several cases, these entities, and alliances among them, are

[18] NBI Global Resource Centre / GIZ. 2024.
[19] Hong, J., & Kim, Y. Y. (2022).
[20] Ravaomanana, J., Michaud, V., Jori, F., Andriatsimahavandy, A., Roger, F., Albina, E., & Vial, L. (2010).
[21] Hong, J., & Kim, Y. Y. (2022).

producing measurable results on the ground. The following profiles document the mandates of supporting entities and their direct engagement with the sector. A summary of the research team's field discussion with the Ministry of Agriculture and Livestock's (MINAE) Animal Production Department closes this section.

### Government institutions

**Ministry of Agriculture and Livestock (MINAE)**

**Madagascar's primary governmental agriculture body recognizes the value of BSF.** MINAE is the lead government body for agricultural policy, food safety, livestock regulation, and the promotion of sustainable food systems in Madagascar.[22] The Ministry's acknowledgement of the value of BSF includes issuance of a formal agricultural certification to a BSF practitioner in Tamatave, endorsing BSF-based livestock feed for its nutritional contribution.[23] Madagascar's National Nutrition Plan, coordinated by MINAE with the National Nutrition Office (ONN), explicitly identifies insects as an important nutritional resource.[24] MINAE has also participated in national policy dialogues on insect farming[25] and launched a food-systems transformation study in partnership with FAO and international research partners.[26]

**Bureau de Normes de Madagascar (BNM)**

**Madagascar's National Standards Bureau is the first in the world to establish norms for direct human consumption of BSF products.** The Bureau de Normes de Madagascar (BNM) is Madagascar's national standards body, operating under the Ministry of Industrialization and Commerce. In March 2025, BNM conducted a technical visit to EXA's production facility in Antsiranana (Diego Suarez) to gather the information required to draft a national standard for BSF larvae products. EXA's operation provided the technical foundation for the process.[27] The resulting standard - NMG 132-13, covering dried BSF larvae and larval powder for direct human consumption[28] - makes Madagascar the first country in the world to establish such a standard.[29] This regulatory milestone formally legitimizes BSF as a human food product and creates the quality and safety framework necessary for commercial development.

### Research institutions and national NGOs

**Madagascar Biodiversity Center (MBC)**

**Madagascar Biodiversity Center (MBC) is a Malagasy nonprofit scientific institution advancing biodiversity research, scientific training, conservation, and applied insect-based solutions.** Founded in 2006 and based at the Parc Botanique et Zoologique de Tsimbazaza in Antananarivo, MBC's core work includes biodiversity research, scientific collections, training, and conservation, alongside applied programs addressing food security, soil restoration, and rural livelihoods.[30] Its BSF work is one of several applied programs that build on MBC's broader biodiversity mission.

[22] Ministère de l'Agriculture et de l'Elevage (MINAE).
[23] L'Express de Madagascar (6 April 2023).
[24] ZEF / Bonn Sustainability Portal (18 November 2019).
[25] Ibid.
[26] Zero Hunger Coalition (undated).
[27] Bureau des Normes de Madagascar (BNM) (2025a).
[28] Bureau des Normes de Madagascar (BNM), (2025b.
[29] Ramaroson, V., Simon, S., Fisher, B.L. and Burza, S. (2026).
[30] Madagascar Biodiversity Center (MBC).

**MBC is a leading research and extension institution in the Madagascar BSF sector.** Its BSF Solutions Program has developed and field-tested BSF microfarms at multiple sites, including Farafangana, Fenerive Est, and Anivorano. The Morafeno village site near Farafangana, developed in collaboration with Health In Harmony (HIH) and Fahasalamana Mirindra (FAMI), is one of the world's largest community-owned BSF farms.[31] As of late 2025, MBC had established approximately 100 BSF farms in the Farafangana area alone.[32] MBC's knowledge-dissemination tools include three farmer guides in English and Malagasy, covering BSF farming practice, use of larvae as feed and frass as fertilizer, and safe preparation for human consumption.[33] Seven how-to videos in Malagasy supplement these guides.[34] All materials are designed for smallholder farmers, women, and youth without formal agricultural training.

**MBC has produced peer-reviewed research on BSF frass.** Field trials found that composted BSF frass increased maize yields by 38 percent compared with cattle manure, even at one-third of the recommended nitrogen dose.[35] A 2025 study demonstrated that BSF frass outperforms both cattle manure and synthetic NPK in supporting the growth of native tree seedlings for reforestation, achieving survival rates of up to 95 percent for fast-growing pioneer species.[36] Research co-led by MBC published in 2026 found high acceptance of processed BSF products among rural households near the Manombo Special Reserve.[37] MBC has collaborated with EXA Food, a separate private entity, on research and product-development activities involving insect-based foods. [38]

**Gasy Insectes Comestibles (GIC)**

**Gasy Insectes Comestibles (GIC) is Madagascar's national edible insect platform.** The organization was established in 2022 and registered as an NGO in Antananarivo. Its mandate is to unite all stakeholders in the edible insect value chain – researchers, producers, processors, and exporters – to transform insects into opportunities for nutrition, economic growth, social development, and environmental sustainability. BSF is among the primary species represented.[39]

**GIC identifies stigma and an inadequate regulatory environment as the principal obstacles to sector growth.** Persistent societal stigma around insect consumption and an inadequate regulatory framework spanning multiple ministerial jurisdictions are the two primary impediments to growth in Madagascar's BSF sector according to GIC.[40] The platform convened Madagascar's first Forum on Insects for Human and Animal Food in September 2023, held during the International Agriculture Fair, to promote debate and facilitate professional networking in support of the sector.[41] GIC has also signaled its intention to move into the production of insect protein powder for commercial animal feed.[42]

[31] Health in Harmony (29 January 2026).
[32] Mongabay (28 November 2025).
[33] MBC Solutions Program (18 September 2025).
[34] SIANI (15 January 2026).
[35] Solofondranohatra, C.L., Andrianorosoa Ony, C., Burza, S. and Fisher, B.L. (2025).
[36] Andrianorosoa Ony, C. and Solofondranohatra, C.L. et al. (2025).
[37] Ramaroson, V., Simon, S., Fisher, B.L. and Burza, S. (2026).
[38] PortalJob Madagascar (1 October 2024).
[39] 2424.mg (14 May 2023).
[40] Ibid.
[41] 2424.mg (20 September 2023
[42] Newsmada (27 September 2024).

### FAMI (Fahasalamana Mirindra)

**FAMI partners with international NGOs to increase BSF activity in communities.** FAMI is a Malagasy NGO and local partner of the international NGO Health In Harmony (HIH). FAMI operates in south-eastern Madagascar, principally around the Manombo Special Reserve in the Farafangana area, where it serves as the primary community-level implementation partner for BSF farm establishment. FAMI is responsible for implementing 350 BSF farms across 20 villages in the Manombo region. As of early 2026, 10 percent were already operational and had doubled production after their first harvest cycle.[43] FAMI is also exploring, in partnership with Médecins Sans Frontières (MSF), the potential of BSF farming to alleviate seasonal food insecurity in the Ikongo district.[44]

## International development partners

### Health In Harmony (HIH)

**Health In Harmony is a US-based international NGO supporting BSF farming in Madagascar.** Founded in 2006 in Portland, Oregon, HIH's mission is to reverse tropical rainforest deforestation by addressing the economic and social drivers that push communities into unsustainable forest use.[45] HIH launched its Madagascar program in 2019 in the Manombo Rainforest, reaching over 12,000 community members.[46] BSF farming is a central pillar of HIH's sustainable food systems work, co-developed with MBC as an intervention that simultaneously addresses protein nutrition, soil fertility, waste management, and forest conservation.[47] HIH co-authored the 2025 study on BSF frass as maize fertilizer[48] and the 2026 community acceptance study.[49]

### Swedish International Agricultural Network Initiative (SIANI)

SIANI **is a Swedish network funding efforts to improve BSF farming in Madagascar.** SIANI – a network funded by the Swedish International Development Cooperation Agency (Sida) – supports the introduction and scaling of Black Soldier Fly (BSF) farming in Madagascar through grants and technical assistance to improve food security, rural livelihoods, and environmental sustainability. Through its Small Grants Program, SIANI funds the Madagascar Biodiversity Center (MBC) to pilot and disseminate low-cost BSF microfarm models in multiple regions. Activities focus on farmer training, development of locally adapted educational materials, and promotion of BSF as a circular solution for converting organic waste into animal feed and frass. Reported outcomes include improved poultry productivity and higher market prices for BSF-fed chickens. MBC also leads a SIANI-supported expert group on insect-based protein. In addition, SIANI collaborates with partners such as Health In Harmony and FAMI to link BSF adoption with climate resilience, reduced deforestation, and biodiversity protection. In January 2026, SIANI published a detailed case study on MBC's farmer-led BSF innovations, providing international visibility and contributing to south-south knowledge sharing.[50]

[43] Health in Harmony (29 January 2026).
[44] Médecins Sans Frontières (undated).
[45] Health in Harmony. N.d. Madagascar Programme Overview.
[46] ReliefWeb / Health in Harmony. N.d.
[47] Health in Harmony. 2026.
[48] Solofondranohatra, C.L., C. Andrianorosoa Ony, S. Burza, and B.L. Fisher. 2025.
[49] Ramaroson, V., S. Simon, B.L. Fisher, and S. Burza. 2026.
[50] SIANI (15 January 2026).

### Private sector

**Groupe EXA**

**Groupe EXA is a privately held Malagasy company operating feed and food activities through EXA Feed and EXA Food.** EXA Feed operates an industrial BSF production facility in Diego Suarez. In 2025, EXA Feed contributed biological starter material to MBC's independently operated BSF farming program in Anivorano. In May 2025, 30 rural farmers participated in training conducted by MBC, receiving starter kits valued at approximately US$40 that included 800 grams of BSF pupae provided by EXA Feed, together with trays, a love cage, water sprayer, and oviposition substrate (SIANI,15 January 2026).

EXA also contributed technical input to the development of Madagascar's national BSF standard (NMG 132-13). The Bureau de Normes de Madagascar (BNM) led the standards process and conducted a technical visit to EXA Feed's Antsiranana facility to inform drafting. EXA Feed provided operational and technical information that supported development of the standard for dried BSF larvae and larval powder for human consumption.[51] EXA appears again in the value chain section of this analysis.

### Vocational training

**Don Bosco Vocational Training Network (Salesians of Don Bosco, Ivato)**

**Don Bosco is a Catholic-affiliated network that includes BSF in its technical and vocational education centers in Madagascar.** The Salesians of Don Bosco are a Catholic religious congregation operating educational and vocational institutions globally. The group has been present in Madagascar since 1981, with 11 centers across the country. Their facility at Ivato, on the northern outskirts of Antananarivo, is among the country's principal technical and vocational education and training (TVET) institutions. It operates under Don Bosco Tech Africa, a network coordinating approximately 118 TVET centers across 34 countries in Africa.[52] The group's center in Ivato integrated a BSF farming module into its agricultural studies program.[53] All four full-time workers at a BSF operation in Tamatave the research team visited during fieldwork in June 2025 had received their agricultural training at this institution, offering a concrete example of vocational training generating a pipeline of skilled labor for the BSF sector.[54]

### Community knowledge networks

**Black Soldier Fly Madagascar Facebook Group and BSF Messenger Community**

**Facebook-based peer knowledge-sharing platforms link practitioners across Madagascar.** Peno Manitra founded the Black Soldier Fly BSF Madagascar Facebook group in 2021.[55] The group's prevailing norm is the offer of free training to new entrants, with trained farmers then purchasing starter colonies to begin production. This model has enabled the organic spread of BSF practice from Tamatave to Antananarivo, Marovatana, Ambohidratrimo, and other locations.[56] As of March 2026, the group has more than 12,000 users. A separate Facebook Messenger-based practitioner community of BSF operators had grown to over 200 members by July 2025. The community, founded by a farmer based in Tamatave who is

[51] Bureau des Normes de Madagascar (BNM) (1 April 2025).
[52] Don Bosco Tech Africa (undated).
[53] Primary fieldwork, 2025.
[54] Ibid.
[55] L'Express de Madagascar. 2023.
[56] No Comment Magazine. 2024.

also the first MINAE-certified BSF practitioner in Madagascar,[57] offers troubleshooting support to community members when they encounter production challenges.

### Additional grant support

**Other small grants have enabled BSF development in the field.** Conservation International awarded a US$10,000 grant to support sustainable income alternatives to charcoal producers living in a rural village adjacent to a zoological park and forestry station (Parc Zoologique Ivoloina) in the Tamatave vicinity. The Madagascar Agricultural Council Forum (FCA) awarded a US$4,500 grant for a BSF farming training-of-trainers program in Southwest Madagascar. Neither Conservation International nor FCA has targeted grants specific to the BSF sector. These contributions, while not representing sustained institutional engagement with the sector, have nevertheless directly enabled field-level development work.

## Ministry of Agriculture and Livestock (MINAE): Animal Production Department

**Field discussion summary**

At the national level, the Ministry of Agriculture and Livestock (MINAE) has recognized the strategic potential of the edible insect sector and is actively developing its engagement. Conversations with the Animal Production Department reveal a Ministry that sees genuine opportunity – strong stakeholder interest, alignment with national nutrition and food security priorities, and growing commercial momentum – and is working to build the institutional framework to support it. The Ministry acknowledges that a full sector mapping is currently underway and that formal strategic structures are still being developed.

Looking ahead, the Ministry has proposed a four-pillar approach to sector development: establishing a model demonstration unit; providing adapted equipment to small producers; developing structured markets and distribution channels; and strengthening actor autonomy for long-term sustainability. Specific actions under discussion include a national needs assessment, comparative analysis with other countries, a national sector forum within nine months, and a public awareness campaign through media and trade fairs. On the support side, the Ministry identified two potential mobilizing mechanisms: the DEFIS Program (Development of Inclusive and Resilient Agricultural Value Chains) and its affiliated CGEAF farm advisory services, which support smallholder entrepreneurship and technical assistance; and the existing network of sanitary veterinarians, who are present on the ground and could serve as relay agents despite not being specialized in entomology or livestock extension. The Ministry also noted that an 'oil drop' strategy – elevating successful farmers as community role models – and high-level advocacy for official sector recognition would be important complements to any formal support structure.

The Ministry has not yet developed a formal national strategy and cited several structural barriers to sector growth: insufficient infrastructure, limited data on profitability and economic viability, weak coordination among producers, and persistent negative perceptions around insect consumption. Potential health risks – including heavy metal contamination – are a concern, and the Ministry considers a robust regulatory and control framework a prerequisite before pursuing large-scale BSF promotion. Agricultural extension services were also noted as severely underfunded, with outreach capacity largely dependent on project-based support and therefore not sustainable once project funding ends.

[57] L'Express de Madagascar. 2023.

It is worth noting that BSF producers consulted during field research were largely unaware of the government's current or planned involvement in the sector – a gap the Ministry itself appears to recognize, given its emphasis on extension outreach and awareness campaigns as near-term priorities.

## 3.2 Value Chain Analysis

**Section 3.2 presents five value chain cases that document the commercial range and structural patterns of BSF farming in Madagascar.** The cases cover a spectrum of production scale and business models. Fanantenana, a solo micro-enterprise launched with under US$60 in equipment, demonstrates that even small operations can generate positive returns when output is diversified. Nutrix, a semi-commercial farm shows that wet larvae margins alone can appear negative while the overall operation remains economically positive. The integrated aquaculture case — a smallholder tilapia farmer in Anivorano who produces all BSF output for internal use — demonstrates that BSF need not enter a market at all to create economic value. BSF Tamatave illustrates the commercial maturity achievable through diversification, with high-margin biological products and frass complementing larvae sales. EXA Feed, an industrial pilot with a target capacity of three metric tons per day, represents a different logic: a deliberate learning-phase investment in standards compliance, process optimization, and downstream market access that also positions the company as a sector development platform. Four of the cases demonstrate economic viability across different models, though not all of it commercial: Nutrix and BSF Tamatave earn from the market, while Fanantenana and the Anivorano tilapia farm realize value on-farm through diversified returns and cost substitution rather than sales. EXA Feed, still in its scaling phase, represents a deliberate bet on commercial viability at industrial scale rather than a proven instance of it. Across all five, what determines the outcome is how value is captured, how substrate is secured, and how production integrates into the wider farm or market system.

### An Entrepreneurial Start-up: Company Profile and Value Chain

#### Company profile

**Company history and founder background**

**A solo entrepreneur used learning from other farmers and minimal investment to start a BSF operation.** This entrepreneur, Mlle. Fanantenana, began operations in mid-May 2025, just six weeks before the research team’s visit. She gained experience in insect farming through hands-on work with a farmer specializing in mealworm production and an internship with another farmer. She further developed her expertise through online resources, primarily YouTube and ChatGPT. Initially, she acted as an intermediary, connecting buyers with suppliers. Recognizing strong demand for BSF larvae, she subsequently established her own BSF farming operation. She relocated to Bevalala to establish the business and rents two small, one-room buildings – one for operational activities and the other for her living quarters – at a total monthly cost of MGA 100,000. The farm has no employees other than the founder.

**Start-up equipment**

**Simple, inexpensive equipment and inputs provided the basis for her operation.** Fanantenana began with six 20-liter plastic jerrycans (MGA 4,000 each),[58] which she cut in half to create 12 larval growing trays. She also fabricated a love cage (MGA 15,000) and purchased 5 grams of eggs for MGA 15,000. Additional equipment included small plastic sieves placed atop small plastic basins; a configuration commonly used in BSF farms in Madagascar as a nursery. Eggs are placed on the sieve, and newly hatched larvae fall through the screen into the nursery feed below (starter chicken feed). Figure 3.4 shows the jerrycans used as larval growing trays along with the nursery sieve and basin setup with BSF eggs on top of the screen and starter chicken feed in the basin.

**Figure 3.4: Halved jerrycan used as growing trays (left); nursery setup with eggs on top and feed in basin (right)**



Source: Authors.

**BSF production and market activity**

**Household production balances revenue through sales and continuation of the insect colony.** At the time of the team's field research visit, the farm was transitioning from the third to the fourth production cycle. Larvae from the third cycle were being sold, while eggs from the fourth cycle were being harvested. Approximately 20 grams of eggs were harvested in each cycle. Of this, 10 grams of eggs were sold (MGA 4,000 per gram), and 10 were retained for colony propagation. One gram of eggs yields from 1 to 1.6 kilograms of wet larvae; on average, the 10 grams of retained eggs yield approximately 12 kg of wet larvae. Of this, 11 kilograms are sold (MGA 8,000 per kilogram) and 1 kilogram is retained for reproduction. Although the client base is still developing, all saleable products are sold each cycle. The owner personally delivers products to clients, with the clients covering the transport costs.

In addition to eggs and wet larvae, other sources of income include:

- Up to 50 kg of frass is produced in a cycle and is sold to local farmers for MGA 2,000/kg.
- On-farm training services (MGA 30,000 per person). Training is 3 hours, and one to three people participate each week, but generally one rather than three.

[58] The jerrycans are 20-liter plastic containers in which cooking oil is packaged for bulk sale. After the container is empty, the containers are resold and repurposed for various uses, in this case for BSF farming. The containers were commonly used by the smallholder BSF farmers engaged during field research.

- Fabrication and sale of love cages for MGA 45,000 and a cost of MGA 20,000 each, including 5,000 for external sewing services. Each cage requires about 30 minutes to produce. She has already sold 15 love cages, which she delivers to clients.
- Three sets of oviposition media eggies sell for MGA 20,000, with a fabrication cost of MGA 10,000.

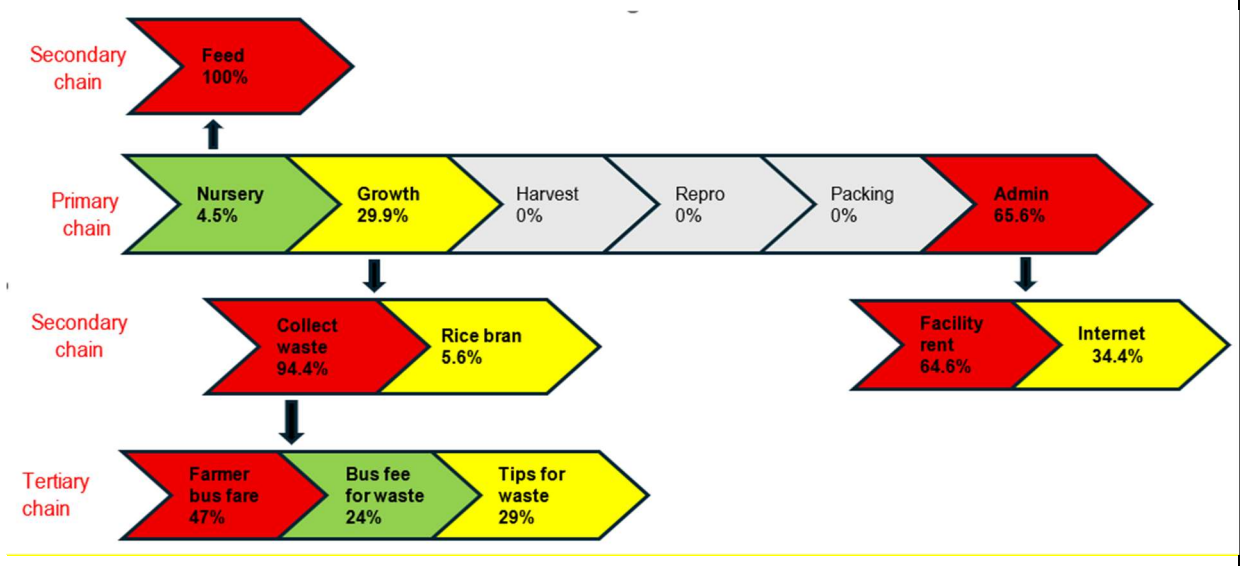
**Next steps**

**The operation is investing in additional cages and pest control.** Within a month of the research team's interview, the founder invested MGA 350,000 to purchase materials for constructing two cages. She personally constructed the cages, demonstrating both resourcefulness and commitment to improving farm security. The farm has experienced losses due to rodents consuming larvae. To mitigate this, the owner will construct protective cages specifically designed to safeguard the larvae. Rather than pursuing a microcredit loan, the terms of which she considers unfavorable and difficult to repay, she will reinvest earnings and borrow from family members. Looking ahead, Fanantenana has set a goal to operate five active love cages within a year, further expanding her capacity and production capabilities.

### Fanantenana's sole-proprietor value chain

Figure 3.5 below is a graphical representation of Fanantenana's individual farming value chain, with details following below.

**Figure 3.5: Fanantenana solo farming value chain**




Source: Authors.

**The single-person value chain has no direct labor costs, but invests the operator's own time.** The owner is the sole worker on the farm. She works six days per week on the farm, averaging two hours per day. As there are no employees, the value chain does not include labor costs. Without labor costs, there is no cost contribution from either harvesting, reproduction, or packing – each of which is a labor-only process for this farm. This entrepreneur works approximately 2 hours per day, 6 days a week. Time-use by activity includes:

- Egg collection: 1.25 hours per cycle
- Substrate collection: 18 hours per cycle
- Feed preparation: 1.5 hours per cycle
- Larvae harvesting: 3 hours (low active labor)
- Delivery: ~3 hours per trip (except for a delivery that took 1 full day)
- Breeding/prepupae harvesting/handling: ~3 hours.

Larvae are harvested using a basic sieve system. Though the process spans 3 hours, active labor time is only 10–15 minutes. Manual harvesting can be done in 30 minutes (10 minutes/tray; maximum of 1 kg fresh larvae per tray) if a customer requires expedited delivery.

**The largest cost component in the value chain is administration at 65.6 percent of overall costs.** The greatest cost per kilogram of larva is the rent paid for the production building, which accounts for 64.4 percent of administration costs and 42.3 percent of total production costs. The other cost associated with administration is Internet access, representing the remaining administrative cost (34.4 percent of administrative costs). While Facebook advertising is free, it requires daily Internet costs of MGA 900. The advertisements are effective, as evidenced by her receiving calls from three new customers during the approximately two-hour meeting held with the research team.

**The growth phase represents the second-largest expense, at 29.9 percent of total costs**. The main contributor to growth-phase costs is the round-trip bus fare to market to collect substrate. Bus fare is MGA 1,600 and comprises 47 percent of the growth costs. The market is 1.5 hours away, and she makes the journey every three days. She carries two buckets, each capable of holding 20 kilograms, and typically fills them with about 10 to 15 kg of fruit waste. While she receives the waste free of charge, she gives tips to the suppliers totaling approximately MGA 1,000 per trip. Transporting the full buckets back to the farm incurs a fee of MGA 800 for both. Rice bran, used for moisture control in the growing trays, contributes a small share to the cost of growth (5.6 percent). The bran costs MGA 1,000 per kg and lasts about 15 days, depending on the need.

**The final cost in the primary value chain is the nursery process.** The only cost factor within nursery is that of starter chicken feed. One kilogram of feed costs MGA 3,800, and approximately 0.25 kg is used in each nursery tray. When mixed with water, the feed creates an ideal substrate with a soft texture and high protein content, appropriate for newly hatched and young larvae. Table 3.2 presents a detailed cost breakdown along the primary value chain.

**Table 3.2: Value chain cost breakdown for Fanantenana**

| Phase | MGA/kg | US$/kg | % of Total |
|---|---|---|---|
| Nursery | 225 | $0.05 | 4.5 |
| Growth | 1,500 | $0.34 | 29.9 |
| Harvest | 0 | $0.00 | 0.0 |
| Reproduction | 0 | $0.00 | 0.0 |
| Packing | 0 | $0.00 | 0.0 |
| Admin | 3,286 | $0.75 | 65.6 |
| ***Total cost/kg*** | ***5,011*** | ***1.14*** | ***100*** |

Source: Authors.

**Fanantenana's solo BSF operation is profitable.** The total cost per kilogram of wet larvae prepared for delivery is MGA 5,011, and the revenue from this kilogram of wet larvae is MGA 8,000: a gain of MGA 2,989/kg: a gross margin of 37.4 percent. In addition, she sells BSF eggs and frass, as well as the BSF farming necessities: love cages and oviposition eggies. She also receives income from delivering training sessions. The total economic benefit by the time of the third cycle, taking into account all activities and sales, is presented in Table 3.3.

**Table 3.3: Fanantenana net income for the 3rd BSF cycle**

| **Core 3rd-cycle BSF farming activities** | **MGA** | **US$** |
|---|---|---|
| Core activity income | 228,000 | 51.82 |
| Core activity cost | 60,129 | 13.67 |
| Net income | 167,871 | 38.15 |
| **Additional 3rd-cycle net income**[1] | | |
| Additional income | 290,000 | 65.91 |
| Additional cost | 85,000 | 19.32 |
| Additional net income | 205,000 | 46.59 |
| ***Total net income for 3rd cycle*** | ***372,871*** | ***84.74*** |

[1] Conservatively estimated to include 1 set of eggies (actual quantity not reported), 1.5 people trained (based on weekly average), and 5 love cages sold (15 were reportedly sold over 3 cycles).

Source: Authors.

**This is an operation in its infancy, yet it is already turning a profit on each product offering.** The bottom line will likely improve further after the new protective cages are installed, thereby mitigating the loss caused by rodents. As production scales, substrate acquisition will likely evolve from its current pattern of regular market trips into a more structured supply arrangement, a natural transition that mirrors the growth path of more established BSF operations.

## Nutrix Company Profile and Value Chain

### Company profile

**Driven by a commitment to sustainable agriculture, the founder of Nutrix incorporated black soldier fly farming into the business in April 2024.** He is self-taught in insect farming through online resources such as YouTube. After approximately one year of learning and experimentation, Nutrix achieved steady production of 18 to 20 kilograms of wet larvae per week by early May 2025. The learning process involved iterative adjustments to tray size, egg loading, substrate composition, and stocking density of five-day-old larvae (5DOL).

#### Previous activities

**Since 2023, Nutrix has produced cereals, edible flowers, and microgreens for sale to restaurants.** Before adopting BSF farming, it fertilized these crops with purchased worm compost (50 kg per month at

MGA 2,000/kg, or MGA 10,000 per month). Nutrix also cultivated maize and rice on a 500 $m^2$ plot and fertilized with compost at an estimated cost of MGA 100,000 per week.

**BSF production and market activity**

**Nutrix uses BSF products to lower costs and diversify revenue sources**. BSF frass fully replaced both worm compost and other organic composts in the company's production, achieving comparable agronomic results. Nutrix harvests 40 grams of BSF eggs weekly from 2 kilograms of pupae. Of this, 20 grams are retained for internal production, and 20 grams are sold to other BSF farmers at MGA 4,000 per gram. On average, 0.6 grams of eggs produce one kilogram of larvae within 15 to 18 days, resulting in weekly production of 18 to 20 kilograms of fresh larvae. Approximately 10 percent of larvae are retained for colony propagation, and the remainder are sold to poultry farmers at MGA 5,000 per kilogram. The company maintains five regular clients for BSF products, in addition to ad hoc customers. Deliveries are handled by third-party service providers, with transport costs paid by the buyers. Product visibility is supported through Facebook advertising. Frass is not sold; instead, it is fully utilized in Nutrix' own crop production.

**Funding and expansion plans**

**Support from external funders and planned investment fuel plans for expansion.** Nutrix received a MGA 3 million grant (approximately US$6,000) from JICA (Japan International Cooperation Agency), to support salaries and infrastructure improvements. The owner currently spends three half-days per week at the farm and intends to transition to full-time farm work when financially feasible. Having attained practical BSF farming experience and consistent production, Nutrix plans to expand BSF farming operations. This includes seeking equity investment of approximately MGA 100 million (approx. US$20,000) to develop a climate-controlled facility with approximately 30 personnel and a projected weekly production capacity of 1 ton of wet larvae.

**Perspective on sector challenges**

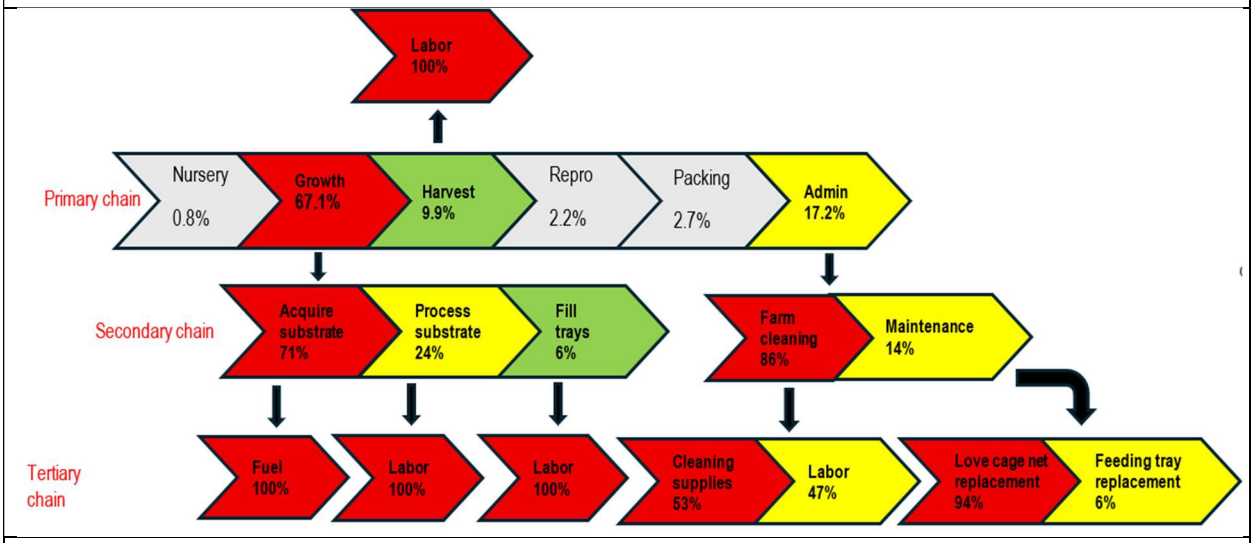
Per Nutrix's founder, key constraints affecting BSF farming in Madagascar include:

- **Lack of external support:** There is no evident government or institutional support for BSF farming.
- **Food waste issue:** Antananarivo generates 500 tons of food waste daily, most of which is not presorted, and only a small fraction of which is repurposed.
- **No agribank financing:** There is no specialized agricultural bank to finance BSF farming.
- **High microcredit rates:** Microcredit loans carry annual interest rates of approximately 20 percent.

### Nutrix value chain

Figure 3.6 below is a graphical representation of the Nutrix black soldier fly farming value chain, with details following below.

**Figure 3.6: Nutrix BSF farming value chain**




Source: Authors.

**The largest cost component in the value chain is fuel costs related to substrate acquisition.** Growing larvae from 5DOL to harvestable wet larvae accounts for 67 percent of the overall production cost. Within this phase, substrate acquisition accounts for 71 percent of growth-related costs. There is no direct cost to acquire the substrate. The two sources – a canteen and a restaurant – presort the waste and provide it free of charge. The costs arise solely from the fuel used to collect and transport the waste to the farm. The owner collects waste using his own vehicle three times per week, aligning with scheduled farm visits, and therefore incurring no associated labor cost. Fuel expenses alone account for 47.6 percent of the entire cost of producing wet larvae ready for sale. Table 3.4 shows the cost breakdown along the primary value chain.

**Table 3.4: Value chain cost breakdown for Nutrix**

| Stage | MGA/kg | US$/kg | % of Total |
|---|---|---|---|
| Nursery | 52 | 0.01 | 0.8 |
| Growth | 4,250 | 0.97 | 67.1 |
| Harvest | 625 | 0.14 | 9.9 |
| Reproduction | 142 | 0.03 | 2.2 |
| Packing | 174 | 0.04 | 2.7 |
| Admin | 1,091 | 0.25 | 17.2 |
| ***TOTAL COST/KG*** | ***6,333*** | ***1.44*** | ***100.0*** |

Source: Authors.

Producing 1 kilogram of larvae requires 12 kilograms of processed waste, 0.6 grams of eggs, and 0.5 kilograms of sawdust to control substrate moisture. Two hundred kilograms of substrate are collected per trip, with fuel costs of MGA 50,000. Normalizing this to per-kilogram of wet larvae produced results in a petrol cost of MGA 3,000 per 12 kg of substrate delivered.

**Outlays for processing waste inputs are driven by labor costs.** Although Nutrix owns an electric grinder for processing substrate, the processing is performed manually. Manual grinding (daily capacity: 120 kg

per 8 hours) and mixing the feed require 1 hour of labor. Therefore, processing waste – the second-leading cost factor of the growth phase – is fully attributed to labor and reduces to MGA 1,250 (1 hour of labor @ MGA 10,000 per 8 hours), which equates to 24 percent of the growth phase cost. Filling trays contribute an additional 6 percent and is also labor-driven. Nutrix employs one full-time person (MGA 300,000/month) who works 5.5 days each week, and two part-time workers (MGA 10,000/day). The part-time employees alternate working two days one week and three the next.

**Administration and harvest are the secondary and tertiary drivers of Nutrix's costs.** The second leading cost driver in the primary value chain is administration at 17.2 percent of total cost. Administration costs primarily consist of cleaning activities (86 percent of administration). Cleaning – critical to reducing pathogens and pests that can destroy a colony – requires 7 hours of labor and MGA 10,000 in materials, for a total of MGA 938 per kilogram of larvae produced. Harvesting, the third-highest cost in the primary chain, accounts for less than 10 percent of total production costs. Larvae are typically harvested using a sieve. However, manual harvesting is required when substrate moisture is suboptimal, resulting in an average labor input of 30 minutes per kilogram.

**Nutrix's BSF operation is a profitable business when accounting for both direct income and costs avoided.** Evaluated across the full range of its activities, Nutrix generates a positive weekly economic benefit of MGA 65,082 (US$14.79). The wet larvae margin alone – MGA 6,333 cost against MGA 5,000 revenue – shows a loss of MGA 1,666/kg, but this metric in isolation understates the operation's economics: egg sales and the avoided cost of compost, which BSF frass fully replaced, together flip the overall picture into positive territory (Table 3.5). When accounting for income from egg sales, net weekly income becomes positive. Including the avoided cost of compost further increases the economic benefit. Prior to BSF adoption, Nutrix spent approximately MGA 10,328 per week on compost. When these savings are included, the total weekly economic benefit of BSF farming increases to MGA 65,082 (US$14.79).

**Table 3.5: Nutrix weekly profitability from BSF farming**

| | Revenue | | Cost | | Net | |
|---|---|---|---|---|---|---|
| | **MGA** | **US$** | **MGA** | **US$** | **MGA** | **US$** |
| Larvae (18 kg) | 90,000 | 20.45 | 113,996 | 25.91 | (23,996) | (5.45) |
| Eggs (20 gr) | 80,000 | 18.18 | 1,250 | 0.28 | 78,750 | 17.90 |
| ***Total*** | ***170,000*** | ***38.64*** | ***115,246*** | ***26.19*** | ***54,754*** | ***12.44*** |

Source: Authors.

**Nutrix will further improve its bottom line by increasing scale and reducing the hauling costs of organic waste.** The company plans to accomplish this by solidifying agreements with more substrate sources, thereby increasing waste-hauling mass per trip. For example, if the fuel cost normalized to 1 kg of wet larvae can be reduced by half (double the delivery mass), the cost per kilogram reduces to MGA 125, which flips the loss from MGA 1,666/kg larvae to a gain of MGA 167/kg. The feasibility of doing so depends on factors such as the vehicle's hauling capacity, the ability to find new waste sources, and the distance to those sources from the farm.

## Integrated Aquaculture-BSF Farm Profile and Value Chain

### Farm profile

**Farmer background and experience**

**This study's aquaculture case highlights a small-scale tilapia farm that adopted BSF to strengthen feed independence.** The farmer in question produces high-quality protein locally at a fraction of the cost of imported commercial feed. His case illustrates a broader opportunity in Madagascar's aquaculture sector, where domestic BSF-based feed can replace an imported supply chain that is costly, concentrated in a single foreign supplier, and unreliable in rural areas. Tilapia production represents the farm's primary revenue-generating activity. Fish are sold at MGA 20,000 per kilogram once they reach market size (300–400 grams), typically after three to four months. Stocking involves purchasing fingerlings at MGA 700 each, with vehicle rental required for collection. In addition to BSF larvae, fish are fed rice bran, carrot waste, and aquatic plants.

**Self-directed learning to increase on-farm feed led to external training to improve production.** The farm is in Anivorano – a rural area approximately 1.5 hours south of Diego Suarez. The farmer has been engaged in BSF farming since January 2024 after learning independently about insect farming through social media (Facebook). He began BSF production without formal training and was the first BSF producer in his locality. In addition to BSF farming and aquaculture, the farm includes poultry and field crop production. BSF farming is embedded within the farm primarily as an on-farm feed source rather than as a commercial activity. In May 2025, the farmer participated in an MBC-supported training program. Unlike approximately 30 other trainees in the region, he had already established a BSF operation before the intervention. His training, therefore, focused on improving production practices rather than initiating BSF farming.

### BSF production and on-farm utilization

**The farmer reported a substantial increase in BSF output following the MBC training, using all outputs on-farm.** Average production improved from before-training levels of 2–3 kg of larvae per day (maximum of 5 kg/day) to an average of 4–6 kg per day (maximum of 10 kg/day) after training. The farmer attributes these gains primarily to technical recommendations, including increasing light exposure in the love cages and improving the larvae-to-tray density during feeding. The farm sells no larvae, eggs, or frass and uses all BSF output internally. Harvested larvae are fed directly to tilapia, while larvae remaining in the frass are consumed by poultry. When substrate moisture is excessive, larvae escape from trays and fall to the ground, where they are eaten by poultry. Approximately 10 kilograms of larvae per month – about 5.5 percent of total production – are retained for reproduction. Breeding larvae are transferred to love cages two days after harvest, with a biological cycle of approximately 18 days to reach the prepupal stage.

**Input sourcing and system management**

**The farm is productive, with room to grow.** Organic waste inputs – sourced from local markets, an abattoir, and poultry operations – total approximately 700 kilograms per week. The farm's single employee harvests BSF eggs every other day, with average yields of about 5 grams per harvest. MBC technical staff accompanying the research team estimated the current biological conversion rate at approximately 6 percent – below the 12–15 percent range achievable under well-managed conditions – indicating meaningful scope for further productivity gains as the farmer continues to apply the techniques learned through training.

**Key operational challenges**

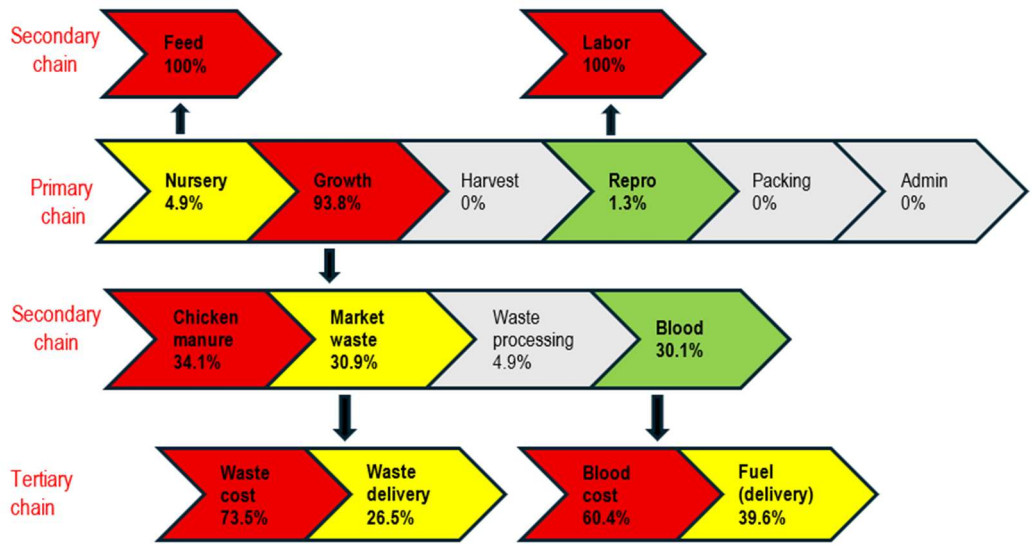
The farmer reported no major operational bottlenecks but cited limited efficiency in harvesting larvae. Although moisture management challenges affect larval containment, the farmer did not prioritize this issue because escaped larvae are consumed by poultry and therefore are not perceived as a loss. The research team was not able to discuss the farmer's perspectives on the operation's low biological conversion rate relative to technical benchmarks.

### Integrated farm's BSF farming value chain

**This section analyzes BSF farming as an internal value chain and quantifies its contribution to tilapia production**. While the farm doesn't market its BSF outputs, their value is realized indirectly through their role as a primary input into aquaculture. The value of BSF production is therefore realized entirely through downstream aquaculture outcomes.

**Labor costs are modest in the farm's BSF operation.** The farmer employs one full-time worker (MGA 300,000/month) whose responsibilities cover all farming activities, but with limited involvement in BSF production. The only labor costs contributing to production in the BSF value chain are associated with this worker. While the farmer spends about 1.5–3 hours per day on BSF tasks, the worker contributes about 1 hour per day, primarily on preparatory activities rather than direct larval handling.

**Figure 3.7: Rural integrated farmer's BSF farming value chain**




Source: Authors.

**The growth stage, especially feed costs, dominates the value chain's outlays.** Figure 3.7 presents a schematic representation of the integrated farm's BSF value chain and Table 3.6 shows the cost breakdown along the primary value chain. Growth-stage costs account for 93.8 percent of all costs in producing BSF larvae. Chicken manure is the leading cost driver in the growth phase, accounting for 34.1 percent of growth costs. Five-hundred kilograms of chicken manure are delivered to the farm each week, with a total cost of MGA 30,000.

**Table 3.6: Cost breakdown per kg larvae harvested**

| Stage | MGA/kg | US$/kg | % of Total |
|---|---|---|---|
| Nursery | 132 | $0.03 | 4.9 |
| Growth | 2,515 | $0.57 | 93.7 |
| Harvest | 0 | $0.00 | 0.0 |
| Reproduction | 36 | $0.01 | 1.3 |
| Packing | 0 | $0.00 | 0.0 |
| Admin | 0 | $0.00 | 0.0 |
| ***Total cost/kg*** | ***2,683*** | ***$0.61*** | ***100.0*** |

Source: Authors.

**Market waste and abattoir blood are the next largest cost drivers within the growth phase** (31% and 30%, respectively). The farmer collects ~120 kg of organic waste from a nearby market twice weekly, with ~100 kg purchased (MGA 200/kg) and ~20 kg obtained free of charge. The purchased market waste accounts for 73.5 percent of the waste acquisition cost, with the remaining 26.5 percent attributed to transportation costs to haul the waste to the farm. Abattoir blood is procured daily (MGA 200/kg) at a local abattoir 3 km from the farm. The farmer travels by motorbike and purchases 80 kg of blood each week. Blood accounts for 60.4 percent, and motorbike fuel accounts for the remaining 39.6 percent of the cost to obtain blood.

**Reproduction accounts for a minimal share of total costs** (less than 2 percent). These costs consist primarily of labor associated with egg harvesting. The only cost involved in reproduction is the four-times-per-week egg harvesting performed by the employee, which is fully allocated to labor.

**Integrating BSF larvae into the tilapia value chain**

**The economic contribution of BSF production is reflected in tilapia production costs rather than in standalone BSF margins.** All BSF larvae harvested on the farm are incorporated into tilapia feed. Tilapia profitability is calculated by comparing total production costs – including BSF-derived feed – with fish sales revenues, as presented in Table 3.7 and Table 3.8.

**Table 3.7: Rural integrated farmer's tilapia farming costs**

| Item | Unit cost (MGA) | Quantity | Extended cost | | Percent of total (%) | |
|---|---|---|---|---|---|---|
| | | | MGA | US$ | | |
| Fingerling (piece) | 700 | 1,200 | 840,000 | 190.91 | 28.9 | |
| Car rental (per trip) | 500,000 | 1 | 500,000 | 113.64 | 17.2 | |
| Carrot waste (kg) | 300 | 400 | 120,000 | 27.27 | 4.1 | Fish feed cost: MGA 1,568,050 (US$356.38) |
| Rice bran (80 kg bag) | 20,000 | 2 | 40,000 | 9.09 | 1.4 | |
| BSF larvae (kg) | 2,682 | 525 | 1,408,050 | 320.01 | 48.4 | |
| ***Total cost to acquire fingerlings and feed fish*** | | | ***2,908,050*** | ***660.92*** | 100.0 | |

Source: Authors.

**BSF larvae are the dominant feed expense for the farm's tilapia.** The farm's MGA 1,568,050 (US$356.38) cost of the feed for the tilapia is highlighted in Table 3.7. The total feed mass is approximately

1,085 kg, with BSF larvae accounting for nearly 89 percent of the total feed cost. Carrot waste and rice bran – 7.6 percent and 3.8 percent of feed costs, respectively – are inconsequential compared to the larvae cost in a feed cost sensitivity analysis. Given the feed mass of 1,085 kg, the cost per kilogram of feed is MGA 1,445 (US$0.33). The other costs reported by the farmer were for acquiring tilapia fingerlings. The car rental cost includes fuel, leaving the price paid for fingerlings – MGA 700/fingerling, of which he purchased 1,200 for his current cycle – the remaining cost in the value chain for fish farming for this farmer's model.

**Profitability changes with the survival rate of the farm's tilapia, but even low-survival scenarios create positive margins.** Table 3.8 shows profitability under different survival-rate scenarios, while holding total feed input constant at 1,085 kg over the production cycle. Results indicate that profitability is sensitive to survival outcomes, as feed inputs are relatively fixed costs over the production cycle. Regardless, all survival scenarios in Table 3.8 show ample gross margin: from a low of 42 percent at a 60 percent survival rate, to a high of 65 percent with 100 percent survival. However, since BSF larvae represent the principal cost component of the aquaculture value chain, enhancing operational efficiency in BSF farming could reduce feed input costs and bolster profitability. Given that the farmer had recently received formal training from MBC, other operational efficiencies may eventually materialize.

**Table 3.8: Profitability by survival rate**

| Survival rate (%) | Total harvest weight (kg) | Total income (MGA) | Net income (MGA) | Total income (US$) | Net income (US$) | Gross margin (%) |
|---|---|---|---|---|---|---|
| 60 | 252 | 5,040,000 | 2,131,950 | 1,145.45 | 484.53 | 42 |
| 65 | 273 | 5,460,000 | 2,551,950 | 1,240.91 | 579.99 | 47 |
| 70 | 294 | 5,880,000 | 2,971,950 | 1,336.36 | 675.44 | 51 |
| 75 | 315 | 6,300,000 | 3,391,950 | 1,431.82 | 770.90 | 54 |
| 80 | 336 | 6,720,000 | 3,811,950 | 1,527.27 | 866.35 | 57 |
| 85 | 357 | 7,140,000 | 4,231,950 | 1,622.73 | 961.81 | 59 |
| 90 | 378 | 7,560,000 | 4,651,950 | 1,718.18 | 1057.26 | 62 |
| 95 | 399 | 7,980,000 | 5,071,950 | 1,813.64 | 1152.72 | 64 |
| 100 | 420 | 8,400,000 | 5,491,950 | 1,909.09 | 1248.17 | 65 |

Source: Authors.

**Madagascar's fish feed market is dominated by imports from Mauritius, which are much more expensive than BSF-derived feed**. While the above analysis focuses on the profitability of using on-farm BSF larvae as the main feed protein source, Table 3.9 puts on-farm BSF feed production costs into context with Madagascar's broader fish feed market. The table highlights import statistics for fish feed brought into Madagascar between 2020 and 2024, including total imports (world) and those specifically from Mauritius. Mauritius is important given the country's dominance of the Madagascar fish feed market. In 2023 virtually 100 percent of Madagascar's feed emanated from Mauritius. In 2024 the number was 93 percent. Import data show that commercial fish feed, which is overwhelmingly imported and characterized by high supplier concentration, is priced well above the cost of this farmer's feed regimen.

**Table 3.9: Madagascar's import of fish feed (HS230120) from world and from Mauritius**

| | Import partner | | | | | | |
|---|---|---|---|---|---|---|---|
| | World | | | Mauritius | | | Percent of import from Mauritius (%) |
| Year | Import value (US$) | Quantity (kg) | US$/kg | Import value (US$) | Quantity (kg) | US$/kg | |
| 2024 | 312,786 | 281,096.3 | 1.11 | 297,738 | 261,091 | 1.14 | 93 |
| 2023 | 279,464 | 241,413.0 | 1.16 | 279,302 | 241,393 | 1.16 | 100 |
| 2022 | 233,406 | 263,637.0 | 0.89 | 202,518 | 206,137 | 0.98 | 78 |
| 2021 | 278,578 | 219,739.3 | 1.27 | 174,534 | 161,114 | 1.08 | 73 |
| 2020 | 131,308 | 96,026.5 | 1.37 | 49,836 | 40,122 | 1.24 | 42 |

Note: In 2020, France was Madagascar's leading import partner for HS230120.

Source: UN Comtrade, compiled by Authors.

**If the farmer were to purchase imported feed, his gross margins would decline dramatically**. For example, assuming a 65 percent survival rate, the current scenario achieves a 47 percent gross margin while providing 1,085 kg of total feed mass over the cycle. In this context, on-farm BSF production offers a means of reducing exposure to imported feed costs, provided the farmer's BSF production remains stable or increases over time. The benefits of on-farm BSF larvae in fish feed are shown by comparing the farmer's case – assuming 65 percent survival – to the commercial imported feed. Tilapia farmed in muddy earthen ponds have an approximate feed conversion ratio (FCR) of 2.0.[59,60] Given the initial 1,200 fingerlings, an average 350-gram harvest weight, a 65 percent survival rate (~268.5 kg total harvest weight), and a 2.0 tilapia FCR, the resultant commercial feed requirement is 525 kg (pellets). Using the per-kilogram import value of fish feed from 2024 in Table 3.9, the extended total feed cost is about US$599, or ~US$2.23/kg, which is 41 percent higher than the cost of the BSF-based feed formulation the farmer uses (Table 3.10).

These calculations are based on the 2024 import feed valuation listed in Table 3.9, but the US$1.14/kg value is the average import value at the port (CIF). The figures exclude inland freight to rural Anivorano, importer margins, distributor margins, and retail markup. In rural Madagascar, a realistic landed retail price would certainly be higher. With a conservative 33 percent markup, the retail price increases to US$1.52, pushing the savings due to BSF feed to US$442 per cycle, potentially more than the farmer's entire BSF feed cost.

**BSF-based systems have benefits in addition to lower cost relative to commercial feed.** These additional benefits include:

- BSF-based feed improves supply chain reliability, as commercial feed availability is not always guaranteed, particularly in rural areas.
- Reduced dependence on imported feeds, thereby (i) mitigating exposure to price volatility associated with imported goods, and (ii) retaining foreign exchange within the country.

[59] Kubitza, F. (2024).

[60] The quantity of feed the farmer gives to the tilapia farmed in a muddy earthen pond, resulting in a tilapia FCR of about 2.0, a 65 percent survival rate is likely.

- Environmentally sustainable feed production through the substitution of BSF larvae protein for fishmeal, reducing pressure on wild fisheries, and, for soymeal, lowering land-use demand and allowing space for alternative crops.

**Table 3.10: Feeding cost comparison - BSF-based feed vs. commercial feed**

| | BSF-based system | Commercial feed (CIF) |
|---|---|---|
| Feed quantity (kg) | 525 wet BSFL + inputs[1] | 525 (pellets) |
| Total feed cost (US$) | US$356 | US$599 |
| Fish produced (kg) | 269 | 269 |
| Feed cost per kg of fish (US$/kg) | US$1.32 | US$2.23 |
| **Savings: BSF vs. commercial** | **US$243 (41%)** | |

* Assumptions: Tilapia FCR of 2.0; 1,200 fingerlings; 65% survival rate, 350 gr harvest weight.
[1] Inputs include 160 kg rice bran and 400 kg fresh carrot waste: a total of 1,085 kg feed with BSFL included.

Source: Authors.

**On-farm BSF production can serve as a cost-saving input-substitution strategy within smallholder aquaculture systems**. By replacing imported feed with locally produced insect protein, the farmer reduces production costs and limits exposure to price volatility and supply constraints in Madagascar's highly import-dependent feed market.

**Overall, this case suggests that even at a smallholder scale, integrated BSF-based farming systems can generate meaningful economic and systemic benefits.** Beyond improving farm-level profitability, such models contribute to reduced dependence on imported inputs, more efficient use of organic waste streams, and improved resilience in rural food systems. These characteristics underscore the potential role of BSF farming as a scalable component of sustainable agricultural development strategies in Madagascar.

## BSF Tamatave Company Profile and Value Chain

### Company profile

**A self-taught female entrepreneur started BSF Tamatave, one of Madagascar's leading BSF farming operations.** The founder, owner and operator of BSF Tamatave is named Lamiah. Like many BSF farmers in Madagascar, she is self-taught – in her case, through Indonesian YouTube videos. Her entry into BSF farming was unplanned: while searching for ways to reduce the cost of feed for her chickens, Lamiah discovered BSF pupae in a container of chicken manure, placed them in a separate container, and began experimenting. After approximately six months, she made her first commercial larvae sale in June 2022: 23 kilograms at MGA 200,000 per kilogram (MGA 4,600,000 total). She applied this income toward the purchase of 4,000 square meters of land dedicated to insect farming, covering one-third of the land's MGA 6,000,000 purchase price. As of mid-2025, BSF Tamatave produced approximately 150 kilograms of wet larvae per day.

### Other activities

**Other BSF-related income streams, especially training, supplement income from BSF Tamatave.** In addition to BSF Tamatave, Lamiah operates a retail shop (TBS). She also provides on-farm BSF training to prospective and active BSF farmers at a fee of MGA 25,000 per person for a half-day session. Through grant funding, she has traveled across the country to deliver these trainings. To date, per her estimates, she has trained 3,000 people throughout Madagascar in BSF farming – either directly or through a train-the-trainer model. Approximately 20 percent of participants in her trainings are actively farming BSF. Lamiah also founded and administers a BSF farming community on Facebook Messenger. According to Lamiah, the group had approximately 200 members in July 2025, allowing farmers across Madagascar to share experiences, ask questions, and receive remote troubleshooting support, including photo-based diagnosis of on-farm problems.

### BSF production and market activity

**BSF Tamatave differentiates its product offerings based on larvae quality.** The operation collects approximately 1 ton of food waste per day for use as substrate. The larvae raised on this feedstock are sorted into three quality grades. The highest-quality larvae are reserved for colony propagation. Second-quality larvae are roasted and sold as a pet treat product marketed as pop larvae.[61] Third-quality larvae are either sold wet for livestock feed or dried and ground into livestock feed flour. The operation produces the three quality levels in approximately equal proportions.

**BSF Tamatave serves a geographically broad customer base.** Approximately 20 of the operation's clients are in Tamatave, approximately 20 in Antananarivo (delivered via taxi-brousse at MGA 7,000 per 10 kilograms), and clients in the far south and southwest – including Fort Dauphin and Toliara – served via ocean freight at MGA 10,000 per 10 kilograms (two-day delivery). The farm's selling prices for all products and byproducts are presented in Table 3.11.

**Staff benefitted from past technical education and continued to grow through data-informed process improvement.** BSF Tamatave employs a total of six full-time staff: a driver, four farm workers, and a farm manager. The driver earns MGA 300,000 per month; the four farm workers each earn the national minimum wage of MGA 266,500 per month; and the farm manager earns MGA 400,000 per month. The farm workers attended the Don Bosco (Salesian) vocational training high school in the Antananarivo area, where they received agricultural training that included BSF practices. Lamiah and farm staff systematically collect and review data from the operation. Lamiah holds weekly team meetings to monitor performance, troubleshoot problems, and drive process improvement.

[61] Pop larvae occupy the pet-treat segment of the pet market, distinct from formulated pet foods that use BSF larvae meal as an ingredient.

**Table 3.11: BSF Tamatave saleable production and unit pricing**

| Item | MGA |
|---|---|
| Wet larvae per kg to preferred customers | 3,000 |
| Wet larvae per kg to casual customers | 4,000 |
| Dried larvae per 1 kg bag | 12,000 |
| Larvae powder per 2 kg bag | 25,000 |
| Pop larvae pet treats per 1 kg bag | 17,500 |
| Eggs per gram | 4,000 |
| 5DOL per kg | 20,000 |
| Pupae per kg | 40,000 |
| 1st quality frass (pelletized) per 1.5 kg bag | 5,000 |
| 2nd quality frass - bulk in 50 kg sacks | 50,000 |
| 3rd quality frass - bulk, unpackaged[1] | 0 |

[1] Via transfer pricing solely for Lamiah's farm.

Source: Authors.

### Capacity building initiatives

**Donor-funded BSF training partnerships led revenue for BSF Tamatave's founder as well as conservation and livelihood gains for participants.** In early 2025, Lamiah received a US$10,000 grant from Conservation International to train 50 residents of a rural community adjacent to Ivoloina Park, a zoological park and forestry station near Tamatave, in BSF farming as an alternative livelihood to charcoal production from tree clearing. From those 50 trainees, 10 (6 women, 4 men) were selected to receive a BSF farming startup package and ongoing weekly coaching from BSF Tamatave's farm manager. All 10 began farming operations in late May 2025, and none have reverted to tree cutting. A concern for any new BSF farming operation is reliable access to substrate. Lamiah addressed this proactively by identifying and securing commitments from three nearby fruit and vegetable processors as waste sources before training began, and she will teach the farmers how to ferment waste to maintain supply through lean seasons. Lamiah also received a grant of MGA 20,000,000 (approximately US$4,500) from the Forum du Conseil Agricole de Madagascar (FCA) to conduct a one-week train-the-trainer program in southwestern Madagascar.

### Expansion plans

**Future partnerships with industrial-scale substrate providers, along with investment in equipment, may drive an expansion in operational capacity.** A large manufacturing facility is to be established within 10 kilometers of the farm, employing approximately 5,000 workers. The factory canteen is expected to generate approximately 5 tons of organic waste per day, and Lamiah has already secured an agreement with the company to receive all the waste. This additional substrate supply is the key enabler of her medium-term production goal of 1 ton of wet larvae per day, which will also require capital investment in mechanized equipment – including a waste digester, electromechanical sieve, and conveyor dryer for pop larvae – and the addition of 5 workers. A silo construction project is underway to store substrates during the lean season (typically lasting around two months). Her long-term goal is 2 tons per day, which she estimates would require approximately 20 full-time workers, roughly triple her current workforce.

## Sector challenges

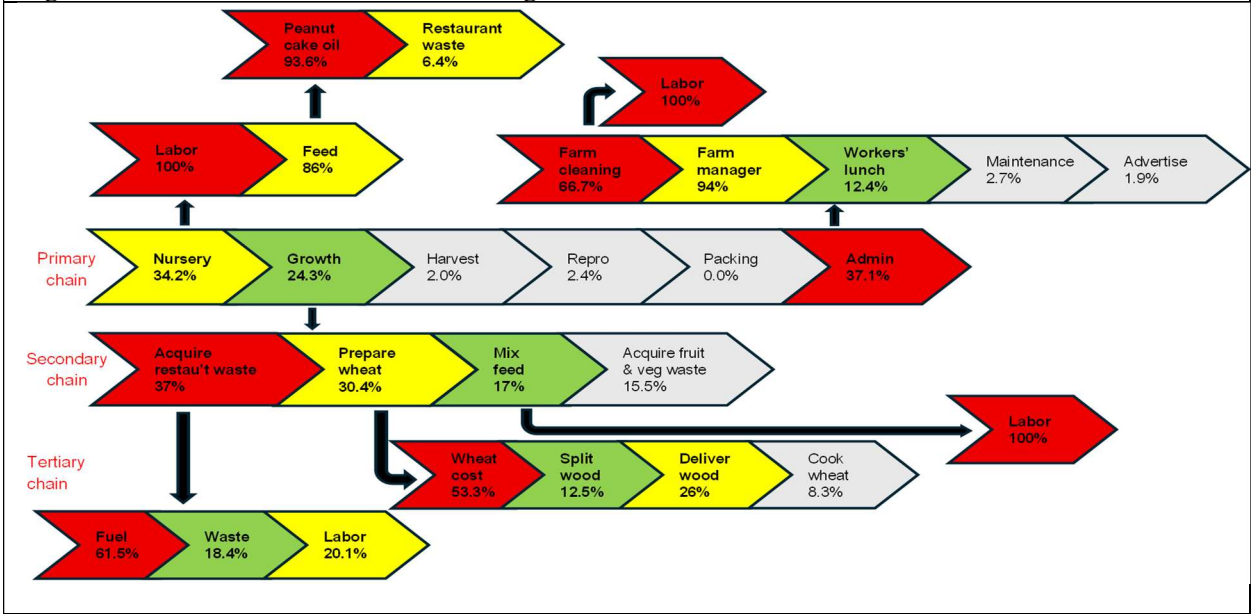
**Concerns and issues for BSF farming in Madagascar, from the perspective of BSF Tamatave, include**:

- **Contamination risk:** Fungal outbreaks originating in kitchen waste and mite infestations from damp frass are recurring risks across the BSF farming community in Madagascar. Such issues have caused the complete loss of BSF Tamatave production three times since the farm was established, though they are not isolated to BSF Tamatave. Lamiah's Facebook Messenger user group has identified the same fungus problem on farms elsewhere in the country, underscoring the need for sector-wide dissemination of hygiene best practices.
- **Substrate availability:** Consistent access to adequate organic waste is a limiting factor for BSF farming expansion, particularly in rural and peri-urban areas where food processing infrastructure is sparse.
- **Market awareness and acceptance:** Despite strong theoretical demand for BSF-derived protein as a feed input, broad market uptake among poultry and aquaculture farmers remains limited. Wider adoption will likely require coordinated sector-level promotion of BSF larvae as a sustainable, cost-effective alternative or supplement to conventional feed ingredients.

## BSF Tamatave value chain

**A diverse revenue base across market sectors and levels of quality characterizes BSF Tamatave's value chain.** BSF Tamatave operates a multi-tier value chain that processes larvae into four distinct commercial forms, wet larvae, dried larvae and larvae powder, pop larvae, and live biological products (eggs, five-day-old larvae, and pupae), while independently monetizing frass across three quality grades. This diversification shapes the farm's cost structure, revenue profile, and economic viability. Figure 3.8 shows the cost breakdown across the BSF Tamatave value chain. Downstream products are not part of this value chain, as each downstream product that uses the output of another value chain (e.g., wet larvae as an input to produce dried larvae) is considered value chain integration.

**Figure 3.8: BSF Tamatave's BSF farming value chain**




Source: Authors.

Downstream products are not part of this value chain, as each downstream product that uses the output of another value chain (e.g., wet larvae as an input to produce dried larvae) is considered value chain integration.

### Primary value chain cost structure

**Nursery, growth-stage, and administration categories dominate the cost structure of BST Tamatave's operation.** As a complement to Figure 3.8, Table 3.12 presents the cost breakdown per kilogram of wet larvae produced. Total production cost is MGA 1,526 per kilogram (US$0.35), distributed across five active stages of the primary value chain: nursery (34.2 percent), growth (24.3 percent), reproduction (2.4 percent), harvest (2.0 percent), and administration (37.1 percent). Packing cost is negligible.

**Table 3.12: BSF Tamatave primary value chain cost breakdown per kilogram of wet larvae produced daily**

| Stage | MGA/kg | US$/kg | % of Total |
|---|---|---|---|
| Nursery | 522 | 0.12 | 34.2 |
| Growth | 371 | 0.08 | 24.3 |
| Harvest | 31 | 0.01 | 2.0 |
| Reproduction | 36 | 0.01 | 2.4 |
| Packing | 0 | 0.00 | 0.0 |
| Admin | 566 | 0.13 | 37.1 |
| ***Total cost per kg*** | ***1526*** | ***0.35*** | ***100.0%*** |

Source: Authors.

**Administration, especially cleaning, is the single largest cost component in the primary chain.** These costs, at MGA 566 per kilogram, represent 37.1 percent of total production cost. Table 3.13 presents the secondary value chain for administration, breaking this cost into its five constituent elements. Farm cleaning is overwhelmingly the dominant driver, at MGA 377 per kilogram of wet larvae harvested: 66.7 percent of total administration cost. The economic importance of rigorous cleaning at BSF Tamatave is well established by operational history: the farm has suffered three complete production collapses since founding, two caused by fungal contamination introduced through kitchen waste and one by a mite infestation originating in damp frass. Weekly full-farm deep cleaning, involving all farm workers for half a workday, is the primary preventive measure, and its cost is virtually all labor. The farm manager's salary is the second-largest administration cost component at MGA 92 (16.3 percent) per kilogram of daily wet larvae harvested, followed by workers' daily meals at MGA 70 per kilogram (12.4 percent), maintenance at MGA 15 (2.7 percent), and advertising at MGA 11 (1.9 percent).

**The nursery phase, especially feed, is the second-largest cost component, followed by growth-phase costs in third position.** These costs come to MGA 522 per kilogram (34.2 percent of total). Feed dominates nursery costs at 86 percent, of which peanut oil cake accounts for 93.6 percent – reflecting its nutritional importance for early-stage larvae and its comparatively high unit cost. Restaurant waste accounts for the remaining 6.4 percent of nursery feed cost. The growth phase, at MGA 371 per kilogram (24.3 percent of total), is the third-largest primary chain cost. Taken together, the nursery and growth phases – spanning the full arc of larval development from hatching to harvest – account for 57.1 percent of total production costs, underscoring the substrate intensity of larval development. Reproduction (2.4 percent) and harvest (2.0 percent) together account for less than 5 percent of the total cost of producing market-ready wet larvae.

**Table 3.13: Secondary value chain for administration costs**

| | MGA | % of total |
|---|---|---|
| Maintenance | 15 | 2.7 |
| Advertise | 11 | 1.9 |
| Cleaning | 377 | 66.7 |
| Employee's lunch | 70 | 12.4 |
| Farm manager | 92 | 16.3 |
| ***Total cost*** | ***566*** | ***100.0*** |

Source: Authors.

### Secondary and tertiary chains: substrate acquisition and feed preparation

**Organic waste acquisition from restaurants, fruit and vegetable processing, and grain shipping sources have distinct acquisition modalities and costs.** Within the growth secondary chain, restaurant waste acquisition is the costliest activity, accounting for 37 percent of the chain's costs. Breaking down restaurant waste acquisition across the tertiary chain, the farm driver's vehicle fuel is the leading cost, accounting for 61.5 percent of the subsegment. The labor associated with collecting restaurant waste is the driver's alone. The cost of the waste is not a formal charge, but rather consists of tips given to the kitchen staff. Wheat preparation follows restaurant waste acquisition, at 30.4 percent of the secondary chain associated with growth. Wheat preparation is broken down into a tertiary cost structure: wheat costs at 53.3 percent, wood fuel delivery at 26 percent, wood splitting at 12.5 percent, and cooking labor at 8.3 percent. The wheat, sourced from the unusable lower-grade grain at the bottom of ships' hulls, which would otherwise be burned, is obtained at no purchase cost. The 53.3 percent attributed to wheat in the tertiary chain reflects only the one-time trucking expense incurred to collect it from the port. Although contributing the least to the cost of growth, a third feed component is fruit and vegetable waste, sourced free of charge from a nearby commercial processor and exporter via the part-time driver. All three substrate types – restaurant waste, fruit and vegetable waste, and wheat – fed to the larvae during the growth stage are fermented for 2 days and mixed before being added to the growth trays. Mixing the feeds accounts for 17 percent of the growth segment of the value chain.

**Grain preparation incurs wood fuel costs.** Wood fuel, used both to boil wheat and to roast pop larvae, is consumed at approximately 3.36 cubic meters every 4 days and is hauled from Lamiah's 20-hectare property, approximately 30 kilometers from the farm, once per week. The cost to haul the wood from the property to the farm is shown in the wheat preparation chain to be 26 percent of the overall cost. Wood splitting, which consists solely of labor, adds 12.5 percent of the cost in the wheat preparation chain. In total, the costs associated with wood account for 38.5 percent of the total cost to prepare wheat. Lamiah plans to replace wood as fuel with a waste-oil-fueled boiler (estimated cost: MGA 500,000). Doing so is expected to reduce fuel costs and align with efforts to reduce the environmental impact of BSF Tamatave's operations.

### Wet larvae production cost and revenue

**Scale promotes profitability.** At MGA 1,526 per kilogram of wet larvae (US$0.35), BSF Tamatave's unit production cost is well below its blended selling price of MGA 3,700 per kilogram – derived from 70

percent of sales to casual clients at MGA 4,000 per kilogram and 30 percent to preferred high-volume clients at MGA 3,000 per kilogram – yielding a gross margin of 58.8 percent on wet larvae. This suggests an indicator of operational maturity and the advantages of scale: at smaller or less-established BSF operations, the gap between production costs and the larvae selling price is tighter, and – as illustrated in other cases presented in this document – production costs can exceed the selling price.

### Processing and biological product value chains

**Differentiated larval and frass products form distinct secondary value chains.** Beyond wet larvae, BSF Tamatave produces and sells seven additional larval products and three grades of frass integrated with the larva value chain.[62] Tables 15 through 22 present the value chains for each. Because the upstream cost of producing wet larvae is already fully captured in Table 3.12, the product-specific value chains in Tables 15 through 22 reflect the incremental cost of transforming wet larvae into each finished product, with the cost of the raw material input reflecting its production rate.

### Larvae-derived processed products

**The cost and profitability of wet larvae define secondary larval value chains.** Tables 3.14 – 3.16 present the value chains for dried larvae, larvae powder, and pop larvae, respectively. Across all three, the raw material – wet larvae – accounts for the overwhelming share of total cost: 93.9 percent for dried larvae (MGA 4,922 of MGA 5,241 per kilogram), 94.0 percent for larvae powder (MGA 10,118 of MGA 10,767 per two-kilogram bag), and 86.8 percent for pop larvae (MGA 4,577 of MGA 5,272 per kilogram). Processing and packing contribute only marginally to all three cases, making the economics of downstream transformation primarily a function of the selling price premium achieved over wet larvae.

**Three categories of larvae-derived products offer different advantages, drawbackjs, and profit margins.** This premium is most pronounced for pop larvae. Roasting and packing add just 13.2 percent to the raw material cost, yet the finished product sells at MGA 17,500 per kilogram – 4.7 times the blended wet larvae price of MGA 3,700 – resulting in a gross margin of 69.9 percent. That people with pets may exhibit relatively inelastic price sensitivity for a product with appeal as a novelty treat is consistent with this premium. Dried larvae and larvae powder achieve margins of 56.2 percent and 56.9 percent, respectively, with dried larvae priced at MGA 12,000 per kilogram and powder at MGA 12,500 per kilogram (in two-kilogram bags at MGA 25,000), offering a lesser premium over the wet larvae input cost but providing the operational benefit of extended shelf life and expanded geographic reach.

[62] In an integrated value chain, as in this case, the output of one value chain becomes the input to another value chain. For example, cotton farming has a complex value chain, and the output, cotton, is the input for the cotton ginning value chain. The resulting lint cotton is the input for the textiles value chain, which, in turn, becomes the input to the garment manufacturing value chain: four distinct and complex value chains integrated within an industry. In the case of BSF farming, the resulting wet larvae serve as input for producing dried larvae, which can be a component of a more complex commercial feed production value chain.

**Table 3.14: Value chain per kilogram of packaged dried larvae**

| Stage | MGA/kg | US$/kg | % of Total |
|---|---|---|---|
| Raw material (wet larvae)* | 4,922 | 1.12 | 93.9 |
| Drying | 38 | 0.01 | 0.7 |
| Packing | 281 | 0.06 | 5.4 |
| ***Total cost/kg*** | ***5,241*** | ***1.19*** | ***100.0*** |

* Producing 1 kg of dried larvae requires 3.23 kg of wet larvae.

Source: Authors.

**Table 3.15: Value chain per two-kilogram bag of packaged larvae powder**

| Stage | MGA/2kg | US$/2kg | % of Total |
|---|---|---|---|
| Raw material (dried larvae)* | 10,118 | 2.30 | 94.0 |
| Grinding | 318 | 0.07 | 3.0 |
| Packing | 331 | 0.08 | 3.1 |
| ***Total cost/kg*** | ***10,767*** | ***2.45*** | ***100.0*** |

* Raw material is 2 kg unpackaged dried larvae and accounts for 2%.

Source: Authors.

**Table 3.16: Value chain per kilogram of packaged pop larvae**

| Stage | MGA/2kg | US$/2kg | % of Total |
|---|---|---|---|
| Raw material (wet larvae)* | 4,577 | 1.04 | 86.8 |
| Roasting | 364 | 0.08 | 6.9 |
| Packing | 331 | 0.08 | 6.3 |
| ***Total cost/kg*** | ***5,272*** | ***1.20*** | ***100.0*** |

* Producing 1 kg of pop larvae requires 3 kg of wet larvae.

Source: Authors.

**Biological products**

**Sales of BSF eggs, larvae, and pupae provide attractive profit margins.** Tables 3.17 – 3.19 present the value chains for BSF eggs, five-day-old larvae (5DOL), and pupae. These products require minimal processing yet command the highest unit prices in the BSF Tamatave portfolio – MGA 4,000 per gram for eggs, MGA 20,000 per kilogram for 5DOL, and MGA 40,000 per kilogram for pupae – reflecting the value buyers place on live biological material for establishing or expanding their own BSF colonies.

**For eggs, the value chain is brief and composed almost entirely of packaging costs.** Harvesting labor (8.3 percent of cost at MGA 74 per five-gram minimum order) and packing (91.7 percent at MGA 800 per container plus MGA 20 for labor). The packaging dominance reflects the minimum order structure: egg orders have a minimum of 5 grams, and an MGA 800 container cost per order, fixed regardless of quantity, accounts for nearly all the incremental cost. Buyers placing larger orders benefit from lower packaging costs per gram, but Table 3.17 conservatively overstates costs by assuming all transactions are at the minimum order size.

**For five-day-old larvae, the value chain is more complex, with higher input costs**. Substrate acquisition accounts for 82.2 percent of total cost (MGA 6,732 per kilogram), followed by egg harvesting at 13.5 percent (MGA 1,106), feeding at 2.9 percent (MGA 236), tray division at 1.4 percent (MGA 118), and packing at 9.4 percent (MGA 770). The substrate intensity of 5DOL production indicates that even the initial five days of larval development require a full feed cycle, making this the most cost-intensive biological output per kilogram.

**Pupae costs are derived from the cost of larvae production.** For pupae, raw material – the wet larvae from which pupae develop – accounts for 98.2 percent of total cost (to produce 1 kg of pupae, approximately 1.37 kg – with a production cost of MGA 2,090 – are needed), with packing contributing only MGA 39 (1.8 percent). The cost structure of pupae is therefore almost entirely a pass-through of upstream production costs, and the economics are driven by the selling price of MGA 40,000 per kilogram.

**Table 3.17: Value chain per five-gram package of eggs**

| Stage | MGA/5g | US$/5g | % of Total |
|---|---|---|---|
| Harvesting | 74 | 0.02 | 8.3 |
| Packing* | 820 | 0.19 | 91.7 |
| ***Total cost/kg*** | ***893*** | ***0.20*** | ***100.0*** |

* Minimum order is 5 gr; container cost is MGA 800. The value chain assumes the minimum order for all sales, likely overstating total cost, which is driven by packaging materials at MGA 800 per container.

Source: Authors.

**Table 3.18: Value chain per kilogram of packaged 5DOL**

| Stage | MGA/1kg | US$/1kg | % of Total |
|---|---|---|---|
| Harvest eggs* | 1,106 | 0.25 | 13.5 |
| Acquire substrate | 6,732 | 1.53 | 82.2 |
| Divide trays | 118 | 0.03 | 1.4 |
| Feeding | 236 | 0.05 | 2.9 |
| Packing | 770 | 0.18 | 9.4 |
| ***Total cost/kg*** | ***8,192*** | ***1.86*** | ***100.0*** |

* Ten percent of total eggs harvested will yield 10% of 5DOL.

Source: Authors.

**Table 3.19: Value chain per kilogram of packaged pupae**

| Stage | MGA/1kg | US$/1kg | % of Total |
|---|---|---|---|
| Raw material (wet larvae)* | 2,090 | 0.48 | 98.2 |
| Packing | 39 | 0.01 | 1.8 |
| ***Total cost/kg*** | ***2,129*** | ***0.49*** | ***100.0*** |

* 1 kg of wet larvae yields approximately 0.73 kg of pupae.

Source: Authors.

### Frass

**Three forms of frass offer different production modalities, costs, and sale prices, all with high margins.** Table 3.20 and Table 3.21 present the value chains for pelletized frass (first quality) and bulk frass (second quality) in 50-kilogram sacks, respectively. Third-quality frass is set aside for Lamiah's agricultural plots at a transfer price of MGA 500 per kilogram with no attributed costs; there is no value chain. For pelletized frass, packing dominates cost at 89.9 percent (MGA 331 per 1.5-kilogram bag), with pelletizing labor accounting for only 10.1 percent (MGA 37). Total cost per 1.5-kilogram bag is MGA 368, against a selling price of MGA 5,000 per bag – a margin of 92.5 percent. For bulk frass, the value chain consists entirely of the labor cost of filling 50-kilogram sacks, at MGA 1,102 per sack against a selling price of MGA 50,000 – a margin of 97.8 percent. The extremely high margins on frass across all grades reflect a fundamental characteristic of frass as a byproduct: all costs associated with generating frass – feed acquisition, substrate preparation, and BSF husbandry – are fully attributed to larval production in the primary value chain. The incremental cost of preparing and packaging frass for sale is negligible relative to its market value as an organic soil amendment.

**Table 3.20: Value chain per 1.5-kilogram bag of pelletized frass**

| Stage | MGA/1kg | US$/1kg | % of Total |
|---|---|---|---|
| Pelletizing | 37 | 0.01 | 10.1% |
| Packing | 331 | 0.08 | 89.9% |
| ***Total cost/kg*** | ***368*** | ***0.09*** | ***100.0%*** |

Source: Authors.

**Table 3.21: Value chain per 50-kilogram sack of bulk frass**

| Stage | MGA/1kg | US$/1kg | % of Total |
|---|---|---|---|
| Packing | 1,102 | 0.25 | 100.0 |
| ***Total cost/kg*** | ***1,102*** | ***0.25*** | ***100.0*** |

Source: Authors.

### Profitability across all product lines

**Table 3.22 presents an overview of BSF Tamatave's net income across all ten product lines.** The figures are normalized to a daily harvest of approximately 150 kilograms of wet larvae and 300 kilograms of frass. The detailed value chains underpinning these results are presented in the sections above.

**High margins and high unit costs characterize BSF Tamatave's greatest generators of gross income.** The highest-margin products are the biological outputs and frass: eggs (95.6 percent), pupae (94.8 percent), second-quality bulk frass (97.8 percent), first-quality pelletized frass (92.5 percent), and 5DOL (79.5 percent). These margins reflect both premium pricing and, in the case of frass, the absence of allocated upstream cost. In daily gross income terms, however, it is pop larvae that contribute most, at MGA 350,000 (US$79.55 per day). Pop larvae's 40 percent share of the daily harvest and strong per-kilogram selling price together make it the farm's largest single income stream. Pupae generate the second-highest gross income at MGA 330,000 (US$75), driven by their MGA 40,000 per kilogram selling price despite representing

only 11.25 percent of the daily harvest, followed by first-quality pelletized frass at MGA 295,000 (US$67.05) per day. The three frass grades together contribute MGA 460,000 per day in gross income, reinforcing the point that the byproduct of larval production is itself a significant revenue source. However, the product achieving the highest daily net income is pupae (MGA 312,796/ US$71.09), followed by pelletized frass (MGA 272,931/US$62.03), and then pop larvae (MGA 244,564/US$55.58). Aggregated across all ten product lines, BSF Tamatave generates an estimated daily net income of MGA 1,313,051 (US$298), reflecting the commercial maturity and scale of BSF Tamatave's operations. How these results are achieved has been detailed in the preceding sections.

**Table 3.22: BSF Tamatave profitability by product line (daily basis, ~150 kg wet larvae harvest)**

| | | Approx % of daily harvest | Total cost (MGA) | Total cost (US$) | Total income (MGA) | Total income (US$) | Net income (MGA) | Net income (US$) | Mar-gin (%) |
|---|---|---|---|---|---|---|---|---|---|
| **Larvae[1]** | Wet larvae[2] | 15 | 34,330 | 7.80 | 83,250 | 18.92 | 48,920 | 11.12 | 59 |
| | Dried larvae | 7.5 | 18,343 | 4.17 | 41,850 | 9.51 | 23,507 | 5.34 | 56 |
| | Dried larvae powder[3] | 7.5 | 18,842 | 4.28 | 43,750 | 9.94 | 24,908 | 5.66 | 57 |
| | Pop larvae | 40 | 105,436 | 23.96 | 350,000 | 79.55 | 244,564 | 55.58 | 70 |
| | Eggs | 25 | 8,737 | 1.99 | 200,000 | 45.45 | 191,263 | 43.47 | 96 |
| | 5DOL | 10 | 8,192 | 1.86 | 40,000 | 9.09 | 31,808 | 7.23 | 80 |
| | Pupae[4] | 11.25 | 17,204 | 3.91 | 330,000 | 75.00 | 312,796 | 71.09 | 95 |
| **Frass[5]** | 1st quality (pelletized)[6] | 30 | 22,069 | 5.02 | 295,000 | 67.05 | 272,931 | 62.03 | 93 |
| | 2nd quality | 40 | 2,646 | 0.60 | 120,000 | 27.27 | 117,354 | 26.67 | 98 |
| | 3rd quality[7] | 30 | 0 | 0 | 45,000 | 10.23 | 45,000 | 10.23 | 100 |
| | ***Net income based on daily 150 kg wet larvae harvest & 300 kg frass production:*** | | | | | | ***1,313,051*** | ***298.42*** | |

1 Normalized to kilograms of fresh larvae harvested daily (~150 kg).

2 Pricing split: 70% casual customers (MGA 4,000/kg) and 30% preferred customers (MGA 3,000/kg).

3 Although not reported during data collection, total income reflects an estimated 2% loss from grinding.

4 Based on retaining 25% of the 30% wet larvae harvested.

5 Based on 300 kg/day production.

6 Although not reported during data collection, total income reflects an estimated 2 percent pelletizing loss.

7 Income via transfer pricing from BSF Tamatave owner's farm.

Source: Authors.

**Lower-margin products have an important role in the operation's value chains and customer relationships.** The three larvae processing products – wet larvae, dried larvae, and larvae powder – are the lowest-margin items in the portfolio, with margins of 58.8, 56.2, and 56.9 percent, respectively, reflecting the high raw material cost relative to selling price in each case. Nevertheless, these products serve an important commercial purpose: wet larvae are the primary product underpinning customer relationships

and regular purchasing patterns, while dried larvae and powder extend the farm's effective market geography by enabling longer transit times.

### Pathway to expanded output

**Growth is expected to further boost profitability.** BSF Tamatave's economics will strengthen further as production scale increases, and fixed cost components – e.g., the farm manager's salary – are spread across a larger output base. The near-term agreement with a nearby large factory, whose canteen is expected to generate approximately 5 tons of organic waste per day, as described in the company profile, is the key substrate enabler of Lamiah's medium-term target of 1 ton of wet larvae per day. At that scale, the leverage on fixed costs, combined with anticipated investment in mechanized equipment, should further compress per-kilogram production costs and improve margins across the entire product portfolio. The case study in Box 3.1, involving BSF Tamatave and a commercial poultry farm in Antananarivo, is an example of the unconventional opportunities for BSF farming when scale increases combine with circular efficiencies.

**Box 3.1: Unlocking Economic Value through Circular Agriculture: A BSFL-Poultry Partnership Model**

**Context and opportunity**

In July 2025, a commercial poultry farm operator managing 100,000 chickens across 300 cages contacted BSF Tamatave to implement an innovative circular farming model. The initiative is designed to improve organic waste management, reduce the cost of chicken feed, and generate additional value from frass, demonstrating both environmental and economic sustainability.

**Business model and economic impact**

Under the model, the poultry farmer purchases five-day-old larvae (5DOL) from BSF Tamatave at MGA 20,000 per kilogram and places 1 kg of 5DOL beneath each cage every 10 days. Feeding on chicken manure and other supplemental substrates (e.g., rice bran, which helps reduce ammonia odor), the larvae grow into approximately 10 kg of wet larval biomass per cage. At a market value of MGA 4,000 per kg, the resulting biomass is worth MGA 40,000.

This creates a net economic gain of MGA 20,000 per cage per cycle, as the initial larval input cost is fully offset by the value of the mature larvae produced. Because the cycle can be repeated three times per month, the projected monthly economic benefit across 300 cages is:

MGA 20,000 × 300 cages × 3 cycles/month = MGA 18,000,000 per month

This gain is achieved with minimal labor or infrastructure requirements, as the larvae naturally process manure beneath the cages as they grow into a valuable on-farm feed resource.

**Feed efficiency and cost reduction**

According to the farm operator, feed costs account for approximately 80 percent of total poultry production costs. Under this model, the larvae produced beneath the cages during each 10-day cycle replace a portion of the purchased commercial feed, reducing feed expenditure by approximately 30 percent. Applied to the feed cost share of total production, this yields a reduction in overall farm input costs of approximately 24 percent – a substantial saving achieved through a biological process that requires no additional land, feed crops, or imported inputs, and that simultaneously reduces manure accumulation on the farm.

The frass generated through larval feeding also serves as a nutrient-rich organic fertilizer that can either be applied on-site or sold as an agricultural input, further enhancing the economic value of the system.

**Waste-to-value conversion**

Beyond reducing feed costs, the system serves as an efficient biological conversion platform that transforms poultry waste into high-value agricultural inputs. Each kilogram of 5DOL placed beneath a cage converts manure and organic residues into approximately 10 kg of larval biomass within 10 days. Across the farm's 300 cages, running three cycles per month, this process generates approximately 9,000 kg of larvae per month from organic waste streams already present on the farm – biomass that re-enters the production system as feed, displacing purchased inputs and closing the nutrient loop. By converting an unavoidable waste stream into a productive resource, the model improves nutrient recycling efficiency, reduces the environmental externalities associated with unmanaged poultry waste, and strengthens on-farm input self-sufficiency.

**Circular Agriculture in Practice**

This model illustrates a scalable circular agricultural system in which livestock waste is transformed into animal feed and organic fertilizer. The arrangement benefits both participants in the value chain: the BSF farmer gains a reliable market for larvae, while the poultry farmer reduces feed costs, improves waste management, and creates additional agricultural inputs through frass production.

**Development Implications**

The example highlights a replicable model with clear co-benefits for waste management, agricultural productivity, and rural income diversification. By converting locally available organic waste into valuable feed and fertilizer, black soldier fly farming can strengthen agricultural value chains while supporting more resilient and resource-efficient food systems. The farmer intends initially to sell the frass (currently marketed at approximately MGA 1,000/kg), but over time plans to apply it to maize production and incorporate it into on-farm feed formulation, further increasing cost savings and strengthening farm-level input self-sufficiency.[63]

## EXA Feed: Recent Start-up Industrialized Insect Farming - Company Profile and Value Chain

### Company profile

**Background and location**

**Structural advantages and infrastructure investment position EXA Feed for successful BSF production.** EXA Feed is one of two divisions of the recently established Malagasy firm Groupe EXA, specializing in the production of insect-based alternative proteins. The group has two divisions: EXA Feed, focused on livestock proteins and organic fertilizer, and EXA Food (Antananarivo) which has collaborated with the Madagascar Biodiversity Center on research and product development using insect flours, including BSF larvae flour produced by EXA Feed. In September 2024, EXA Feed launched its vertically integrated BSF production facility in Diego Suarez (Antsiranana), the capital of Diana Region. The location was chosen for strategic reasons. The area's tropical, warm-to-hot, and humid climate aligns well with environmental requirements for BSF larvae growth and adult breeding. The annual mean temperature is

[63] Fieldwork for Box 3.1 was conducted in July 2025. Intense Tropical Cyclone Gezani made direct landfall at Tamatave on February 10, 2026, with wind gusts exceeding 250 km/h, causing catastrophic damage to the city's infrastructure. BSF Tamatave's operations were destroyed. The analysis above reflects conditions at the time of the fieldwork visit and does not account for subsequent developments.

26.1 °C, the average temperature of the coldest months is 24.4 °C, and the average temperature of the hottest months is 27.6 °C.[64] Its long dry season makes solar energy viable, and EXA has taken advantage of this, completing the conversion of the facility to 100 percent solar power. The facility is also strategically located within 0.5 km from Star Brewery (1 km driving), EXA's source of brewer's spent grain (BSG) – the company's most prominent feed ingredient in its larval substrate. This eliminates one of the greatest cost drivers experienced by other BSF farms in Madagascar: the cost of acquiring substrate.

EXA holds both HACCP and FSSC 22000 food safety certifications, demonstrating compliance with internationally recognized standards for food safety management and hazard control.[65,66]

### Infrastructure

**EXA Feed uses high-quality equipment and facilities.** The factory uses specialized, high-quality Chinese BSF processing equipment that is cost-effective (3–4 times less expensive than European alternatives and 2 times less than Indian alternatives). In addition to operating on solar energy, EXA harvests rainwater and integrates BSF farming with aquaculture, crop farming, and broiler chicken production. At the time of fieldwork in July 2025, EXA planned additional equipment and construction by the end of 2025, including an incubator for the nursery, a centrifuge for processing, and a new climate-controlled building to support expansion and increase larval biomass.

### Early-stage value chain and learning orientation

**EXA Feed's BSF value chain is an industrial pilot engaged in deliberate learning and optimization as a prelude to future profitability.** Production began in September 2024; the company had less than one year of operational experience at the time of fieldwork (July 2025). During this period (and continuing beyond), EXA prioritized experimentation and process understanding over short-term profitability, with the objective of identifying agronomically robust, biologically stable, and economically scalable production parameters under Malagasy conditions. Unlike smaller BSF farms that, out of necessity, converge quickly on a narrow set of practices, EXA intentionally maintained flexibility. Multiple variables were tested in parallel, including substrate composition and sequencing, attractants, larval stocking densities, feed timing, duration of individual production stages, and batch handling procedures. As a result, the company's observed production costs during this phase exceeded revenues by a wide margin – an outcome that reflects learning-phase inefficiency rather than structural unviability.

---

[64] Climates to Travel. https://www.climatestotravel.com/climate/madagascar/antsiranana

[65] Food Safety System Certification (FSSC) 22,000 is an internationally recognized, GFSI-benchmarked food safety management system based on ISO 22,000, sector-specific prerequisite programs, and additional scheme requirements. It verifies that an organization has a comprehensive, independently audited system in place to systematically identify, manage, and continuously improve food safety controls.
*Source:* Foundation FSSC, "What is FSSC 22000?" (official scheme owner).

[66] Hazard Analysis and Critical Control Points (HACCP) is a science-based, preventive food safety system that identifies, evaluates, and controls biological, chemical, and physical hazards at critical points throughout the food production process. Its application principles are established by the FAO/WHO Codex Alimentarius and form the foundation of most modern food safety standards.
*Source:* Codex Alimentarius Commission (FAO/WHO), "Hazard Analysis and Critical Control Point (HACCP) System.

### Input sourcing and substrate experimentation

**Long-term contracting for substrate provides low input costs and price stability.** At the upstream end of the value chain, EXA benefited from secure, low-cost access to brewer's spent grain sourced from a nearby industrial brewery. This removed a major binding constraint faced by most BSF producers in Madagascar – namely, the cost and reliability of substrate acquisition. With ample availability of the key feeding substrate used throughout the larval developmental stages from hatching to harvest, EXA Feed adjusted substrate blends and feeding protocols to evaluate their effects on larval growth rates, survivorship, conversion efficiency, and the consistency of harvested biomass.

### Processing, safety systems, and standards readiness

**Downstream processing and handling were developed alongside rearing activities rather than after biological stabilization was achieved.** EXA's early adoption of HACCP and FSSC 22000 food safety systems reflects a strategic decision to build production discipline and compliance capacity from the outset, even while core biological processes were still being refined. Although this increased operational complexity and cost during the startup phase, it positioned EXA to engage with downstream markets – such as human food ingredients and specialty feed markets – where certification and traceability are non-negotiable requirements.

### Other activities and sector engagement

**EXA Feed also contributes to BSF sector development and food security.** In parallel with its internal value chain development, EXA Feed undertook several externally oriented activities that extend beyond immediate commercial returns. As referenced in the Institutional Support section above, using internal resources, the company supported 30 rural farmers in establishing BSF micro-farms, contributing to local skill development and diffusion of practice. EXA also played a central technical role in developing Madagascar's national standard for human consumption of BSF larvae flour, an effort documented in the institutional support section and indicative of its contribution to sector formalization. EXA Feed's larvae flour is further used by EXA Food in collaboration with the Madagascar Biodiversity Center to develop high-protein insect-flour biscuits combining BSF and cricket flour. These products are intended for school-age children who are at risk of protein and micronutrient deficiencies. At the time of fieldwork, the initiative remained in a pilot and funding-constrained phase, with additional resources required to support randomized control testing and eventual deployment through school feeding channels. While not yet commercially significant, the initiative illustrates the broader nutritional and societal applications that EXA's compliance-oriented production model is designed to support.

### Pathway to optimization and scale

**EXA Feed's operation will change, likely in the direction of profitability, and contribute further to BSF sector development.** The value chain characteristics observed at EXA Feed during its first year (presented below) should be interpreted as transitional. As tested parameters converge toward stable operating norms and as operational scale increases, unit production costs are expected to decline materially, particularly given secure and plentiful substrate access, on-site renewable energy, and the elimination of downstream market barriers through early compliance investment. In this sense, in its early operational

phase, EXA functions less as a representative BSF producer and more as a sector development platform for transitioning to industrial-scale, standards-compliant insect farming in Madagascar.[67]

### BSF production and market activity

**EXA's early-stage operation experimented with a range of products and customers.** Daily harvests of approximately 120 kg of wet larvae were being achieved by mid-2025, notwithstanding frequent procedural adjustments. About 100 kg was sold daily to EXA's two clients, and an additional 20 kg was set aside for processing into dried larvae, larvae flour, and/or defatted larvae flour. EXA sold only fresh larvae in these early stages of operations. Eggs were used internally or were given to the smallholder farmers. The frass was dedicated to research purposes. EXA also resold brewer's spent grain (BSG) when not fully consumed as BSF substrate. The company had negotiated with the brewery to offtake all the BSG produced, but this amount was well beyond EXA's needs, given that it produced only 120 kg of larvae per day. EXA's 12 temporary workers were tasked with managing the incoming BSG, including spreading, containerizing, drying, and packaging it for resale. EXA sold wet grain, which was essentially a pass-through, and dry grain. The average monthly income from BSG is displayed in Table 3.23.

**Table 3.23: EXA BSG resale**

| BSG form | EXA cost (US$/MT)[2] | EXA price (US$/MT)[2] | Average monthly sales (MT) | Monthly average income (US$) |
|---|---|---|---|---|
| Wet | 4.40 | 12.20 | 180 | 2,196.00 |
| Dry[1] | 18.00 | 244.00 | 30 | 7,320.00 |
| | | | ***Total income from BSG*** | ***9,516.00*** |

[1] All brewer's spent grain (BSG) is delivered wet. The quoted cost comprises EXA's labor (12 temporary workers) to dry the BSG.

[2] Costs and prices were quoted in US$.

Source: Authors.

### EXA Feed value chain

**EXA Feed is well staffed.** As of July 2025, EXA[68] had 23 full-time and 2 half-time employees,[69] including administrative staff and the CEO, and an additional 12 temporary employees who receive incoming BSG to prepare it for resale. It also subcontracts a security company to provide 24-hour security at the facility. Table 3.24 summarizes the employment landscape at EXA.

**Labor makes up nearly 75% of EXA's costs.** The value chain diagram presented below in Figure 3.9 suggests a high-cost impact from salaries categorized within the administrative segment of the value chain. Administrative overhead accounts for more than 84 percent of the entire value chain, and within this overhead, salaries are the dominant factor, contributing more than 88 percent. The resultant contribution from salary to the bottom line is 74.8 percent.

[67] While EXA sold wet larvae commercially during this period, production volumes remained well below its planned capacity of 3 metric tons per day, reflecting a focus on process validation, standards compliance, and staged scale-up rather than steady-state commercial operation.

[68] Unless otherwise specified as EXA Food, subsequent references to EXA refer to EXA Feed.

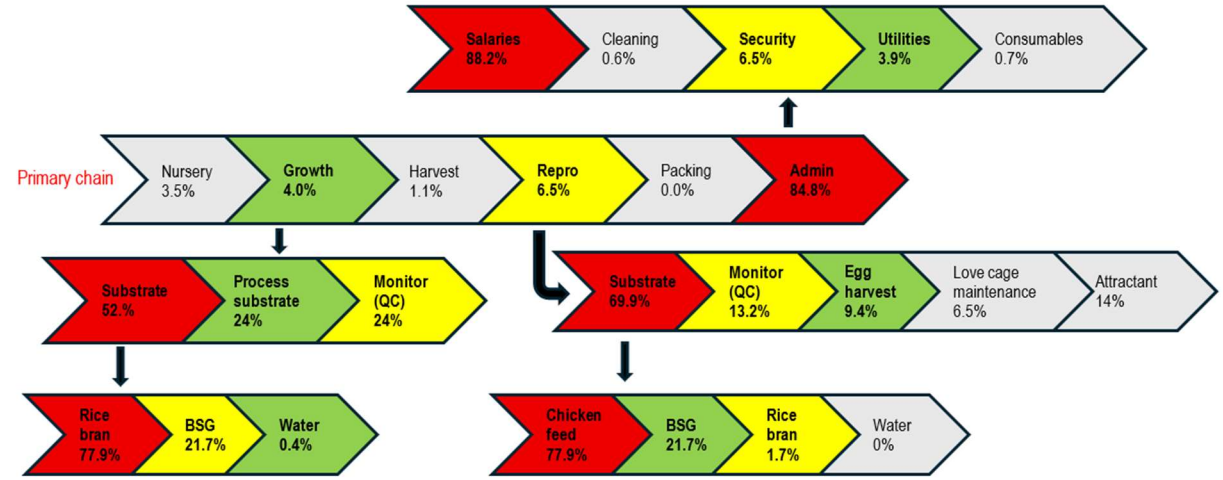
[69] The two half-time employees – both holding management positions – shared their time with EXA Food.

**Table 3.24: EXA employment overview**

| Permanent | | |
|---|---|---|
| **Number of employees** | **Section** | **Notes** |
| 12 | Farming | 4 female, including manager |
| 4 | Processing | 2 female, including manager |
| 1 | Machine maintenance/ technician | male |
| 1 | Quality control | male |
| 1 | Administrator | female |
| 2 | Chicken & fish breeding | 2 male; 1 is manager & heads sales; other is agriculturalist |
| 1 | Janitor | female |
| 1 | Industrialist (half-time) | male; top management: half-time w/EXA Food |
| 1 | Biologist/breeding manager (half-time) | male; top management: half-time w/EXA Food |
| 1 | CEO (unpaid) | male |
| **Temporary** | | |
| 12 | Drying BSG for reselling | all male; will be excess BSG at full capacity |

Source: Authors.

**Figure 3.9: EXA value chain diagram**




Source: Authors.

**Labor costs are high, but staff expertise provides value.** The corresponding costs along the primary value chain in Figure 3.9 are captured in Table 3.25. The administrative costs allocated across wet larvae production were MGA 13,874 (US$3.15) when EXA was harvesting an average of 120 kg of wet larvae daily. EXA had high-level, well-paid experts within the company who conducted investigative research to analyze results and, based on findings, formulate ideas to improve operations. Their expertise led to incremental advancements as EXA worked through the transition phase to establish standard operating

practices for production. For example, only weeks after the research team's visit, in continued communication with EXA industry experts, they conveyed that the processes described and costed during field research had already undergone several changes.[70]

**Table 3.25: EXA primary value chain cost breakdown per kg of wet larvae produced daily**

| Stage | MGA/kg | US$/kg | % of Total |
|---|---|---|---|
| Nursery | 577 | $0.13 | 3.5 |
| Growth | 658 | $0.15 | 4.0 |
| Harvest | 186 | $0.04 | 1.1 |
| Reproduction | 1,065 | $0.24 | 6.5 |
| Packing | 0 | $0.00 | 0.0 |
| Admin | 13,874 | $3.15 | 84.8 |
| ***Total cost/kg*** | ***16,360*** | ***$3.72*** | ***100.0*** |

Source: Authors.

**Site security adds to administration costs, but renewable energy provides savings.** Aside from direct EXA salaries, the second-greatest cost driver in the administration segment of the value chain was security. EXA subcontracts a private security firm to guard the premises 24/7. Security charges accounted for 6.5 percent of administrative overhead. The only other significant administrative cost was electricity. Aside from knowing the kilowatt-hour requirement for mixing feed and for powering the electromechanical sieve in the harvesting process, EXA does not have separate meters to measure electricity usage for each segment of the value chain. All electricity costs – except for mixing and sorting with the power-generated sieve, both of which are accounted for in other segments of the value chain – are allocated to factory overhead. As noted previously in this analysis, EXA's electricity is solar-generated, and the cost to EXA runs approximately US$0.10/kWh. This is a cost savings of at least half when compared with the price of energy from the public grid. The cost of electricity from the grid depends on several factors, including the city, business or household/individual use, and time of use (peak/off-peak). In Diego Suarez, the price for on-grid electricity for businesses ranges from ~$0.2 to ~$0.25 per kWh, depending on the time of use. Cost is only one factor; the other, perhaps more critical factor is reliability. EXA generates its power and has battery capacity to store it. The electrical grid across Madagascar is unreliable, with customers experiencing frequent outages that disrupt businesses that require continuous, dependable electricity.

**Staffing and administration costs currently drag EXA below profitability, but increasing volume should increase efficiency and revenue.** Using data as of July 2025, Table 3.25 shows that EXA Feed's cost to produce and deliver a kilogram of BSF larvae was MGA 16,360 (US$3.72), which is far above the prevailing market price. Referring to the value chains of other producers reported above, the highest price charged per kilogram was MGA 8,000. At a production rate of 120 kg per day, administrative salaries

[70] An intensively quantitative value chain analysis depends on accurate reporting of all costs along associated with the entire product cycle. It represents a snapshot in time. Adjusting the information on an ongoing basis is not possible due to the interrelationship of costs along the chain. That said, a value chain update can occur after analysis of the original snapshot. At the time of preparing this analysis, for example, EXA had already doubled its production, restructured the company, and reduced salaries. See Box 3.2 for more recent updates.

contribute MGA 12,240 (US$2.78) to production. But EXA is designed to produce approximately 3 MT per day. Assuming all else remained the same, at 1 ton per day, the administrative burden on production is reduced to MGA 1,469 (US$0.33). At the 3 MT per day goal, the administrative salary cost contribution reduces to a per-kilogram rate of MGA 490 (US$0.11) (see Table 3.26), and the total cost per kilogram to produce larvae drops 72 percent: from MGA 16,360 to MGA 4,610. The same logic applies to security costs, which are fixed at MGA 3,300,000. The overhead charged to security drops from MGA 907 (US$0.21) at 120 kilograms of larvae produced daily to MGA 36 (less than US$0.01). Most of the electricity overhead – that associated with lighting and air conditioning, which together comprise up to 85 percent of the total electricity cost – also drops accordingly. Other efficiencies will likely emerge as the company scales up. For example, according to the EXA CEO, the company can increase production well beyond a ton per day without hiring additional people. Also, as production increases, the need for BSG increases, leaving less to resell and requiring fewer workers to process resale of the spent grain.

**Table 3.26: Cost contribution of administrative staff at different production levels**

| | Kg larvae harvested daily | | | |
|---|---|---|---|---|
| | **120 kg** | **1 MT** | **2MT** | **3MT** |
| Admin staff cost per kg larvae harvested (MGA) | 12,240 | 1,469 | 734 | 490 |
| Admin staff cost per kg larvae harvested (US$) | 2.78 | 0.33 | 0.17 | 0.11 |
| ***Total admin cost to produce 1 kg of larvae*** | ***16,360*** | ***5,589*** | ***4,855*** | ***4,610*** |

Source: Authors.

**The reproduction segment accounted for 6.5 percent of total costs.** Reproduction represents MGA 1,065 across the primary value chain, driven by substrate. The raw materials of feed ingredients and labor represent 69.9 percent of reproduction costs, though the feed ingredients alone, without labor, accounted for 68 percent of the total cost of reproduction. The reproduction diet consists of the ingredients listed in Table 3.27. Chicken feed comprises 22 percent of the formulation, yet at MGA 3,334/kg, it contributes 97.3 percent of the total cost of substrate components. BSG, comprising 19 percent, accounts for less than 1 percent of feed costs. BSG is a waste product of the beer brewing process, but it has commercial value in the livestock market. For example, from Table 3.23, EXA sells nearly 15 MT of wet BSG to a local pig farmer each month.

**Table 3.27: Substrate components of the reproduction diet per tray (9.6 kg)**

| Ingredient | Kg | % by weight | Unit cost (MGA) | Extended cost (MGA) | % by cost |
|---|---|---|---|---|---|
| Chicken feed | 2.12 | 22 | 3,334 | 7,077 | 97.7 |
| Spent grains (wet) | 1.81 | 19 | 19.54 | 35 | 0.5 |
| Rice Bran | 0.32 | 3 | 400 | 127 | 1.7 |
| Water | 5.35 | 56 | 0.6 | 3 | 0.0 |
| ***Totals*** | ***9.6*** | ***100*** | ***--*** | ***7,242*** | ***100.0*** |

Source: Authors.

**The remaining reproduction costs comprise effectively only labor.** Labor was already included in feed preparation, but other labor requirements are quality control (13.2 percent of reproduction costs), egg handling (9.4 percent), love cage maintenance (6.2 percent), and mixing attractant (1 percent).

**The growth phase is the third-leading cost driver in producing wet larvae (4 percent of costs), with low costs deriving from ready access to spent grain**. Comparing the cost of the substrate for the bioconversion diet to that of the reproduction diet shows EXA's cost advantage with its readily available BSG. The substrate cost for 9.6 kg of reproduction feed is MGA 7,242 (MGA 754/kg), whereas the substrate cost for 200 kg of bioconversion diet is MGA 10,267 (MGA 51/kg) (Table 3.28). The significant difference is the absence of chicken feed in the bioconversion diet and the higher BSG percentage (57 percent by weight). During field research, another farmer reported paying MGA 500/kg for dried BSG – roughly half the price EXA charges – and an additional MGA 5,000 to transport it via taxi-brousse. If EXA had to purchase dried BSG for the EXA selling price, the bioconversion diet as formulated in Table 3.28 would increase to MGA 130,430 – nearly a 13-fold increase over the bioconversion diet cost in the table, and this is without delivery costs factored in. This example sheds light on the economic advantage associated with EXA's strategic decision to locate in Diego Suarez, particularly next to the brewery. The remaining growth costs are essentially labor, except for less than 5 percent attributable to electricity for the ribbon mixer. Labor costs include substrate preparation (23.9 percent) and quality control (24.1 percent), an essential component of FSSC 22000.

**Table 3.28: Substrate components of the growth (bioconversion) diet per basin (200 kg)**

| Ingredient | Kg | % by weight | Unit cost (Ar) | Extended cost (Ar) | % of cost |
|---|---|---|---|---|---|
| Spent grains (wet) | 114 | 57 | 19.54 | 2,228 | 21.7 |
| Rice Bran | 20 | 10 | 400 | 8,000 | 77.9 |
| Water | 66 | 33 | 0.6 | 40 | 0.4 |
| Totals | 200 | 100 | -- | 10,267 | 100.0 |

Source: Authors.

### Processing

**Processing uses primary outputs in subsequent secondary value chains.** EXA was not selling processed larvae at the time of field research, but they explained their prospective processes and costs to allow value chain analysis. As noted in the section above regarding BSF Tamatave, the value chains for the processed products are dependent on the output of the initial value chain – in this case, fresh larvae. Using outputs of earlier stages in the next level, therefore creates an integrated value chain of fresh larvae to dried larvae, which is further integrated into either fatted or defatted powder, with defatted powder creating the byproduct larvae oil.

**Technical steps to improve food safety incur few labor costs.** Before EXA processes wet larvae, the larvae are starved for 24 hours. This stage allows the larvae to purge their digestive tracts of frass, an important step in processing powders destined for human food. There is neither labor nor equipment cost involved in the fast, but it results in a 15-18 percent weight reduction. For the following example, 24 kilograms of wet larvae are used as the starting point.[71] The process flow, beginning with a larval starvation period, is as follows:

[71] EXA began the discussion, stating that approximately 20 percent of wet larvae harvested are processed; 20 percent of 120 kg equals 24 kg.

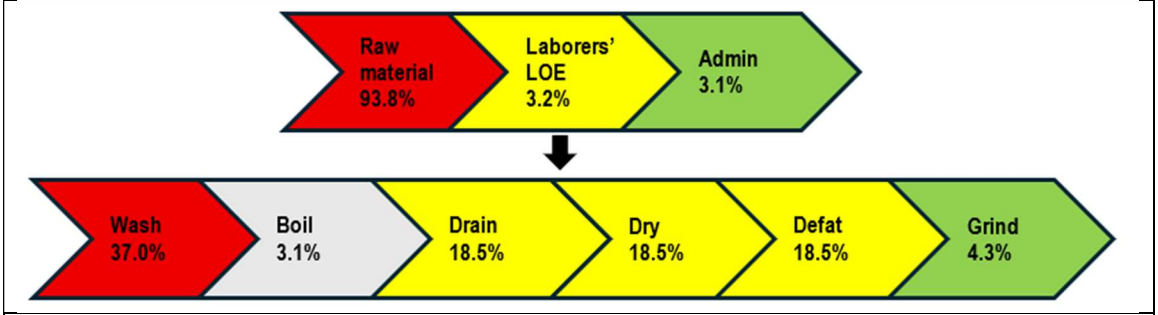
Raw material => wash => boil => drain => dry (microwave) => defat => grind => admin

Except for the larval input, all steps in the processing value chain are heavily labor-intensive.

**Electricity and water input costs are difficult to attribute within specific secondary value chains.** There are electricity costs at each stage, but without an electricity usage meter, neither the breakdown of electricity costs at each step nor the overall electricity cost attributable to processing can be determined. The electricity cost would be useful to know, particularly considering the machinery used in processing. The other missing cost is that of water, and the only steps that use water are washing (rinsing the starved larvae upon intake) and boiling. At MGA 0.6 per kg, the water cost of processing would be inconsequential. One hundred kilograms of water would cost MGA 60 (US$0.01) and, on a per-unit-of-production basis, would register as 0% in the final assessment.

**The primary cost factor for defatted larvae is that of the wet larvae.** The value chain is shown in Figure 3.10. All costs are normalized to account for 1 kilogram of defatted powder produced. Using information from an EXA specialist, 24 kg of wet larvae experience a 15-18 percent loss of mass in the 24-hour starvation period, resulting in 19.7-20.4 kg of starved larvae (assume approximately 20 kg post-starvation mass). The 24 kg of larvae equated to a production cost of MGA 56,091 as of July 2025, accounting for 94.6 percent of the cost to produce defatted powder.

**Figure 3.10: Value chain for defatted BSF larvae powder**




Source: Authors.

**Labor for processing is the second-highest cost in producing larva powder.** For simplicity, all labor is grouped into one segment of the primary value chain. This segment is broken down into specific processes, as shown in the secondary value chain. Twenty kilograms of post-starvation larvae begin their conversion to powder by being washed. Washing, however, is the production bottleneck for the overall program; the apparatus has a 15 kg limit. Given this, two sessions are required to accommodate processing more than 15 kg (up to 30 kg). Washing requires 60 minutes for two people (120 minutes LOE), which constitutes 1.2 percent of the value chain cost (the third-leading cost across the chain). After the wash, the larvae are boiled at 101°C (LOE: 5 minutes for 2 people => 10 minutes total). Next, larvae are drained to a moisture content of 70 percent. Two people are engaged for 30 minutes (total LOE: 60 minutes), but EXA plans to purchase a centrifuge that will reduce draining time to 2 minutes. Drying is next and is done with microwave technology. The machine's capacity is 56 kg/hr. Larvae at 70 percent moisture content are fed into the conveyor and emerge at 5 percent moisture content: a 65 percent reduction. This process also requires 30 minutes for both employees (60 minutes LOE).

Larvae at 5 percent moisture are loaded into the defatting apparatus. The process takes 60 minutes, but only one worker is required; thus, the LOE is 60 minutes. Defatting results in a 24 percent mass reduction: 7 kg of dried larvae weigh 5.3 kg after defatting. The final step is grinding, which requires 7 minutes for two workers: 14 minutes LOE. The grinding loss is 10.5 percent, yielding nearly 5 kg of defatted BSF larvae powder at 62 percent protein and 2 percent calcium, approved for human consumption. The resultant components of processing are summarized in Table 3.29.

**Table 3.29: Processing output based on 7 kg of dried larvae input**

| | | Wet larvae input (kg) | |
|---|---|---|---|
| **Results after defatting & grinding** | **Percent of each result (%)** | **10.5** | **7** |
| Powder | 68 | 7.14 | 4.76 |
| Fat/oil | 24 | 2.52 | 1.68 |
| Loss | 8 | 0.84 | 0.56 |
| ***Total*** | 100 | ***10.5*** | ***7*** |

* Resulting powder = 62% protein & 2% calcium

Source: Authors.

**There is a related administrative labor cost in the value chain**. As shown in Figure 3.10, the presence of a manager throughout the process adds cost. EXA management says this is temporary and that the technicians will soon manage the process independently. Eliminating the manager overseeing operations will reduce costs by MGA 2,573 (US$0.58) per kilogram of powder produced.

**Processing results in some losses.** Producing 7 kg of dried larvae requires 24 kg of newly harvested wet larvae. The losses realized during processing are displayed in Table 3.30. The total mass reduction from start to finish is approximately 80 percent – from 24 to 4.8 kilograms.

**Table 3.30: Losses along the processing value chain**

| | **Kg at start** | **Percent loss** | **Kg remaining** |
|---|---|---|---|
| Initial input at larvae harvest | **24** | NA | NA |
| Starvation loss | 24 | 15-18 | 20 |
| Dry (microwave) | 20 | 65 | 7 |
| Defat | 7 | 24 | 5.3 |
| Grind | 5.3 | 10.5 | **4.8** |

Source: Authors.

**Larvae powder does not currently result in revenue.** As reported earlier, EXA did not sell larvae powder in 2025. EXA Food and MBC used the powder for research to develop nutritious, palatable biscuits for schoolchildren, especially those in food-insecure regions (Box 3.2).[72]

[72] The update in Box 3.2 is based on EXA's internal cost analysis covering October 2025 through March 2026, provided by the CEO after July 2025 field research.

**Box 3.2: EXA Feed Production and Cost Update (March 2026)**

Since the July 2025 fieldwork, EXA Feed has made measurable progress on the two principal cost drivers identified in the value chain analysis above: production volume and the per-kilogram burden of fixed costs.

**Production growth**

Daily wet larvae output has more than doubled, from approximately 120 kg per day at the time of fieldwork to approximately 250–280 kg per day by early 2026. The year-end target is 500–600 kg per day with fixed expenditures unchanged. If achieved, that trajectory will bring production within the range of the 500 kg/day scenario modeled in Table 3.26.

**Revised cost accounting methodology**

EXA's internal cost analysis uses a direct-cost methodology that differs from the fully loaded overhead approach used in *EXA Feed value chain* segment of Section 3.2. Rather than allocating all administrative and infrastructure costs to larvae production, overhead is distributed across EXA's expanded portfolio of revenue-generating activities – wet larvae, brewer's spent grain resale, chicken sales, and frass – reflecting the diversification of commercial operations since July 2025. The figures below, therefore, represent only direct production costs: biological inputs and breeding labor.

**Direct cost of wet larvae production**

At a current daily production of approximately 250–280 kg, the direct cost of wet larvae production is 2,401 MGA/kg (approximately US$0.57 at the 4,181 MGA/US$ exchange rate prevailing at the time of this update report), comprising feed inputs (985 MGA/kg; 41 percent) and breeding labor (1,416 MGA/kg; 59 percent). The feed cost is calculated using a chained methodology that allocates the cost of each biological stage to the final harvested larvae: grow-out feed accounts for 500 MGA/kg, reflecting EXA's continued access to low-cost brewer's spent grain from the adjacent brewery. The nursery stage contributes 321 MGA/kg and the full cost of the breeding and reproduction stage – including all inputs required to produce the eggs that seed each nursery batch – is allocated at 164 MGA/kg. Together, these represent the complete biological cost chain from breeding through harvest. The fixed daily breeding payroll of 349,855 MGAis the single largest cost lever: as the analysis in Table 3.26 establishes, its per-kilogram contribution falls proportionally with production volume. At 494 kg/day, the labor cost per kilogram is halved to 708 MGA, reducing total direct cost to 1,693 MGA/kg; at 1,235 kg/day, it falls further to 1,268 MGA/kg.

**Biological performance**

Data from 8,699 grow-out trays over 117 days (November 2025 – March 2026) show an average harvested larval weight of 75 mg, a survival rate of 98 percent, a feed conversion ratio of 7.76 (nursery included), and an average harvest of 2.47 kg per tray over a six-day development cycle. These indicators reflect a production system that has moved beyond the experimental phase described above, with stable biological performance across a large and consistent production dataset.

**Feed formulation development**

EXA is conducting trials on new substrate formulations incorporating locally sourced fruits and vegetables at approximately 125 MGA/kg, a low-cost input whose supply chain is currently being verified. Preliminary projections indicate that adoption of the new formulas across the reproduction and nursery stages could reduce feed costs by 29 to 38 percent relative to current inputs, pending confirmation that the new formulations support equivalent larval growth and survival outcomes. If confirmed, these reductions would lower the feed component of the direct cost from 985 MGA/kg to between 612 and 702 MGA/kg, with corresponding reductions in total direct cost at all production scales.

### EXA's key development impacts

**EXA is pioneering a new phase in Madagascar's nascent BSF production sector.** Its work in developing the standard for insect flour opens great avenues for supporting the food insecure. Several of the development impacts supported by EXA's approach to insect farming are briefly listed below and have been addressed in the text above. Several of these development impacts are common to other BSF farming operations, but EXA's approach is more deliberate and consequential.

- **Import substitution**: Potential to reduce reliance on imported soy and fishmeal.
- **Circular economy**: Integrated operations with fishponds and poultry rearing, feeding livestock with BSF larvae. Cultivating crops onsite using frass to fertilize.
- **Employment generation**: Rural employment; local jobs in farming, processing, logistics.
- **Nutrition and food security**: High-protein animal feed and future human food products.
- **Waste valorization**: Utilize food waste and brewery byproducts; minimal waste.

Box 3.3 highlights an exceptional advancement for the BSF sector globally.

## Cross-case Synthesis

**BSF farming in Madagascar is not a single business model, but a spectrum of production systems at different stages of maturity, integration, and market orientation.** At one end is the low-cost entrepreneurial start-up, represented by Fanantenana, where BSF farming functions as a small-scale income-generating activity built on simple equipment, self-training, and highly localized market linkages. At the other end is EXA Feed, a capital-intensive industrial pilot in which BSF production is being developed as a standards-compliant, vertically integrated platform designed for scale, food safety, and future downstream market development. Between these two poles sit intermediate models that reveal how the sector can evolve: Nutrix as a semi-integrated farm enterprise, the EXA-trained aquaculture farmer as an example of internal feed substitution, and BSF Tamatave as a commercially diversified lead firm combining production, training, and product innovation.

**The cases suggest that BSF farming in Madagascar is already commercially viable in more than one form, but that viability depends on how value is captured.** Fanantenana demonstrates that even a very small operation can generate positive returns when output is diversified across eggs, larvae, frass, training, and sales of basic equipment. Nutrix shows that BSF farming may appear weak when evaluated solely on wet larvae margins yet becomes economically positive when egg sales and frass substitution are included. The integrated aquaculture case shows that BSF need not be sold at all to be economically important: its value can be realized indirectly through lower feed costs and reduced exposure to imported feed markets. BSF Tamatave illustrates the strength of diversification at scale, with high-margin biological products and frass complementing larvae sales, while EXA shows that short-run losses in an industrial start-up phase may reflect deliberate investment in learning, systems, and standards rather than underlying unviability.

**Box 3.3: From Organic Waste to World-Class Caviar – EXA and Acipenser Madagascar**

**Context**

Acipenser Madagascar, located at Lake Mantasoa in the central highlands, is Africa's first and only caviar producer.[73] Founded by Delphyne Dabezies and partners, the company farms six species of sturgeon across land and lake-based ponds situated at approximately 1,400 meters elevation – a temperate microclimate that allows year-round growth and accelerates sturgeon maturation by roughly two years compared to Northern Hemisphere production. The resulting Rova Caviar, introduced to international markets at the Sirha Lyon culinary expo in 2019, now appears on menus at some of Europe's most prestigious establishments, with the premium product selling for approximately €11,670 per kilogram. Acipenser employs around 300 people and produces 8 to 10 tons of caviar annually. The operation is largely self-sufficient in feed, producing approximately 500 tons per year with roughly 75 percent local raw materials.[74] The company holds ISO 14001 environmental management certification and is actively working to increase the share of locally sourced inputs.

**The partnership**

Acipenser's pursuit of traceable, high-quality local inputs drew it to EXA's Diego Suarez facility. In the words of Acipenser's management team, the partnership was a natural fit: EXA's solar-powered production, commitment to quality, and long-term environmental vision aligned with Acipenser's own standards.[75] Following extensive exchanges on quality, traceability, and nutritional specifications, Acipenser was satisfied with EXA's BSF meal on all dimensions – nutritional value, logistics, and communication – and incorporated it into R&D feeding trials.

**Toward full adoption**

The partnership has completed a pilot test on one sturgeon species using a 500-kilogram order of BSF meal. R&D trials across the full operation are expected to conclude in May 2026,[76] at which point Acipenser intends to approve EXA's BSF meal as a confirmed ingredient in the feed formula for its entire sturgeon operation. Upon full adoption, projected annual procurement is approximately 23,000 kilograms of BSF meal.[77]

**Development implications**

This partnership illustrates an exceptional value chain linkage: organic waste processed at an industrial BSF facility in Diego Suarez becomes a feed ingredient for sturgeons maturing in the central highlands, whose roe ultimately sells in five-star restaurants in Paris and the Seychelles. The connection between an insect farming operation serving sustainability objectives at one end and a globally recognized luxury product at the other demonstrates the breadth of markets that high-quality, traceable BSF meal can reach. It also reinforces a supply-side argument for industrial-scale BSF production: the rigorous food safety and traceability standards demanded by a supplier to premium international markets. The standards that EXA meets through its FSSC 22,000 and HACCP certifications could only be achieved by a production operation with the technical capacity and consistency that artisanal or smallholder farms are not positioned to provide. In this respect, EXA's investment in certification is not merely a compliance exercise; it is the credential that opens doors to high-value buyers for whom ingredient traceability and safety documentation are non-negotiable.

73 Korber Hoffman, J. (2025, February 11). At over $10,000 per kilogram, Africa's first caviar is surprising the luxury food industry.

74 Acipenser Madagascar management statement. In EXA Annual Report 2025 (p. 24). EXA.

75 Ibid.

76 Personal communication, EXA CEO, 2026.

77 Acipenser Madagascar management statement in EXA Annual Report 2025.

**A second finding cutting across the cases is that, for operations that have established stable production, substrate logistics are the main operational constraint on scaling.** In the smallholder and semi-commercial models, waste is often available at little or no direct purchase cost, but acquiring it remains expensive because of transport, fuel, time, and the absence of organized aggregation systems. This is evident in Fanantenana's reliance on repeated bus trips to collect market waste and in Nutrix's cost structure, where fuel costs dominate substrate acquisition despite waste itself being free. By contrast, EXA Feed's proximity to the brewery supplying spent grain largely removes this binding constraint, while BSF Tamatave's path to expanded production depends directly on securing a large new waste stream from a nearby factory. The implication is that the sector's immediate bottleneck is less about discovering substrates than about organizing reliable access to them.

**Third, the cases show that technical efficiency remains below potential across much of the sector, even where commercial promise is evident.** Small and emerging producers continue to rely heavily on self-training, informal experimentation, and peer learning. Moisture control, contamination, larval separation, and biological conversion efficiency recur as practical challenges. In the integrated aquaculture case, EXA's technical advice noticeably increased output, yet conversion efficiency remained below expected benchmarks. BSF Tamatave's history of complete production collapses due to fungal contamination and mite infestation underscores that operational maturity does not eliminate biological risk; it changes the scale at which such risk is managed. EXA Feed, in turn, demonstrates that industrialization requires not just equipment, but systematic experimentation, standard operating procedures, and compliance systems. A notable cross-cutting constraint is the lack of systematic production record-keeping among most producers, limiting their ability to monitor performance, optimize production, and demonstrate financial viability to potential investors or lenders.

**Fourth, the cases suggest that the most promising pathway for sector growth lies in integration, diversification, and system-level value capture.** Nutrix and the aquaculture farmer both show that BSF becomes more compelling when embedded in a wider farm system, where frass replaces purchased fertilizer, and larvae substitute for commercial feed. BSF Tamatave demonstrates that additional product streams – eggs, pupae, 5DOL, pop larvae, dried larvae, powder, and multiple frass grades – can significantly improve resilience and margins. EXA Feed extends this logic further by linking BSF production not only to livestock feed and fertilizer, but also to human-grade food products and national standard-setting. In other words, the strongest cases are not those in which BSF is treated as a single output, but those in which it is positioned as a platform technology within a broader circular agricultural economy.

**Finally, the five cases reinforce the broader structural conclusion that the BSF sector in Madagascar is advancing faster at the farm level than at the institutional level.** The profiles reveal entrepreneurial energy, practical innovation, and growing commercial experimentation, but they also show that producers are still operating in a weakly coordinated environment characterized by limited formal extension, minimal access to appropriate finance, immature market structuring, and incomplete support systems for data, standards diffusion, and risk management. This is why the recommendations that follow focus not only on farm-level technical improvements, but also on the enabling environment needed to move BSF farming from promising individual successes to a more organized, scalable, and investable sector.

**Comparisons to other African countries offer perspective on Madagascar's place in the regional BSF sector.** A final cross-cutting observation concerns the regional price context in which Madagascar's BSF sector is developing. Table 3.31 places the product prices documented across the five case studies alongside

prices reported from Kenya and Zimbabwe. Kenya, with a more established BSF sector than Madagascar, is characterized by higher producer density, more organized markets, and substantially lower prices. Zimbabwe, by contrast, is dominated by a small number of producers and significantly shaped by early NGO and donor pricing structures, resulting in prices that substantially exceed competitive market levels across most product categories.

**Table 3.31 BSF products price comparisons in three African countries in 2026, US$**

| Product | Madagascar[1] | Kenya[6] | Zimbabwe[7] |
|---|---|---|---|
| Eggs (per gram) | 0.91 (MGA 4,000)[2] | 0.19–0.46 | 14.00 |
| Wet larvae (per kg) | 0.68–1.82 (MGA 3,000–8,000)[3] | 0.23–0.39 | 5.00 |
| Dried larvae (per kg) | ~2.73 (MGA 12,000)[4] | 1.00–1.39 | 15.00 |
| Pupae (per kg) | ~9.09 (MGA 40,000)[4] | Not commonly sold | 20.00 |
| Frass (per kg) | 0.23–0.76 (MGA 1,000–3,333)[5] | 0.23–0.39 | ~0.30[8] |

1 Madagascar prices converted at approximately MGA 4,400 = US$1, consistent with the exchange rate used throughout this report's value chain tables.
2 MGA 4,000/gram charged by Fanantenana, Nutrix, and BSF Tamatave.
3 Lower end (MGA 3,000/kg) is BSF Tamatave's preferred-customer bulk price; upper end (MGA 8,000/kg) is Fanantenana's micro-enterprise rate. Most established commercial producers sell in the MGA 3,000–5,000 range.
4 BSF Tamatave prices. Dried larvae and pupae are not widely sold by the other producers surveyed.
5 Bulk frass in 50-kg sacks at MGA 1,000/kg to premium pelletized frass in 1.5-kg retail bags at MGA 3,333/kg (both BSF Tamatave). Fanantenana sells unpackaged frass at MGA 2,000/kg ($0.45).
6 Kenya prices are Nairobi/Central and Western Kenya estimates; prices in remote areas may be moderately higher.
7 Zimbabwe prices reflect monopoly market conditions and legacy NGO/donor pricing and are not representative of a competitive market.
8 Zimbabwe price quoted as US$15 per 50-kg bag; converted to per-kilogram equivalent.

*Sources: Madagascar prices from field consultations documented in Section 2; Kenya and Zimbabwe prices from personal communications with sector experts. Compiled by Authors.*

**Regional experience suggests Madagascar's BSF sector is just starting on the path to market maturity.** Madagascar's prices fall closer to Kenya's competitive market rates than to Zimbabwe's monopoly-influenced prices. Several observations are relevant to the sector's development trajectory. First, among the most established Malagasy commercial producers, wet larvae prices are approaching Kenya's range. BSF Tamatave's preferred-customer price of $0.68/kg is nearing the upper end of Kenya's $0.23–$0.39/kg range. Second, the spread within Madagascar's own price range is substantially wider than in either comparator country, reflecting the absence of price-setting mechanisms and the informality of market relationships that currently characterize the sector. Third, Madagascar's prices are broadly two to two-and-a-half times Kenya's across the products where both countries report prices – eggs, wet larvae, and dried larvae – suggesting that as Madagascar's sector matures and competition intensifies, some downward price

pressure is likely, reinforcing the case for producers to diversify into higher-value products and value-added processing rather than relying on wet larvae alone. Frass is the exception: prices across all three countries are broadly comparable, consistent with frass being a lower-differentiation commodity priced close to the cost of competing organic inputs.

**Diverse BSF sector actors in Madagascar require more than a single model or intervention.** Different producer types face distinct constraints, and the sector requires a layered support strategy: one that lowers entry barriers for small entrepreneurs, strengthens integration into existing poultry and aquaculture systems, supports commercially diversified firms, and enables the transition toward industrial-scale, standards-compliant production. The recommendations that follow are therefore designed not around a single "ideal" BSF production model, but around the range of production systems and bottlenecks identified across the five cases.

## 3.3 Recommendations for Improving the Enabling Environment for Madagascar's Insect Sector

**Improvements to the enabling environment will unlock gains in Madagascar's BSF impact and profitability.** The cross-case analysis reveals a sector that is commercially alive but institutionally underdeveloped. Entrepreneurial energy, practical innovation, and diversified business models are already present across a range of producer types and scales. What is missing is the enabling environment – the coordination mechanisms, financial instruments, market linkages, technical infrastructure, and policy engagement – that would allow these individual successes to compound into a more organized, scalable, and investable sector. The recommendations below are therefore directed not at a single intervention or a single type of producer, but at the layered set of constraints that, taken together, explain why Madagascar's BSF sector remains fragmented despite its evident potential. The development priorities identified below do not reflect constraints on an underperforming sector but rather the enabling conditions that would allow Madagascar's already functioning BSF enterprises and prospective entrants to scale, coordinate, and attract the investment their commercial track record warrants. Table 3.32 provides a compact overview of the eight development priority areas addressed in detail in the sections that follow, with specific enabling actions, institutional pathways, and implementation sequencing addressed in the Summary and Sequencing subsection at the close of this section.

### Establish a Structured, Sustainable BSF Sector Association

**The sector lacks a body capable of advocating for BSF farming interests, facilitating knowledge exchange, and structuring market relationships.** The Gasy Insectes Comestibles (GIC) platform exists in name but has only six members and limited operational reach. A functioning sector association – with formal bylaws, a defined governance structure, elected leadership, and a viable revenue model – is a prerequisite for most of the other recommendations in this section. Without it, there is no credible counterpart for government dialogue, no organized presence at agricultural trade fairs, and no institutional mechanism for disseminating standards, training materials, or market intelligence across the producer base. Whether a body is built on GIC's existing registration or established independently is a question best resolved through direct consultation with sector stakeholders. What matters is that the resulting institution has the mandate, structure, and resources to credibly represent the sector over the long term.

| Table 3.32: Development opportunities | |
|---|---|
| **Priority area** | **Growth opportunity** |
| Sector coordination and representation | A formally structured, financially self-sustaining sector association would give Madagascar's BSF producers a collective voice – in government dialogues, at agricultural trade fairs, and in negotiations with poultry and aquaculture buyer communities – transforming a dispersed network of individual producers into a recognized and investable sector. |
| Organic waste supply chain organization | Organized, reliable access to organic waste would remove the substrate logistics constraint that limits scaling across all producer types, converting Madagascar's abundant urban and industrial food waste from an untapped resource into a structured input supply. |
| Access to finance | Financial instruments tailored to BSF farm economics would unlock growth investments that commercially viable producers are ready to deploy but cannot access through any existing lending product. |
| Technical extension and record-keeping | Systematic technical support, combined with practical financial record-keeping, would raise the baseline of production efficiency across the sector while building the creditworthiness and investor-readiness that commercial growth requires. |
| Market awareness among livestock producers | Closing the awareness gap between BSF producers and the poultry and aquaculture sectors would accelerate uptake in markets where the economic case for BSF larvae as a feed input is already compelling and well documented. |
| Aquaculture sector integration | Active alignment of BSF supply development with Madagascar's government-backed aquaculture expansion programs – the National Action Plan for Fisheries and the Blue Economy (2024–2028) and the GIZ-supported PADM successor program – would connect an existing funded public investment with a domestic feed protein solution that the sector urgently needs to reduce its near-total dependence on imported feed. |
| Standards dissemination and expansion | Translating Madagascar's world-first regulatory achievement allowing direct human consumption of BSF products into a practical commercial advantage would enable producers to access high-value markets and attract buyers for whom certification and traceability are non-negotiable requirements. |
| Agricultural finance and climate risk | Index-based agricultural infrastructure insurance calibrated to Madagascar's cyclone, flood, and drought exposure would reduce the climate risk that currently deters investment in farm improvement and expansion, providing producers with the security needed to commit capital to infrastructure that generates long-term productivity gains. |
| *Source: Authors.* | |

**The professional association should be designed from the outset for financial sustainability rather than donor dependence.** Revenue models used by agricultural associations in comparable contexts include membership fees scaled by farm size or revenue, certification and training fees, collective negotiation of input supply agreements, and commissions on brokered market transactions. Early priorities should include formal affiliation with Madagascar's poultry and aquaculture producer associations – both of which represent the sector's most important end markets – and a visible presence at the Foire Internationale de l'Agriculture (FIAR) and related trade events. The association should also maintain a register of active

producers, which would address the data gap identified above and provide a foundation for sector-level monitoring and investor engagement.

## Capitalize on the Government's Aquaculture Expansion Agenda

**The BSF sector should deepen and formalize linkages to aquaculture.** Madagascar's National Action Plan for Fisheries and the Blue Economy (2024–2028) targets a 116 percent increase in total national fish production to 307,000 MT by 2028, placing aquaculture expansion at the center of that ambition. The GIZ-financed Projet d'Aquaculture Durable à Madagascar (PADM) supported 15,815 fish farms across six regions between 2018 and 2024 and has been extended through a successor program to 2028. This GIZ effort represents active public investment in precisely the semi-intensive intensification pathway that creates demand for locally produced feed protein. Each farmer transitioning from extensive rice-fish to semi-intensive pond management represents an additional unit of BSFL demand – demand that currently goes unmet because there is no structured supply chain linking BSF producers to aquaculture farmers.

**The BSF sector should deliberately align with aquaculture programs rather than wait for market relationships to emerge organically.** Concretely, this means engaging PADM and its successor as a channel for introducing BSF larvae as a feed input among supported farmers. It also means embedding BSF awareness in aquaculture extension activities delivered through PADM's network and working with MINAE's fisheries and livestock departments to recognize BSF larvae as a recommended feed input in national aquaculture guidance. The economic case presented in *Integrated Aquaculture-BSF Farm Profile and Value Chain* of Section 3.2 – showing that on-farm BSF-based feed costs 41 percent less than imported commercial feed even before accounting for inland freight, importer margins, and retail markup – provides a compelling, evidence-based argument for this integration. Given Madagascar's near-total dependence on a single foreign supplier for commercial fish feed, the food security and foreign exchange arguments for domestic feed development are equally compelling and should be part of the advocacy message.

## Develop Organized Organic Waste Supply Chains

**BSF operations face structural challenges they can't resolve alone.** Across all cases analyzed, substrate logistics – not biological potential – emerged as the primary operational constraint to scaling BSF production. Waste is frequently available at no direct purchase cost, yet acquiring it consistently remains expensive and unreliable due to transport, fuel, and the absence of organized aggregation systems. This is not a constraint that individual farms can solve at scale; it requires structural interventions in urban waste management and supply chain organization.

**International experience offers instructive models on organic waste disposal linked to BSF**. China's municipally mandated food waste separation system, introduced progressively across major cities from 2019, created organized organic waste streams that BSF producers can access at low or no cost through formal agreements with city governments or waste management contractors.[78] South Korea's volume-based fee system for food waste, in place since 2013, has similarly generated large, sorted organic waste streams

[78] National Development and Reform Commission and Ministry of Housing and Urban-Rural Development, People's Republic of China. (2017). *Implementation Plan for the Classification of Domestic Waste*. Mandatory urban food waste sorting subsequently enacted city by city from 2019, beginning with Shanghai: Shanghai Municipal People's Congress. (2019). *Regulations on the Management of Domestic Waste in Shanghai Municipality*. Effective 1 July 2019.

that are redirected to composting and insect farming operations.[79] In both cases, the enabling factor was policy that treated organic waste as a resource with a managed destination rather than a disposal problem.

**Madagascar should explore a pilot linking institutional and/or public-sector waste disposal policy to BSF production.** Antananarivo alone generates an estimated 500 tons of food waste daily, most of which is neither sorted nor repurposed. A targeted pilot – working with the city government and existing food processors, markets, and hospitality sector operators to establish organized waste-offtake agreements for BSF producers – would directly address the substrate bottleneck while contributing to the city's waste management objectives. Industrial sources, such as the brewery relationship that anchors EXA Feed's cost structure, provide an additional model: facilitating similar arrangements between BSF producers and food and beverage processors nationwide could significantly reduce acquisition costs and improve substrate reliability at scale.

## Develop Specialized Financial Instruments for BSF Farming

**Finance is a major bottleneck for Madagascar's BSF sector.** Access to appropriate finance is effectively absent for BSF farmers in Madagascar. Formal microcredit carries annual interest rates of approximately 20 percent – a rate that is incompatible with the cash flow cycles and margins of early-stage BSF operations. Multiple farmers consulted during fieldwork explicitly declined microcredit as unviable. No agricultural lending window designed for insect farming exists, and BSF operations lack the collateral profiles, financial records, and sector recognition that conventional agricultural lenders require.

**BSF producers need dedicated, tailored financial instruments and the records required to document creditworthiness.** The finance gap for BSF production is not unique to Madagascar, but it is particularly urgent here given the sector's growth trajectory. Addressing it requires action on two fronts. On the supply side, a dedicated credit facility – potentially structured as a blended finance instrument combining concessional development capital with commercial bank participation – could offer working capital and investment loans at terms appropriate to BSF farm economics: multi-year tenors, grace periods aligned with production cycle build-up, and collateral requirements based on farm assets rather than land titles. The DEFIS Program (Développement des Filières Inclusives et Résilientes), identified by MINAE as a potential mobilizing mechanism for sector support, could serve as an implementation vehicle. On the demand side, the lack of systematic production record-keeping identified as a cross-cutting constraint in the synthesis section is itself a barrier to creditworthiness: farmers who cannot demonstrate income history, cost structure, and production consistency cannot qualify for formal lending. Supporting producers in adopting simple financial record-keeping – a component that could be integrated into any association training program – would simultaneously improve farm management and expand the pool of bankable borrowers.

## Extend Agricultural Insurance to BSF Farm Infrastructure

**Madagascar faces climate and weather risks.** Madagascar's exposure to recurrent climate shocks – including violent cyclones such as the Intense Tropical Cyclone Gezani that destroyed BSF Tamatave's operations in February 2026, seasonal flooding, and prolonged droughts in the south and southwest – creates

[79] Ministry of Environment, Republic of Korea. (2013). *Volume-Based Waste Fee System for Food Waste*. Seoul: Ministry of Environment. See also: OECD. (2020). *Extended Producer Responsibility: Updated Guidance for Efficient Waste Management*. OECD Publishing, Paris.

risks that are currently unmitigated for BSF producers. The loss of an established farm to a single weather event eliminates not only physical assets but the accumulated biological capital (established colonies, breeding stock, equipment) that takes months or years to rebuild.

**Madagascar should pilot an insurance scheme targeting BSF infrastructure and equipment.** Insuring live biological production against disease or colony collapse presents significant actuarial challenges. However, insuring physical farm infrastructure – buildings, equipment, processing facilities, cages, and power systems – against storm, flood, and fire damage is more tractable and follows established models in other agricultural sectors. A pilot agricultural infrastructure insurance product for BSF farms, potentially developed in partnership with an existing agricultural insurer or microinsurance provider operating in Madagascar, would reduce the deterrent effect of climate risk on investment in farm improvement and expansion. For industrial-scale operations such as EXA Feed, which has made substantial infrastructure investments and operates in a cyclone-exposed region, such coverage is particularly material. Index-based insurance products – triggered by verified climatological events rather than individual farm assessments – offer a lower-cost delivery mechanism that may be appropriate for smallholder producers.[80] This is an area warranting a feasibility assessment as part of a broader sector finance agenda.

## Strengthen Technical Extension and Address the Record-keeping Gap

**Madagascar lacks a formal, structured extension system for knowledge dissemination and sharing.** The vast majority of BSF farmers in Madagascar are self-taught, relying on YouTube, Facebook groups, peer learning, and occasional paid training from lead farmers such as Lamiah of BSF Tamatave. While this informal knowledge network has been remarkably effective in spreading BSF practice across the country, it has clear limits: contamination events, suboptimal conversion rates, moisture management failures, and biological collapses remain widespread across the producer base. MBC's technical training of 30 rural farmers – which demonstrably doubled output at one of those farms within months – illustrates what structured technical assistance can achieve even in a short intervention. Scaling this model requires more than individual firm generosity; it requires a structured extension mechanism.

**The country's BSF sector should build on established technical education models and institutions.** The Don Bosco vocational training network, which already integrates BSF farming into its agricultural curriculum at Ivato and has demonstrably produced technically competent farm workers, represents an institutional foundation that could be built upon: expanding BSF content across more centers, developing a nationally recognized BSF technician certification, and linking graduates to the sector through a placement mechanism aligned with the proposed sector association. MINAE's proposal for a model demonstration unit and its suggestion that the existing network of sanitary veterinarians could serve as relay agents for BSF extension – even without entomological specialization – are worth pursuing as complementary channels. Any extension program should include a practical record-keeping component, as the absence of systematic production and financial data was identified across multiple cases as a constraint on both operational improvement and access to finance.

[80] World Bank. (2011).

## Accelerate Standards Dissemination and Build on Standards Allowing Human Consumption

**The trailblazing standard that allows for direct human consumption is not widely known or understood.** Madagascar's establishment of NMG 132-13 – the national standard for dried BSF larvae and larval powder for direct human consumption – is the first of its kind in the world. This is a landmark achievement that positions the country as a regulatory pioneer in the global insect sector. The risk is that this milestone remains largely unknown to the producer base and fails to catalyze the commercial and institutional developments it was designed to enable. Standards only create value when they are widely understood, practically implementable, and actively enforced.

**Madagascar should take actions to increase awareness and utilization of the standard.** Priority actions include: translating the standard into accessible guidance for producers at different scales; developing a straightforward compliance pathway and certification process so that commercial operations can formally demonstrate conformity; using Madagascar's standard as a platform for engagement with regional bodies and international buyers; and advancing the regulatory framework beyond human food to include livestock feed standards, where the commercial volumes are substantially larger. GIC's proposed move into insect protein powder for commercial animal feed makes this expansion particularly timely.

## Promote Sector Visibility and Market Development

**Demand for BSF products in Madagascar's livestock sector remains well below its potential.** This is, not because buyers are resistant, but because awareness is limited and supply chains are not organized to serve them reliably. AGRIVET's reported need for 700 tons of protein per month – a figure that dwarfs current BSF sector output – illustrates the gap between latent demand and actual market penetration. Closing it requires deliberate marketing and market development efforts that no individual producer is positioned to undertake alone.

**Sector-level market development activities – coordinated through the proposed association – would promote visibility and sales.** Activities should include a structured outreach program to poultry and aquaculture producers, participation in agricultural trade fairs with demonstration materials and economic case studies, engagement with feed compounders and agricultural input distributors as potential aggregators and distribution partners, and development of simple, evidence-based marketing materials quantifying the feed cost savings and productivity benefits of BSF larvae inclusion. The economic analyses presented in this report provide ready-made content for such materials. Longer term, as EXA Feed scales toward its production targets and standards-compliant processed products become available, export market development – particularly for dried larvae and defatted flour into regional markets – represents an additional demand channel worth exploring. Acipenser's international market relationships in the caviar market offer one illustration of what traceable, certified Malagasy insect products can achieve.

### Summary and Sequencing

**The recommended actions should occur in deliberate sequence, and several depend on one another.** Establishing the sector association is foundational: it creates the institutional counterpart through which market development, standards dissemination, and policy engagement can be organized at the sector level, and its absence limits the effectiveness of most other interventions. Technical extension and standards

dissemination can be initiated in the near term at relatively low cost and will generate early returns in producer performance and market confidence. Organic waste supply chain development and aquaculture market integration require engagement with ongoing government programs and should be pursued concurrently as medium-term priorities. The financial instruments – credit facility design and insurance product development – are the most complex to structure and will require the longest lead times. Still, the groundwork can begin immediately through feasibility assessments and stakeholder consultations.

**These recommendations constitute a coordinated agenda rather than a single program.** They have the potential to move Madagascar's BSF sector from a collection of promising individual enterprises to a recognized, structured, and investable value chain. A summary of the above recommendations is displayed in tabular form in Table 3.33. The table includes the expected implementation complexity and the expected direct impact of the recommendations.

**Table 3.33: Summary of recommendations: BSF sector development, Madagascar**

| Period | Seq. | Recommendation | Implementation Complexity | Expected Direct Impact |
|---|---|---|---|---|
| Short Term | 1 | **Establish a structured, sustainable BSF sector association** | Medium | **Foundational for all other interventions.** Creates the institutional counterpart for government dialogue, market advocacy, and standards dissemination. Enables organized representation at agricultural trade fairs and formal affiliation with poultry and aquaculture producer associations - the sector's two most important end markets. Provides the governance vehicle for coordinating collective actions in recommendations 4, 5, and 7. A financially self-sustaining association - designed from the outset with dues, training fees, and service revenues - avoids the collapse that accompanies the end of donor funding cycles. |
| Short Term | 2 | **Strengthen technical extension and address the record-keeping gap** | Low | **Immediate production gains at low cost.** EXA's structured training of rural farmers demonstrably doubled output within months. Scaling this model through the Don Bosco vocational network, which already integrates BSF content at its Ivato center, and through MINAE's proposed sanitary veterinarian relay agents would rapidly raise the baseline of technical competence across the producer base. Embedding financial record-keeping within extension programs addresses a cross-cutting constraint that currently |

| Table 3.33: Summary of recommendations: BSF sector development, Madagascar | | | | |
|---|---|---|---|---|
| **Period** | **Seq.** | **Recommendation** | **Implementation Complexity** | **Expected Direct Impact** |
| | | | | limits creditworthiness, investor readiness, and producers' ability to monitor and improve their operations. |
| **Short Term** | **3** | **Accelerate dissemination of NMG 132-13 and build out the regulatory framework** | **Low** | **Leverages an existing regulatory milestone.** Madagascar is the world's first country to establish a national standard for BSF larvae and larvae powder for direct human consumption. This is a landmark achievement that risks going unrealized if producers cannot access, understand, and comply with it. Near-term dissemination – through accessible guidance materials, a compliance pathway, and a certification process – transforms NMG 132-13 from a policy document into a market enabler. Expanding the regulatory framework to livestock feed standards, where commercial volumes are substantially larger, is the logical next step. |
| **Short Term** | **4** | **Launch sector visibility and market development campaign** | **Medium** | **Closes the gap between latent demand and actual market penetration.** AGRIVET, Madagascar's leading agricultural input supplier, has indicated a need for 700 tons of protein per month – a figure that vastly exceeds current BSF sector output. Demand is not the constraint; awareness and supply reliability are. A sector-level campaign – coordinated through the proposed association – targeting poultry and aquaculture producers with evidence-based cost comparison materials, trade fair participation, and engagement with feed compounders and distributors would accelerate uptake. The economic analyses in this report provide ready-made content for such outreach. |
| **Medium Term** | **5** | **Capitalize on the government's aquaculture expansion agenda** | **Medium** | **Aligns BSF sector growth with a government priority already funded.** The National Action Plan for Fisheries and the Blue Economy (2024–2028) targets a 116 percent increase in national fish production, and the GIZ- |

| Table 3.33: Summary of recommendations: BSF sector development, Madagascar | | | | |
|---|---|---|---|---|
| **Period** | **Seq.** | **Recommendation** | **Implementation Complexity** | **Expected Direct Impact** |
| | | | | financed PADM program actively supports smallholder semi-intensive pond farmers across six regions through a successor program extending to 2028. Each farmer transitioning from extensive rice-fish to semi-intensive production is an additional unit of BSFL feed demand. On-farm BSF feed has been shown to cost 41 percent less than imported commercial feed – before inland freight, importer margins, and retail markup. Embedding BSF larvae as a recognized feed input in PADM extension activities requires coordination rather than new funding. |
| **Medium Term** | **6** | **Develop organized organic waste supply chains** | **Medium** | **Removes the primary operational constraint to scaling BSF production.** Substrate logistics emerged as the dominant scaling bottleneck across all five cases. Waste is often free, but acquisition is costly through transport, fuel, and informal arrangements. Antananarivo generates an estimated 500 tons of food waste daily, most of which is neither sorted nor repurposed. Municipal waste offtake pilots, modeled on city-mandated organic waste separation programs successfully implemented in China (from 2019) and South Korea (from 2013), would create organized, reliable waste streams for BSF producers at low or no input cost. Industrial source agreements, such as EXA's brewery partnership, offer a complementary model replicable elsewhere. |
| **Medium Term** | **7** | **Develop specialized financial instruments for BSF farming** | **High** | **Unlocks growth capital that producers currently cannot access.** No viable institutional lending exists for BSF farms. Microcredit rates of approximately 20 percent per year are incompatible with BSF farm cash flows; multiple producers explicitly declined microcredit as unworkable. A dedicated blended finance credit facility – combining concessional development capital with commercial bank |

| Table 3.33: Summary of recommendations: BSF sector development, Madagascar | | | | |
|---|---|---|---|---|
| **Period** | **Seq.** | **Recommendation** | **Implementation Complexity** | **Expected Direct Impact** |
| | | | | participation, with tenors and grace periods aligned to production build-up – would address the investment gap that prevents commercially viable producers from scaling. The DEFIS program, identified by MINAE as a potential vehicle, offers a ready implementation pathway. Complementary support for producer record-keeping expands the pool of bankable borrowers over time. |
| **Long Term** | **8** | **Extend agricultural insurance to BSF farm infrastructure** | **High** | **Reduces the climate risk that deters investment in farm improvement.** Madagascar's exposure to cyclones, flooding, and prolonged drought creates unmitigated infrastructure risk for BSF producers. Intense Tropical Cyclone Gezani destroyed BSF Tamatave's operations in February 2026, eliminating not only physical assets but years of accumulated biological capital. While insuring live colony production presents actuarial challenges, insuring physical farm infrastructure – buildings, cages, processing equipment, and power systems – against storm and flood damage follows established agricultural insurance models. Index-based products triggered by verified climatological events offer a low-cost delivery mechanism suited to smallholder scale. A feasibility assessment that engages existing agricultural insurers and microinsurance providers operating in Madagascar is the appropriate first step. |

## Works Cited

Swedish International Agricultural Network Initiative. 2026. "Farmer-Led Black Soldier Fly Farming Innovations in Madagascar." January 15, 2026. https://www.siani.se/blog/black-soldier-fly-farming-innovations/. Madagascar Biodiversity Center program documentation (various years).

Hong, J., and Y.Y. Kim. 2022. "Insect as Feed Ingredients for Pigs." Animal Bioscience 35 (2): 347. https://doi.org/10.5713/ab.21.0475.

Macrotrends. N.d. "Madagascar Population Growth Rate." Accessed 2025. https://www.macrotrends.net/global-metrics/countries/mdg/madagascar/population-growth-rate.

Thayer, R.H., G. Hubbell, J. Kasbohm, R. Morrison, and E. Nelson. 1974. "Daily Protein Intake Requirement of Laying Hens." Poultry Science 53 (1): 354–364. https://doi.org/10.3382/ps.0530354.

Koko, M., O.F. Maminiaina, J. Ravaomanana, and S.J. Rakotonindrina. 2002. Village Poultry Production in Madagascar: Production Characteristics and Epidemiology. Vienna: IAEA.

FAO. 2023. Aquaculture Growth Potential in Madagascar – WAPI Factsheet. FAO Fisheries and Aquaculture Division. Rome: FAO.

FAO. N.d. Fishery Country Profile: Madagascar. FAO Fisheries and Aquaculture Division. Rome. www.fao.org/fishery/docs/DOCUMENT/fcp/en/FI_CP_MG.pdf.

NBI Global Resource Centre / GIZ. 2024. Aquaculture in Madagascar. nbi.iisd.org/report/aquaculture-in-madagascar.

UN Comtrade. N.d. International Trade Statistics Database. https://comtrade.un.org/.

Oirere, S. 2024. "Madagascar Unveils Five-Year Plan to Double Seafood Output, Create Marine Protected Areas." SeafoodSource, 2024.

FAO. N.d. Fishery Country Profile: Madagascar. FAO Fisheries and Aquaculture Division. Rome. www.fao.org/fishery/docs/DOCUMENT/fcp/en/FI_CP_MG.pdf.

Kubitza, F. 2024. "Green or Muddy Water in High-Density Tilapia Ponds: Comparing Performance, Water Quality and Off-Flavor Intensity." Global Seafood Alliance. https://www.globalseafood.org/advocate/auto-draftgreen-or-muddy-water-in-high-density-tilapia-ponds-comparing-performance-water-quality-and-off-flavor-intensity/.

NBI Global Resource Centre / GIZ. 2024. Aquaculture in Madagascar. nbi.iisd.org/report/aquaculture-in-madagascar.

Hong, J., and Y.Y. Kim. 2022. "Insect as Feed Ingredients for Pigs." Animal Bioscience 35 (2): 347. https://doi.org/10.5713/ab.21.0475.

Ravaomanana, J., V. Michaud, F. Jori, A. Andriatsimahavandy, F. Roger, E. Albina, and L. Vial. 2010. "First Detection of African Swine Fever Virus in Ornithodoros porcinus in Madagascar and New Insights into Tick Distribution and Taxonomy." Parasites & Vectors 3: 115. https://doi.org/10.1186/1756-3305-3-115.

Ministère de l'Agriculture et de l'Elevage (MINAE). N.d. Site officiel. https://www.minae.gov.mg/.

L'Express de Madagascar. 2023. "Elevage – Mouche soldat noire (BSF): une alternative économique à l'alimentation animale." April 6, 2023. https://lexpress.mg/06/04/2023/elevage-mouche-soldat-noire-bsf-une-alternative-economique-a-lalimentation-animale/.

ZEF / Bonn Sustainability Portal. 2019. "Eat It or Feed It: Promoting Insect-Rearing in Madagascar." November 18, 2019. https://bonnsustainabilityportal.de/de/2019/11/zef-eat-it-or-feed-it-promoting-insect-rearing-in-madagascar/.

Zero Hunger Coalition. N.d. "Interview with the Minister of Agriculture and Livestock in Madagascar." https://www.zerohungercoalition.org/en/interview-minister-agriculture-livestock-madagascar/.

Bureau des Normes de Madagascar (BNM). 2025a. "Processus d'élaboration de la norme malagasy pour la farine de larves de BSF, en collaboration avec le Groupe EXA à Antsiranana, mars 2025." April 1, 2025. https://www.bnm.mg/processus-delaboration-de-la-norme-malagasy-pour-la-farine-de-larves-de-bsf-en-collaboration-avec-le-groupe-exa-a-antsiranana-mars-2025/.

Bureau des Normes de Madagascar (BNM). 2025b. Larves séchées de Black Soldier Fly (Hermetia illucens) et leur poudre, Spécifications. Norme Nationale Malagasy NMG 132-13. Antananarivo: BNM.

Ramaroson, V., S. Simon, B.L. Fisher, and S. Burza. 2026. "Consumer Acceptance of Black Soldier Fly (BSF) Larvae-Based Products in Rural South-East Madagascar." Journal of Insects as Food and Feed. https://doi.org/10.1163/23524588-bja10391.

Madagascar Biodiversity Center (MBC). N.d. BSF Farms. https://www.madagascarbio.org/bsf-farms.html.

Health in Harmony. 2026. "How Black Soldier Fly Frass Is Revolutionizing Farming in Madagascar." January 29, 2026. https://www.healthinharmony.org/news/watch-how-black-soldier-fly-bsf-frass-is-revolutionizing-farming-in-madagascar.

Mongabay. 2025. "Les mouches soldats noirs pour renforcer la résilience des communautés et des écosystèmes à Madagascar." November 28, 2025. https://fr.mongabay.com/2025/11/les-mouches-soldats-noirs-pour-renforcer-la-resilience-des-communautes-et-des-ecosystemes-a-madagascar/.

Madagascar Biodiversity Center (MBC). 2025. BSF Farming: A Practical Guide. Version 2.0. MBC Solutions Program, September 18, 2025. https://www.madagascarbio.org/uploads/3/9/4/4/39442661/bsf_farming_eng_final1.pdf.

Swedish International Agricultural Network Initiative (SIANI). 2026. "Farmer-Led Black Soldier Fly Farming Innovations in Madagascar." January 15, 2026. https://www.siani.se/blog/black-soldier-fly-farming-innovations/.

Solofondranohatra, C.L., C. Andrianorosoa Ony, S. Burza, and B.L. Fisher. 2025. "Preliminary Field Evaluation of Black Soldier Fly Frass as an Organic Fertilizer on Maize (Zea mays L.) Growth and Yield in Southeastern Madagascar." Frontiers in Sustainable Food Systems 9: 1673188. https://doi.org/10.3389/fsufs.2025.1673188.

Andrianorosoa Ony, C., C.L. Solofondranohatra, et al. 2025. "Black Soldier Fly Frass Fertilizer Outperforms Traditional Fertilizers in Plant Growth in Restoration in Madagascar." Sustainability 17 (15): 7152. https://www.mdpi.com/2071-1050/17/15/7152.

Ramaroson, V., S. Simon, B.L. Fisher, and S. Burza. 2026. "Consumer Acceptance of Black Soldier Fly (BSF) Larvae-Based Products in Rural South-East Madagascar." Journal of Insects as Food and Feed. https://doi.org/10.1163/23524588-bja10391.

PortalJob Madagascar. 2024. "Recrutement Technicien d'Elevage BSF Junior, Exafood SA, Antananarivo." October 1, 2024. https://www.portaljob-madagascar.com/emploi/view/exafood-sa-technicien-d-elevage-de-black-soldier-fly-bsf-junior150034.

2424.mg. 2023a. "La filière insecte comestible cherche à se promouvoir à Madagascar." May 14, 2023. https://2424.mg/elevage-la-filiere-insecte-comestible-cherche-a-se-promouvoir-a-madagascar/.

2424.mg. 2023b. "La filière insectes à Madagascar se structure et organise son premier Forum des insectes pour l'alimentation humaine et animale." September 20, 2023. https://2424.mg/news/elevage-la-filiere-insectes-a-madagascar-se-structure-et-organise-son-premier-forum-des-insectes-pour-lalimentation-humaine-et-animale/.

Newsmada. 2024. "Ny Aro Andriamiarosoa: La filière insectes, une opportunité cachée." September 27, 2024. https://newsmada.com/2024/09/27/ny-aro-andriamiarosoa-la-filiere-insectes-une-opportunite-cachee/.

Health in Harmony. 2026. "How Black Soldier Fly Frass Is Revolutionizing Farming in Madagascar." January 29, 2026. https://www.healthinharmony.org/news/watch-how-black-soldier-fly-bsf-frass-is-revolutionizing-farming-in-madagascar.

Médecins Sans Frontières. N.d. "Madagascar." https://www.msf.org/madagascar.

Health in Harmony. N.d. Madagascar Programme Overview. https://www.healthinharmony.org/madagascar.

ReliefWeb / Health in Harmony. N.d. "Adapting to Food Insecurity in Madagascar with Climate-Adaptive Farming." https://reliefweb.int/report/madagascar/adapting-food-insecurity-madagascar-climate-adaptive-farming.

Health in Harmony. 2026. "How Black Soldier Fly Frass Is Revolutionizing Farming in Madagascar." January 29, 2026. https://www.healthinharmony.org/news/watch-how-black-soldier-fly-bsf-frass-is-revolutionizing-farming-in-madagascar.

Solofondranohatra, C.L., C. Andrianorosoa Ony, S. Burza, and B.L. Fisher. 2025. "Preliminary Field Evaluation of Black Soldier Fly Frass as an Organic Fertilizer on Maize (Zea mays L.) Growth and Yield in Southeastern Madagascar." Frontiers in Sustainable Food Systems 9: 1673188. https://doi.org/10.3389/fsufs.2025.1673188.

Ramaroson, V., S. Simon, B.L. Fisher, and S. Burza. 2026. "Consumer Acceptance of Black Soldier Fly (BSF) Larvae-Based Products in Rural South-East Madagascar." Journal of Insects as Food and Feed. https://doi.org/10.1163/23524588-bja10391.

SIANI (Swedish International Agricultural Network Initiative). 2026. "Farmer-Led Black Soldier Fly Farming Innovations in Madagascar." January 15, 2026. https://www.siani.se/blog/black-soldier-fly-farming-innovations/.

Bureau des Normes de Madagascar (BNM). 2025a. "Processus d'élaboration de la norme malagasy pour la farine de larves de BSF, en collaboration avec le Groupe EXA à Antsiranana, mars 2025." April 1, 2025. https://www.bnm.mg/processus-delaboration-de-la-norme-malagasy-pour-la-farine-de-larves-de-bsf-en-collaboration-avec-le-groupe-exa-a-antsiranana-mars-2025/.

Don Bosco Tech Africa. N.d. Homepage. https://dbtechafrica.org/.

L'Express de Madagascar. 2023. "Elevage – Mouche soldat noire (BSF): une alternative économique à l'alimentation animale." April 6, 2023. https://lexpress.mg/06/04/2023/elevage-mouche-soldat-noire-bsf-une-alternative-economique-a-lalimentation-animale/. Studio Sifaka. 2022. "Quand la mouche n'est pas nuisible." January 21, 2022. https://www.studiosifaka.org/magazines/environnement-hiakan-ny-tontolo/item/5115-quand-la-mouche-n-est-pas-nuisible.html.

No Comment Magazine. 2024. "Faniry Rasoanaivo: Une solution face au gaspillage alimentaire." May 10, 2024. https://www.nocomment.mg/faniry-rasoanaivo-une-solution-face-au-gaspillage-alimentaire.

L'Express de Madagascar. 2023. "Elevage – Mouche soldat noire (BSF): une alternative économique à l'alimentation animale." April 6, 2023. https://lexpress.mg/06/04/2023/elevage-mouche-soldat-noire-bsf-une-alternative-economique-a-lalimentation-animale/.

Kubitza, F. 2024. "Green or Muddy Water in High-Density Tilapia Ponds: Comparing Performance, Water Quality and Off-Flavor Intensity." Global Seafood Alliance. https://www.globalseafood.org/advocate/auto-draftgreen-or-muddy-water-in-high-density-tilapia-ponds-comparing-performance-water-quality-and-off-flavor-intensity/.

Climates to Travel. N.d. "Climate of Antsiranana, Madagascar." Accessed 2025. https://www.climatestotravel.com/climate/madagascar/antsiranana.

Korber Hoffman, J. 2025. "At over $10,000 per Kilogram, Africa's First Caviar Is Surprising the Luxury Food Industry." CNN Travel, February 11, 2025. https://www.cnn.com/travel/caviar-madagascar-luxury-spc [URL may be incomplete; verify].

Acipenser Madagascar. 2025. Management Statement. In EXA Annual Report 2025, p. 24. EXA.

National Development and Reform Commission and Ministry of Housing and Urban-Rural Development, People's Republic of China. 2017. Implementation Plan for the Classification of Domestic Waste. Beijing. Shanghai Municipal People's Congress. 2019. Regulations on the Management of Domestic Waste in Shanghai Municipality. Effective July 1, 2019.

Ministry of Environment, Republic of Korea. 2013. Volume-Based Waste Fee System for Food Waste. Seoul: Ministry of Environment. OECD. 2020. Extended Producer Responsibility: Updated Guidance for Efficient Waste Management. Paris: OECD Publishing.

World Bank. 2011. Weather Index Insurance for Agriculture: Guidance for Development Practitioners. Agriculture and Rural Development Discussion Paper 50. Washington, DC: World Bank. Barnett, B.J., and O. Mahul, eds. 2007. Agriculture Insurance in Latin America: Developing the Market. World Bank Working Paper No. 8. Washington, DC: World Bank.

# Chapter 4. Lessons from the BSF Pilot Program in Kenya, Malawi, and Zimbabwe

**This chapter presents lessons from the Insect for Food, Feed and Fertilizer program, referred to here as the black soldier fly, or BSF, pilot program.** The World Bank, UNHCR, and partners developed and implemented the program in refugee settlements and host communities in Kenya, Malawi, and Zimbabwe.

The assessment draws on field missions, structured interviews, quantitative surveys, observation guides, and a workshop with implementing partners and beneficiaries. It examines what BSF farming can deliver in displacement-affected and host-community settings, what enables pilots to succeed or stall, and what is needed to turn a technical pilot into a sustainable livelihood enterprise. Box 4.1 outlines the assessment components and methodology.

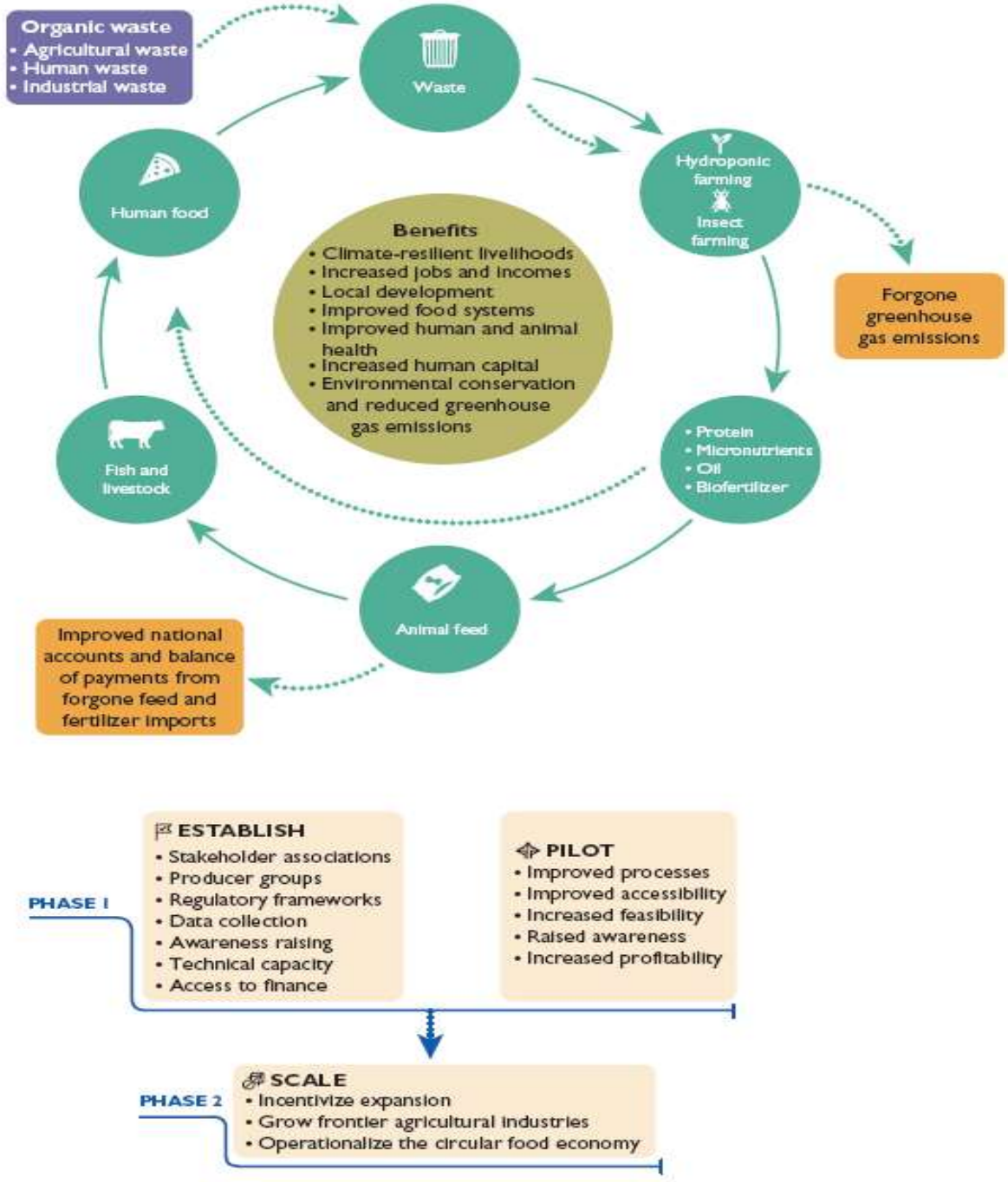
**The four pilot sites provide the empirical base for the chapter.** The program operated at Dadaab Refugee Complex in Kenya, Dzaleka Refugee Camp in Malawi, Tongogara Refugee Settlement in Zimbabwe, and the adjacent Chibuwe host community. These sites ground the assessment of the challenges and enabling factors for insect-based models in refugee and host-community settings, and they inform the recommendations for rollout, adaptation, and scaling.

**The pilots tested whether circular BSF systems can support livelihoods in displacement-affected settings.** The program examined whether BSF farming can generate income, improve food security, and strengthen agricultural systems in fragile contexts. These questions have become more urgent as humanitarian funding declines, displacement in Africa rises, and refugees face food insecurity, limited access to land and livelihoods, high agricultural input costs, and climate pressures. BSF farming applies a circular-economy logic by using certain organic waste streams to feed farmed insects, turning waste from a liability in the linear food economy into an input for the circular food economy. Figure 4.1 explains this logic.

**Overall, this chapter finds that BSF farming offers a promising circular-economy model for refugee and host-community settings.** Across the four pilots in Kenya, Malawi, and Zimbabwe, BSF production generated income, strengthened technical and business skills, improved crop production through frass, reduced poultry feed costs through larvae, and contributed to food-security gains. The pilots also produced social benefits, especially for women and refugee youth, including stronger teamwork, a sense of purpose, access to savings groups, and safer spaces for participation. The evidence shows that BSF farming is technically feasible and commercially promising, but the pilots also exposed clear conditions for success: reliable organic-waste supply, climate-appropriate production systems, motivated beneficiary selection, structured training, peer learning, and explicit business-model development. The path from technical pilot to sustainable enterprise is visible, but it depends on stronger production systems, cost and pricing data, multiyear financing, and market development.

**The chapter is organized in four sections.** Section 4.1 presents findings from Malawi, Zimbabwe, and Kenya, followed by a cross-pilot comparison and discussion of coordination, knowledge sharing, and financing. Section 4.2 quantifies impacts across the four pilot sites using baseline-to-endline survey results. Section 4.3 presents beneficiary testimonies. Section 4.4 presents conclusions and recommendations and closes with a 10-point implementation checklist for new BSF projects in refugee and host-community settings.

**Figure 4.1: BSF in a Circular Food Economy Model**




Source: Verner et al 2021.

**Box 4.1: BSF pilot program assessment methodology**

The assessment triangulated evidence from production data, beneficiary surveys, interviews, field observation, missions, workshops, and joint country team meetings. Production metrics were captured in a daily production log designed jointly by the World Bank and UNHCR and standardized across pilot sites. Key indicators included egg production, larval growth, feed-conversion ratio, frass yield, and mortality. Data were aggregated monthly and reviewed for trends.

Beneficiary surveys were administered at baseline, alongside initial training, and at endline to measure changes in outcomes. Baseline questions were piloted in Zimbabwe in June 2022. Enumerators were trained, and the instrument was programmed in Kobo. The survey covered identification and demographics, household composition, insect consumption, farming background, insect experience and perceptions, prior insect-farming practices, food-security consumption categories, and coping strategies.

The assessment also used semi-structured interviews, focus group discussions, and direct field observations. Interviews covered participant motivations, technical challenges, household effects, and scaling needs. Field observations followed a structured observation guide. The team also reviewed technical processes, including breeding management, larval rearing, and harvesting standards, to assess how sites adapted the model to local conditions. Interviewees included refugee and host-community BSF beneficiaries, local UNHCR staff, and implementation partners.

Joint UNHCR-World Bank missions and biweekly meetings with country teams took place from November 2022 to May 2026 to support learning and troubleshooting across pilot sites. A Nairobi workshop convened by the World Bank in February 2026 brought together UNHCR headquarters and country staff, implementing partners, World Bank staff, and consultants to discuss pilot experience, scaling, waste access, beneficiary selection, and market linkages.

## 4.1 Insect Farming Pilots

The BSF pilot program grew out of a 2021 World Bank and UNHCR effort to test insect farming in fragile settings. In mid-2021, the World Bank approached UNHCR to explore whether circular-economy approaches to BSF farming could work in refugee and host-community contexts. UNHCR consulted management and field operations, and 11 countries expressed interest. Sites were prioritized based on local partner capacity, government interest, and the presence of both institutions. The process first supported a five-month proof of concept in South Sudan, where BSF farming was tested at Jamjang and Yei in refugee settings (Verner et al. 2022). That proof of concept was followed by pilots at Dadaab in Kenya, Dzaleka in Malawi, Tongogara Refugee Settlement in Zimbabwe, and Chibuwe host community in Zimbabwe. In mid-2022, a launch workshop in Zimbabwe brought together participants from all three pilot countries, including UNHCR Geneva and country staff, government representatives, and implementing partners.

### Malawi: Dzaleka Refugee Camp

Dzaleka's overcrowding, food insecurity, and livelihood restrictions shaped the need for the BSF pilot. Malawi hosts about 57,000 forcibly displaced people from the Democratic Republic of Congo, Burundi, Rwanda, Somalia, Ethiopia, and 76 other countries. Most live in Dzaleka Refugee Camp in Dowa District, about 41 kilometers from Lilongwe. The camp was established in 1994 for a maximum of 12,000 refugees, but now hosts more than 52,000 people and is projected to reach 60,400 by the end of 2026. UNHCR data indicate that women and children account for 93 percent of the camp population. A 2023 government "Back

to Camp" policy returned refugees living in rural and urban areas to an already overcrowded camp, worsening conditions. Strict encampment policies limit refugees' ability to do business, work, or earn income outside the camp. UNHCR Malawi covered only 22 percent of its US$26.3 million funding needs in 2025, and food assistance in Dzaleka was cut by about 50 percent that year. A 2025 study found that 91 percent of women in Dzaleka experienced extreme food insecurity.[81]

Overall, the Dzaleka case shows that BSF scaling potential depends as much on participant selection and ownership as on infrastructure. The case details that follow show how this lesson emerged through facility development, cohort replacement, technical support, waste sourcing, product pricing, and business support. The pilot's shift from using a vulnerable first cohort to a motivated youth second cohort produced a team with stronger ownership, leadership, and capacity to operate independently. The team now trains other farmers and contributes to Malawi's emerging BSF knowledge base. Existing infrastructure, growing demand for BSF products, and early income from BSF sales give the pilot a clearer path toward enterprise development. The pilot has also produced positive outcomes for beneficiaries, including BSF-related skills, a stronger sense of purpose and agency, and a shift from aid dependency toward enterprise.

### Facility

Dzaleka has infrastructure that can support scaling with targeted facility and power upgrades. The site has two greenhouses housing ten large love cages with air-conditioning units, a shed for the larvarium and hatchery with crate racks, a storage shed, and an outdoor concrete waste basin. The larvarium has about 240 crates, with 260 additional crates in storage to support growth. Three sieving tables of about 1 by 2.5 meters are used for self-harvesting. The site also has 12 small wooden solar dryers, each about 50 by 100 centimeters and covered with greenhouse paper. Larvae are currently dried in the greenhouse over six days while the solar dryers are being re-covered, but solar drying reduces drying time to two to three days. Adjacent space holds about 600 broiler chickens, which are fed about 2.5 kg of live larvae per day as a supplement to commercial broiler feed. The infrastructure can support scaling with minor restructuring of the hatchery and harvesting areas and re-covering of the solar dryers. Equipment comprises a shredder, 6 solar dryers, 4 to 5 sieves, tray racks, heaters, fans, 3 weighing scales, lighting boards, solar panels with inverters, 10 love cages, a freezer, wooden pupation boxes, two air-conditioning units in each greenhouse, 125-liter waste bins, and personal protective equipment. All electrical equipment runs on the grid, but three-phase power for larger machines is not yet available.

### Beneficiary selection

Dzaleka shifted from vulnerability-based selection to a youth cohort selected for motivation and interest. The first cohort, recruited in 2023, consisted of 30 participants. Selection prioritized vulnerability, including elderly people and women engaged in survival sex. Training lasted one week, with a separate week-long course for 16 implementing partners and government staff. Many participants had experience with incentive-paying programs and expected short-term returns. The original group was dismantled after about 18 months because of limited interest, weak ownership, collaboration challenges, and management challenges. The second cohort was selected based on expressed interest and personal motivation. A new strategy launched in August 2024 focused on youth, group dynamics, and expressed interest. The youth were trained for three days, and a learning-exchange visit was conducted to a local insect farm. The current

[81] https://reliefweb.int/report/malawi/wfp-malawi-country-brief-november-2025

team members are all refugees under the age of 25. The team displays strong technical knowledge, ownership, innovation, and perseverance. It develops its own learning materials and social media content and trains other farmers.

### Implementation and technical capacity

**Dzaleka pairs specialist management with a pilot team that now operates Malawi's largest BSF facility.** BSF activities were managed directly by a BSF specialist hired by UNHCR and the World Bank. The implementing partner was initially CARD, but responsibility shifted from CARD to Plan International in 2024. The pilot team operates the facility and maintains a healthy BSF colony. Average production is 200 kg of frass per month and 200 kg of live larvae. BSF production is tracked daily on a production log sheet and discussed in global insect meetings held every two weeks by the World Bank and UNHCR with all three pilot countries. To date, the Dzaleka BSF facility is the largest in Malawi, according to the project's BSF specialist. Before the project, there was very little BSF activity in Malawi. Today, an associated national WhatsApp group focused on BSF has more than 270 members. Dzaleka team members are active contributors to the growing body of knowledge on BSF in Malawi, interacting with and training new and existing farmers and sharing their expertise through podcasts and social media platforms.

### Waste

**Organic-waste supply became Dzaleka's main operational constraint and required a shift to regular school-waste deliveries.** Waste management in the camp was carried out through a UNHCR-funded partnership agreement, but implementation faced efficiency challenges. Waste was highly contested by animal farmers, and plastic contamination was a recurring problem. Competition for organic waste is intense because poultry and pig farmers already pay for it. Brewer's spent grain was trialed but discontinued because costs were high and available quantities were small. The breakthrough came from a regular supply contract with a boarding school outside the camp, which delivers about 800 kg every two weeks at a cost of MWK 70,000, or US$40, per trip, financed from BSF pilot sales revenue. Beneficiaries were trained in household segregation, but volumes remained small and logistics challenging. Earlier proposals for tricycles proved impractical, and a motorbike with a trailer is being explored to support hauling from the school to the settlement. Waste preprocessing combined fermentation and manual size reduction. Young larvae were fed maize bran, and pest pressure from fruit flies and rodents required padlocks, protective insect-net covers, and traps. Alternative waste streams are under consideration, including pig manure from the on-site piggery and chicken manure from the team's own poultry operation.

### Market Linkages, Demand, and Pricing

**The Dzaleka team developed several revenue streams, but pricing still needs to be tested against competing products.** The team sold liquid fertilizer, frass, dried larvae, BSF starter kits of live larvae, and broiler chickens. It also offered BSF training to interested farmers, and they have trained more than 700 people in BSF farming. The team initially charged US$23 per kg for dried larvae, or MWK 40,000, and US$35 per kg for live-larvae starter kits, or MWK 60,000. During the business support trajectory, the team adjusted these prices to US$5.78, or MWK 10,000, per kg of dried or wet larvae and US$14.46, or MWK 25,000, for a BSF starter kit. Based on competing product prices, BSF product pricing may still need further revision. Fishmeal in Dzaleka costs about MWK 5,000, or US$2.88, per kg, and a 10 kg bag of conventional broiler feed costs about MWK 32,000, or US$18.45. Frass was sieved and applied to vegetables in the on-

site demonstration garden, with small quantities sold at trade fairs at US$0.58, or MWK 1,000, per kg. Liquid fertilizer was produced occasionally and sold in 5-liter bottles at US$17.35, or MWK 30,000. It used manual grinding, and pest controls in the facility mainly target fruit flies and rodents. Demand for frass has grown in Dzaleka and Lilongwe, with single requests of up to 100 kg. Opportunities include 2-liter bottle packaging with labels, 25 kg and 50 kg bag formats for frass, on-site sales by weight, and a motorbike with trailer for delivery.

**Box 4.2: Support Trajectory for Commercialization of BSF Enterprises in Refugee and Host Communities**

The support trajectory helped technically feasible BSF pilots move toward commercial management. In contexts that permit refugee entrepreneurship and provide an enabling environment, this transition is a critical stage for BSF initiatives. The pilots showed technical feasibility, but teams still needed support to understand production efficiency, costs, pricing, and business planning. The trajectory combined agripreneurship knowledge, BSF production expertise, and practical understanding of refugee and host-community contexts.

The Business Model Canvas gave teams a shared structure for linking production, customers, revenue, and costs. The trajectory used three modules: Know Your Business, Know Your Production, and Know Your Financials. Know Your Business helped teams understand their business model and align it with customer needs. Know Your Production focused on standardizing processes, identifying bottlenecks, and improving consistency. Know Your Financials helped teams use financial data to understand operating costs, set prices, and assess financial sustainability. Figure 1 presents the Business Model Canvas as a strategic visual business framework.

Figure 1 A Business Model Canvas, a strategic visual business framework




Source: Authors, produced in Canva.

The production module turned facility work from intuition into tracked operations. Field observations showed that pilot teams often produced unpredictable volumes and inconsistent quality because many decisions were based on experience rather than data. The training introduced standard operating procedures and metrics such as waste input per crate, grams of five-day-old larvae per crate, and average

harvest yields. Tracking these metrics helps teams identify bottlenecks, estimate future output, and assess whether they can meet customer orders.
The financial module helped teams see whether sales could cover the cost of production. Pilot teams initially lacked insight into operating costs, break-even points, and minimum viable production levels. The training introduced two tools: a profit and loss statement and cost price per unit. The profit and loss statement shows monthly net profit or loss by subtracting expenses from revenue. Cost price per unit shows the cost of producing one unit, such as 1 kg of larvae, and helps teams set prices that cover costs. Weekly sessions kept the support practical and team-led. Each online session focused on a specific Business Model Canvas block and included both beneficiary teams and local project partners. Beneficiaries led the business exercises and made decisions for their own enterprises. Each team completed a Business Model Canvas and financial reports for its current operating scenario. The teams also received tools and templates to review their models, identify bottlenecks, and assess growth opportunities.

Dzaleka shows what the support added without repeating the full case narrative. April 2026 was the first month of comprehensive financial tracking under the trajectory. The team mapped its cost structure, including per-chicken input costs for feed and broiler purchases. The April income statement showed revenue of MWK 3,486,500, expenses of MWK 2,220,980, and profit of MWK 1,265,520, or about US$820. Table 1 presents the BSF business results for Dzaleka in April 2026. These figures gave the team a clearer basis for pricing, budgeting, and enterprise planning.

**Table 1 BSF business in Dzaleka, Malawi for the month of April 2026**

| MONTH: APRIL 2026 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Income** | | | | | | | **Expenses** | | | | | |
| **Item** | **price per unit** | | **units** | **total / month** | | | **Item** | **price per unit** | | **units** | **total / month** | |
| ***Income from BSF product sales*** | | | | | | | ***Fixed Costs per month*** | | | | | |
| Live Larvae | MWK | 10,000.00 | 10 | MWK | 100,000.00 | | Utensils and safety gear (e.g. gloves) | MWK | - | | MWK | |
| Dried Larvae | MWK | 10,000.00 | 23 | MWK | 230,000.00 | | Data bundles | MWK | - | | MWK | |
| BSF Frass | MWK | - | | MWK | - | | | | | | | |
| Frass tea | MWK | - | | MWK | - | | | | | | | |
| BSF Starter Kits / Seed | MWK | 25,000.00 | 8 | MWK | 200,000.00 | | | | | | | |
| | | | | | | | ***Variable Costs per month*** | | | | | |
| | | | | | | | chickens transport | MWK | 100,000.00 | 2 | MWK | 200,00 |
| ***Income from other agricultural products*** | | | | | | | waste transport | MWK | 100,000.00 | 1 | MWK | 100,00 |
| Broilers (á 15,500) | MWK | 15,500.00 | 43 | MWK | 666,500.00 | | Group Lunch | MWK | 17,500.00 | 2 | MWK | 35,00 |
| Broilers (á 16,000) | MWK | 16,000.00 | 140 | MWK | 2,240,000.00 | | Dried larvae transport | MWK | 45,000.00 | 1 | MWK | 45,00 |
| | | | | | | | Input costs per broiler | MWK | 10,060.00 | 183 | MWK | 1,840,98 |
| ***Income from services*** | | | | | | | | | | | | |
| BSF training | MWK | 50,000.00 | 1 | MWK | 50,000.00 | | | | | | | |
| | | | | | | | | | | | | |
| **Total Income** | | | | **MWK** | **3,486,500.00** | | **Total expenses** | | | | **MWK** | **2,220,98** |
| | | | | | | | | | | | | |
| **Profit/Loss** | | | | MWK | 1,265,520.00 | | **Profit/Loss** | | | | MWK | 1,265,52 |

*"We have learnt how to know whether our business is making profit or loss. We have also learnt how to make good income and expenses records; such knowledge helps us to know what product is generated more money and what expenses need to be reduced."* – **Dzaleka Refugee Team, Malawi**

*Source: Authors and the BSF pilot team in Dzaleka, Malawi*

**The team had market reach and digital skills, but still needed basic financial tools to manage the business.** At the time of fieldwork in December 2025, the team lacked insight into operational costs, profit margins, break-even points, and minimum viable production levels. These gaps were addressed in the business support trajectory, which gave the team tools and insights to grow the business and make a profit (see Box 4.2). The pilot team uses LinkedIn, Facebook, WhatsApp, and other digital platforms for advertising and dissemination. AgroBiz Malawi featured the team in a podcast, after which several individuals contacted the team to request training.

## Zimbabwe: Tongogara Refugee Settlement and Chibuwe Host Community

**Zimbabwe's two BSF pilots operate in neighboring refugee and host-community settings in Chipinge District.** The pilots are located at Tongogara Refugee Settlement and Chibuwe Host Community in southeastern Zimbabwe, near the border with Mozambique. Implementation builds on a working relationship with the local government and the Ministry of Lands, Agriculture, Fisheries, Water and Rural Development.

**Tongogara's remoteness, climate stress, and resource constraints shaped what the pilot could test.** Zimbabwe hosts about 23,444 refugees and asylum-seekers, mostly from the Democratic Republic of Congo, Mozambique, and Burundi. About 16,000 live in Tongogara Refugee Settlement, which is 80 kilometers from Chipinge town and about 250 kilometers from Mutare. The settlement uses 800 hectares for residential and farming purposes. Households have 20-by-20-meter plots, and the surrounding agricultural zone includes a 175-hectare irrigation scheme producing maize, beans, and chili trials. Large-scale piggery and poultry units were commissioned by the end of March 2026. The climate is dry and hot, with summer temperatures often exceeding 40 degrees Celsius and winter nights falling to 2 degrees Celsius. The severe El Niño-induced drought in 2024 caused crop failure and reduced groundwater. The settlement is not connected to the national grid, so energy comes from solar power, candles, firewood, and charcoal. The target water supply is 20 liters per person per day, but this target is often not met during droughts. Encampment policies require gate passes, and remoteness limits employment opportunities, contributing to elevated levels of substance abuse, sexual harassment, and gender-based violence. In December 2025, the Government of Zimbabwe and UNHCR launched a campaign to voluntarily repatriate about 1,700 Mozambicans, and the government's 2026 vision shifts the model from a camp to a settlement integrated with national systems. As of December 31, 2025, 47 percent of the operation was unfunded.[82]

**Overall, the Tongogara case shows strong ownership and clear potential to reduce poultry feed costs, but technical stability and profitability remain unresolved.** The case details below trace that finding through the two-site model, beneficiary selection, operations, markets, and handover. At Tongogara, the first refugee group declined after colony loss, low ownership, and participation challenges, and was replaced by a youth cohort drawn from the Transformation Innovation Hub. At Chibuwe, the host-community team has remained stable, and the pilot is providing farmers with frass and feed. Endline survey findings show that the refugee pilot produced a sense of purpose, belonging, and empowerment, while the farm also offered some protection from sexual abuse, gender-based violence, and substance abuse. The main challenges are colony collapse from extreme heat, reduced hatching in containers because of light-spectrum issues, high competition for waste, and the need to reach profitability as the project transitions to local ownership and financing.

### Facility

**The Zimbabwe pilot operates two linked sites that combine BSF farming with livestock, aquaculture, and crop demonstrations.** One production site is in Tongogara Refugee Settlement, and the other is in the adjacent Chibuwe host community. Each site integrates BSF farming with fish farming, layer hens, and crop demonstration plots. A refurbished, climate-controlled, solar-powered shipping container is the breeding center of each site, holding two love cages of about 1.5 by 2 meters and shelves for 210 crates.

[82] Zimbabwe Funding Update - 2025 | UNHCR as of 31 December 2025.

The refugee site has two greenhouses of about 8 by 16 meters with greenhouse paper and brick floors, three sheds for storage, hatchery, and office use, and a large processing shed of about 15 by 5 meters with a concrete floor and steel roof. The processing shed is equipped with a pelletizer and four metal solar dryers. The site also has three tilapia fishponds, a layer-hen unit, and demonstration plots for maize, cabbage, leafy greens, and other vegetables. The host-community site has the same components on a smaller scale: one greenhouse, one fishpond, demonstration plots, the same chicken unit, and a container.

**The container breeding system improved climate control but created new hatching problems.** Both teams reported a decline in egg-hatching rates after the containers were introduced, most likely because of insufficient artificial light or the wrong light spectrum. Flies in the love cages have been observed to be dormant. The teams are testing adapted container lighting and rotation of love cages outside during milder seasons, and these changes appear to address the issue. Larvae are more resilient than flies, eggs, and neonates, and low-cost climate measures were also introduced, including covering crates with greenhouse paper at night.

**Tongogara and Chibuwe developed their infrastructure in stages as power, equipment, and site upgrades became available.** Tongogara has 2 hammermills, 2 shredders, 4 pelletizers, including 2 small and 2 large units, 4 solar dryers, 2,000 plastic trays, and 2 steel-framed love cages produced locally. Two greenhouses with cement pavers and suspended fabric ceilings provide temperature management, and a multifunction storeroom supports feed storage for chicken rearing, larval shelter, and changing facilities. Ten cement troughs originally intended for the larvarium were repurposed for duckweed cultivation after an April 2023 storm destroyed their cover and caused the loss of more than half of BSF production. Duckweed raises crude protein from 20 percent to more than 40 percent of dry mass. Starter colonies of 5 kg of early-stage larvae were procured from Chinhoyi University of Technology at US$75 per kg, totaling US$450. Greenhouse procurement took four months and construction one week, while the storeroom and shed were built locally in one month. Electricity reached Tongogara only in September 2024, with three-phase conversion completed in early 2025. The Chibuwe host-community site started in mid-March 2023 with one fenced and locked greenhouse, initially with a dirt floor that was paved in 2024. Tongogara supplied Chibuwe with 2 kg of larvae, which Chibuwe scaled to 6 kg within about five months. Two 40-foot shipping containers adapted for insect farming were delivered to the Zimbabwe sites in late 2025, one to Tongogara and one to Chibuwe.

### Beneficiaries

**Zimbabwe used separate selection processes for refugee and host-community beneficiaries.** The first group of 31 refugees was selected in late 2022 by a committee representing the government, UNHCR, implementing partners, and refugee leadership. Selection criteria included vulnerability, time spent in the camp, household size, resettlement prospects, and existing livelihoods such as poultry or pig farming. In the host community, a selection committee of public agricultural extension workers and village leaders chose 40 beneficiaries from the villages closest to the project. Beneficiaries were estimated to be 45 to 65 years old and use a rotation system, with two working each day and two on standby.

**The refugee site added a structured youth cohort after the first group lost momentum.** Two overlapping groups have operated at the refugee site. The first group declined after the colony collapsed in March 2024 because of extreme temperatures, low ownership, inconsistent participation, and internal

disputes about payment. A second group of 16 youth ages 18 to 25 was added in 2024. They had previously completed a 10-week entrepreneurship training at the Transformation Innovation Hub run by the Ugandan nongovernmental organization SIGA. Roles are clearly assigned, including managers for poultry, fish, BSF, and sales, plus a chairperson, vice chairperson, and treasurer. The youth cohort received on-the-job training from the previous BSF pilot group and technical training from Chinhoyi University of Technology (CUT). The team set daily work hours from 8 a.m. to 3 p.m., and ownership is strong.

### Implementation and technical capacity

**Zimbabwe combined formal technical support with daily peer learning across the two sites.** CUT delivered four days of on-site training, hosted selected members for four days at the university, and provided ten days of training in total, including follow-up on feed formulation. A CUT engineer designed and installed the shipping container at the settlement and provided instructions on its operation. Daily internal knowledge transfer between the original group and the youth cohort, and among members, complements formal training. Practical learning has been constrained at several points by colony instability. Remote support from CUT continues, and World Vision provides weekly site visits, although these are being phased out in December 2026 as funding tightens. UNHCR and World Bank staff supported the two sites. Global insect meetings held every two weeks with the World Bank, UNHCR, and the two other pilot countries provided another learning channel, along with linkages to the Ministry of Agriculture.

### Waste

**Waste sourcing in Zimbabwe relied on mixed feedstocks and constant adjustment to local supply.** The refugee and host-community sites used kitchen waste from beneficiaries' homes, school waste at the host site, market waste, and animal manure. Local competition for organic waste was high because of parallel piggery, poultry, and biogas activities. Banana stems collected free of charge from farms within three kilometers of the camp became the cornerstone of the BSF feedstock, complemented by brewer's spent grain and maize bran, mostly for hatching. Seasonal residues, including cabbage waste in winter and watermelon rind in summer, required regular adjustments to the rearing system. UNHCR procured a tractor for waste hauling, initially operated by World Vision. The government will assume fuel, maintenance, and staffing costs from March to December 2026. Banana stems were cut, crushed, and fermented manually, and pig waste was pretreated for six to seven days in 1,000-liter tanks to suppress competing house-fly larvae.

**Waste volumes are increasing, but tracking and feedstock diversification still need work.** The refugee team received about six buckets of waste per week, or 100 to 120 kg, while the host-community team received about 100 kg from the school and 50 to 100 kg from households, or 150 to 200 kg per week. Starting in May 2026, a large-scale pig farm of about 1,000 piglets per month and a large-scale poultry farm of about 20,000 birds per month will operate near the refugee BSF facility, with waste diverted to the BSF facility as a precondition. Future opportunities include broader feedstock diversification, formal supply agreements with farms and mills for BSF substrate, and improved fermentation protocols. The host-community team still needs to identify additional waste streams, begin measuring substrate volumes for a homogeneous mix, and introduce systematic tracking.

### Market Linkages, Demand, and Pricing

**Frass demand gives the Zimbabwe pilot a clear early market opportunity.** One host-community member reported that tomatoes grown with BSF frass remain fresh longer and sell at 30 percent higher prices. Frass is applied in demonstration plots for maize, tomatoes, okra, and cabbage. Chinhoyi University advises about 30 g per planting station, with a second application after 21 days for tomatoes. Frass is stored in trays in a dedicated room with batch-level recording. Nutrient variability from different substrates complicates standardization, pricing, and user guidance. Because cattle manure is already traded, small packages of BSF frass and differentiated pricing are under consideration.

**Animal-feed demand and internal poultry use create additional market pathways.** Demand for animal feed is strong in Zimbabwe, especially for poultry feed, because poultry farming is widespread. Before the colony collapse, the host-community team sold sun-dried BSF larvae to local poultry farmers at US$2 per kg. Both BSF groups currently focus on internal feed substitution for poultry production. The refugee group requires 30 bags of 50 kg per month for its layer hens, equivalent to about US$900 per month in feed costs. The refugee team sells eggs from layer hens at US$3.50 per tray, with sales of more than 100 trays per month.

### Project Dynamics

**Partner roles were clear, but staff turnover and handover created continuity risks.** UNHCR oversaw, monitored, and provided technical guidance, while World Vision handled day-to-day operations, procurement, training, and market linkages under a partnership agreement with UNHCR until 2025. The Government of Zimbabwe and Chinhoyi University of Technology are key stakeholders. Staff turnover has affected continuity. The January 2026 handover from UNHCR to the Government of Zimbabwe placed all livelihoods projects under one agriculture staff member.

## Kenya: Dadaab Refugee Complex

**Dadaab's scale, remoteness, and livelihood constraints shaped the need for the BSF pilot.** The complex is situated in northeastern Kenya, near the border with Somalia, about 100 kilometers from Garissa town. It consists of several camps, including Hagadera, Ifo, and Dagahaley, all in Garissa County. The area is remote, arid, and semi-arid, with extreme heat, drought, and limited resources. Dadaab was established in 1991 to host Somalis fleeing civil war and saw another major influx of about 130,000 people in 2011 because of drought and famine. Somali refugees account for more than 96 percent of the population, with smaller groups from Sudan and South Sudan. As of February 2026, the complex hosted 406,702 refugees and asylum-seekers across four sub-locations. The complex is managed by Kenya's Department of Refugee Services, with technical support from UNHCR. About 75 percent of Dadaab's refugee population are women and children, 51 percent are female, and 58 percent are children or adolescents, based on May 2025 data. About 84 percent are classified as multidimensionally poor. The share of refugees in employment or self-employment fell from 13 percent in 2022 to 6 percent in 2024, and 89 percent are economically inactive. Aid accounts for 75 percent of household income. In 2024, funding gaps cut food rations to as low as 40 percent of the minimum required food basket.

**The Dadaab pilot began later than the other sites and entered a changing policy environment.** The BSF pilot started in 2024, mainly because of delayed local decision processes. By 2026, the operating

context was shaped by external funding constraints and increased attention to the Government of Kenya's Shirika Plan. The plan is a multi-year effort to transform refugee camps into integrated settlements. This context made the pilot relevant not only as a livelihood activity, but also as part of a broader shift toward self-reliance and settlement-based development.

**Overall, the Dadaab case shows that BSF can support climate-resilient livelihoods for women and low-literacy groups in semi-arid camp settings.** The case details below trace this finding across facility adaptation, beneficiary organization, technical training, waste sourcing, and market development. The pilot organized 40 beneficiaries, 80 percent of them women, into two VSLA groups and generated income from waste collection and crop sales. It also supported growing adoption of permaculture practices using frass. Operations had to adapt to temperatures of up to 45 degrees Celsius and to a fixed camp layout, while the Somali-language curriculum helped make the technical content accessible. Production from March to December 2025 reached 1.2 kg of eggs, nearly 600 kg of live larvae, 147 kg of dried larvae, and more than 5 tons of frass, showing that a self-sustaining colony is feasible in semi-arid conditions. Engagement remains high, although DRC still manages day-to-day operations. Demand for affordable protein and organic fertilizer appears strong, driven by growing poultry production and high feed costs, but the pilot has not yet fully leveraged that demand.

### Facility

**Dadaab adapted existing infrastructure into a centralized BSF group farm suited to extreme heat.** An existing greenhouse was refurbished and partitioned with UNHCR support into breeding and feeding rooms, with cooling and humidity provided by fans and wet gunny sacks. Locally contracted staff built 14 love cages at reduced cost. UNHCR supplied a freezer, shredder, weighing scales, 40 wheelbarrows, 20 hoes, 20 watering cans, 4 bicycles, and 1 large solar dryer. A purpose-built waste building contains three lockable rooms for shredding, waste storage, and cleaned bins. A separate room is dedicated to insect-related materials. The site includes crate shelves and built-in shelves with about 60 kg of waste capacity, a waste-receiving area, storage, a solar dryer, demonstration plots, and a recently installed poultry unit of 50 indigenous birds for meat and eggs. The site is fenced and secured. A temperature meter monitors the greenhouse environment, where semi-arid temperatures often exceed 45 degrees Celsius. The target indoor range is 27 to 32 degrees Celsius with adequate humidity. The facility is largely managed and operated by the Danish Refugee Council with UNHCR support. Production began in November 2024, with eggs harvested from March 2025. Cumulative production from March to December 2025 was 1,208 grams of eggs, 584 kg of live larvae, 147 kg of solar-dried larvae, and more than 5 tons of frass.

### Beneficiary selection

**The Kenya pilot used open recruitment to build a demand-driven beneficiary cohort.** In September 2024, the Danish Refugee Council circulated an open advertisement, and about 120 individuals attended information sessions in September and October 2024. Forty individuals were selected based on interest, and 80 percent were women. The 40 beneficiaries are organized in two Village Savings and Loan Associations, each with a chairperson, and are in the process of being formalized. The cohort includes a wide age range, with the oldest participant aged 67, high illiteracy, mostly Somali participants, and 5 Sudanese participants. Motivations for joining the project included income, food security through improved crop yields, reduced reliance on imported feed, a sustainable alternative, environmental cleanliness, and new skills.

**Participation remains high, but incentives and food-ration cuts affect regular attendance.** A rotation system assigns sub-groups of 8 to 10 beneficiaries to collect waste once every two months. Beneficiaries are paid KES 16 per kg of waste, with a target of 100 kg per delivery, or KES 1,600, about US$12. The facility receives about 2,500 kg of waste every two months. Project staff estimate that 70 to 90 percent of participants are highly motivated, while the remainder expect financial incentives. The project does not provide stipends, to support a more commercial vision. Irregular participation occurs as beneficiaries seek casual work elsewhere, especially as World Food Programme rations have been cut. Beneficiary feedback is largely positive. Some beneficiaries have started to maintain kitchen gardens with permaculture practices using frass, and one beneficiary is actively training community members on permaculture and frass-based kitchen gardens. Training covered four modules of three to five days each: BSF production and entrepreneurship, financial literacy, poultry husbandry, and Village Savings and Loan Associations and market linkage. Technical modules were delivered by external facilitators, while financial literacy was delivered by the Danish Refugee Council. All 40 participants remain engaged.

### Technical Capacity

**Dadaab's training was adapted to participants' language and literacy needs, but hands-on exposure remains limited.** The curriculum was co-developed by external experts, the Danish Refugee Council, and UNHCR, with UNHCR initially trained by the World Bank Group. It was simplified and translated into Somali to accommodate low literacy and limited English proficiency among participants. Topics covered the BSF lifecycle, production processes, hygiene, waste management, permaculture, financial literacy and entrepreneurship, and poultry management and feeding. Most sessions lasted three days and were delivered in person. BSF training was led by a local Kenyan partner, the F&V Group, with occasional remote support by phone. BSF production is tracked daily and discussed in global insect meetings held every two weeks. However, beneficiaries' hands-on technical experience is limited by the rotation system for daily work schedules. Beneficiaries are not exposed to BSF handling on a continuous basis, and most technical knowledge remains with the implementing partner's team and field officers.

### Waste

**Dadaab's waste system improved household sorting but still faces seasonal and quality constraints.** A waste analysis was conducted at inception. A waste consultant mapped slaughterhouse byproducts from camel and goat, market waste, agricultural residues, and household waste from the 40 beneficiaries. The facility mainly used household waste, market waste, and slaughterhouse waste from a nearby facility, with chicken manure expected as an additional stream from the new poultry unit. Household contributions of organic waste began at 1 kg per week and rose to 5 kg per week. Early BSF training improved household sorting of organic waste and clarified production targets, showing that sensitization should precede waste assessments. Waste was collected by rotating groups using donkey carts, with each group delivering up to 100 kg per day. Beneficiaries were paid per kg, including transport, and bins with lids were provided to contain odor. Preprocessing required moisture adjustment because the drier climate requires wetter substrate. Waste quality and composition vary, affecting larval growth, and waste availability also varies greatly by season. Future opportunities include partnerships with hotels and public canteens, lean-season fermentation and stockpiling, and frass-based barter.

### Market Linkages, Demand, and Pricing

**Dadaab's strongest early market signal is demand for cheaper poultry feed.** Insect farming is new in Dadaab, and initial skepticism, especially in the host community, was addressed through sensitization meetings in local languages with community leaders. About 70 percent of people in the area depend on livestock, and pastoralist livelihoods have been harmed by climate change and drought. Poultry keeping is growing rapidly, with feed cost as the main constraint to growth and financial sustainability. UNHCR and World Bank staff visited commercial poultry farmers in Garissa, who all expressed interest in BSF feed if it is cheaper than feed sourced from Nairobi. One Garissa poultry farmer has already purchased dried larvae and intends to make regular purchases. Kenya Bureau of Standards certification is in process for both dried larvae and frass, and the Danish Refugee Council is registering the facility as a business.

**Frass demand is being developed through demonstration plots, product testing, packaging, and certification.** Frass was initially distributed to beneficiaries and used on demonstration plots. Management and quality improved after November 2024 with the addition of a shredder and technical support. Frass is now shredded, packaged, and stored in 90 kg bags. Marketing began in December 2024, supported by positive demonstration-plot results. Nutrient analysis is complete, and branding and certification are under development under the name "Dried BSF Frass." Pricing of KES 60 to 200 per kg is being discussed, against a market average of about KES 40 per kg. Application rates depend on soil quality, soil composition, and crop type. In Dadaab, recommended rates are roughly 10 kg per 16 m² vegetable plot and 50 kg per banana planting area. Frass is offered in 5 kg, 10 kg, 25 kg, and 50 kg bags, targeting both small-scale refugee farmers and larger-scale horticulture producers in Garissa. A three-tier pricing model and graded quality pricing are under consideration.

**The planned sales model uses the two VSLA groups as the route to market.** The plan is for the two Village Savings and Loan Association groups to rotate monthly in selling larvae and frass. This would give both groups a role in product sales and help distribute market experience across the cohort. There is also interest in smaller, decentralized setups, such as household kits or smaller group farms. That interest suggests the market may extend beyond the centralized group farm if production, training, and product quality can be maintained.

## Cross-pilot comparison and messages

**BSF pilots worked best when each site adapted the model to local conditions while keeping core operating practices consistent.** The comparison across the four BSF pilot projects in Kenya, Malawi, and Zimbabwe shows that different environments and locations led to different outcomes, outputs, and impacts. At the same time, some areas and methods were important across sites, especially assessments, organic waste, training, sensitization, and the transition toward business and entrepreneurship. A key message is that each BSF pilot must be anchored in its local context while applying common methods for organic-waste management and business development.

**Beneficiary selection affected retention and performance across the pilot sites.** The three country pilots illustrate a clear pattern. Vulnerability-only selection in Malawi and Zimbabwe was associated with higher turnover. In Kenya, the open, demand-driven self-selection model retained 100 percent of participants, 80 percent of whom were women throughout. The cases suggest that vulnerability targeting worked better

when combined with additional criteria such as willingness to participate, time availability, interest, and trust within the candidate pool. Group size and composition also affected collaboration and income potential, and overly large or heterogeneous groups diluted responsibility.

**Group size shaped collaboration, responsibility, and income potential.** Apart from selection criteria, the number of beneficiaries involved affected the business model. Long-term sustainability and income generation depended partly on the size and set up of the business and how many people could realistically operate the facility while earning income. This was visible in the difference between the relatively compact teams in Malawi and Zimbabwe, which grew into stable commercial enterprises through the project, and Kenya, where income generation remained more challenging because of the large number of beneficiaries. In such cases, other business models, including household micro-enterprises, emerged as possible ways to reach a larger number of beneficiaries while preserving income-generation potential.

**Training built capacity best when it combined formal instruction, exposure visits, and peer learning.** Zimbabwe relied on a comprehensive CUT training package that combined on-site sessions and university visits, complemented by on-the-job training of the youth group by the original group. Malawi received continuous formal training from the BSF specialist, while the pilot team also developed its own learning materials and videos and joined exposure visits to other new Malawian BSF projects. Kenya used a curriculum co-developed by external experts, DRC, and UNHCR and delivered in Somali across multiple three-day sessions covering the BSF lifecycle, hygiene, waste management, permaculture, financial literacy, and poultry management. Across the pilot program, training worked best when it was multidisciplinary, tailored to the cohort, supplemented by exchange visits and demonstration plots, and integrated with existing livelihoods such as poultry rearing, pig farming, and savings groups. The pilots also showed that expectations around income generation had to be managed from the start, because BSF revenue typically materialized only after the colony, processing, and market linkages were in place. Selection and training worked as an integrated package rather than as separate steps, and business training added value when it was offered alongside BSF technical training and adapted to BSF enterprises.

**Climate adaptation and pest management varied by local operating conditions.** Each pilot environment called for a different response. Kenya manages temperatures above 45 degrees Celsius with low-cost techniques, including flooded floors, soaked blankets, and solar fans. Zimbabwe uses refurbished climatized shipping containers equipped with solar panels. Malawi uses air-conditioning units in hot periods. Pest management was also tailored. Malawi addresses fruit-fly infestations through experiments with substrate ratios, protective insect netting, and cow-dung smoke. Zimbabwe addressed an elephant problem by planting chili pepper plants around the facility, and Kenya solved a persistent rodent problem with traps.

**Organic-waste systems worked best when they fit local incentives and transport options. Kenya uses paid rotating teams and donkey carts.** Malawi sources kitchen waste from a boarding school. Zimbabwe collects buckets of organic waste from beneficiaries' homes and a school, with a major boost expected from May 2026 when adjacent large-scale pig and poultry operations will divert waste to the BSF production facility. Strategic partnerships with local actors emerged as an important way to support a continuous waste supply.

**Weekly KPI tracking showed where waste systems constrained production.** Operational key performance indicators related to organic-waste tracking included weekly waste volumes, contamination rates, moisture adjustments, larval growth, hatch rates, and frass sales. Across the four pilot contexts, waste availability and composition were highly context-specific. Sensitization of the wider community, including beneficiaries and waste providers, before assessment improved the accuracy of later design and procurement decisions.

**Feedstock diversity, transport, and preprocessing shaped production reliability.** Diversified feedstock increased resilience, while over-reliance on a single stream disrupted production in every pilot, including kitchen waste in Malawi, maize bran in Zimbabwe, and brewer's spent grain in early trials. Transport often constrained production more than waste availability and had to match terrain, repair capacity, and cost structure. Tractors at the Zimbabwe sites, a motorbike with trailer in Malawi, and donkey carts at Dadaab reflect three context-appropriate responses. Waste preprocessing also had to match local skills and climate; manual cutting, fermentation, pest-proof storage, and climate-specific moisture adjustment formed the operational backbone.

**Infrastructure, partnerships, and government engagement shaped continuity.** Infrastructure worked better when it was financially viable, flexible, and right-sized, with relocatable layouts, shade, secure storage, and upgrades to existing structures preferred to greenfield construction. Partnerships with schools, farms, hotels, slaughterhouses, and mills were central and required simple service agreements with clear roles and continuity provisions. Early government engagement helped secure long-term ownership and cofinancing.

## Technical bottlenecks

**Three technical bottlenecks recurred across the pilots: hatching, harvesting, and standardization.** The first was egg hatching, where hatching rates were closely tied to fly health, light spectrum, ambient temperature, and attractant quality. Neonate mortality was similarly sensitive to substrate moisture, substrate quality, and ambient temperature. The second bottleneck was harvesting, where self-sieving methods were slow and produced losses. The pilots identified handheld sieves with graded hole sizes, using a scoop-and-sieve approach, as a practical option across sites. The third bottleneck was standardization. None of the sites used a fully documented set of standard operating procedures with fixed substrate ratios, harvest days, and love-cage turnover schedules until the last few months of the pilot program.

**Equipment choices affected BSF performance when timing, specifications, or technical input were weak.** Procurement of production equipment was a critical determinant of BSF performance. Early purchases sometimes proceeded with incomplete specifications and limited technical input, leading to cases where equipment such as feeding trays broke or produced suboptimal airflow. Funding delays in some cases were triggered late in the year, leading to bulk procurement of items that were not used, and power machinery was occasionally procured prematurely. Inclement weather damaged production where infrastructure was inadequately protected, as in the cement basins at Tongogara that were destroyed in a storm.

**Procurement worked better when teams matched equipment purchases to site conditions, production needs, and BSF life-cycle timing.** Although annual funding makes this complex, procurement worked

better when it was grounded in clear technical specifications, sequenced gradually, funded on time, and aligned with demonstrated need. The pilots also highlighted the value of embedding BSF technical expertise from a BSF specialist and project manager in design and supervision. Site selection depended on assessment of waste availability, climate, ecosystem, shade, electricity, and water. Facility design also had to account for BSF biology, including the need to separate love cages from the larvarium because high temperatures harm larvae and low temperatures harm eggs. Existing infrastructure could be evaluated and adapted where possible, with movable and scalable layouts, local sourcing, and maintenance planning built in from the outset. The pilot experience also pointed to four implementation phases: design through technical site visits and specifications, procurement through an itemized phased plan, operation through manual operations first, and scale-up after technical and financial justification. Machinery and equipment procurement also had to account for operating and maintenance costs in the business model and the long-term feasibility of independent operation by beneficiaries.

**BSF biology was universal, but production methods had to adapt to local conditions.** The BSF life cycle is biologically universal, but production processes varied with climate, resources, and operational preferences. Local adaptation was therefore essential, and technologies that work elsewhere sometimes produced unintended consequences when they failed to mimic local natural conditions. Kenya received 250 g of eggs, 10 kg of pupae, and 10 kg of larvae from Zihanga, with a colony reboost required in June 2025. Zimbabwe received 20 kg of prepupae per facility from Chinhoyi University of Technology; disease and limited feedstock caused losses, prompting a second 20 kg input for Chibuwe at US$45. Malawi received 5 to 9 kg of larvae from a local farmer at MWK 1,500,000, and the colony has not required further input.

**Breeding and adult-fly management varied with each site's climate, lighting, and substrate options.** Different breeding and adult-fly management models can coexist. Kenya breeds in a greenhouse with racks, basins, and standard crates, but natural shade outside the love cages was more productive than indoor placement. The team experimented with attractants and found blood meal and rotten food waste more effective than slaughterhouse waste. The team also uses solar-powered fans and hydrometer monitoring. For hatching, limited availability and the high cost of maize germ and wheat bran remain constraints, and the team tested millet and sorghum. Zimbabwe rotates between an outdoor shed in summer and a greenhouse in winter. Using a shipping container for breeding caused hatching issues because of insufficient daylight, and the pilot identified options such as modifying the container with appropriate lighting, opening doors, or breeding outside most of the year. Malawi uses large love cages with a small dark cage inside each love cage for hatching pupae. Pig and kitchen manure are used as attractants, and the team adopted an egg-shower hatching method with continuing optimization.

**Larval rearing and harvesting methods varied with production scale and colony stability.** Different models worked in different contexts. Malawi tracks eggs from incubation through hatching, applies standardized substrate feeding, and uses sieving tables. Prepupae are mixed with rice husk to ease pupation. Kenya practices continuous harvesting with daily egg collection and a wheat-bran and poultry-waste mix for hatching, while substrate moisture monitoring remains critical. Experiments with processing techniques, especially sterilizing larvae with hot water and sun-drying, helped improve protein content. Zimbabwe lacked standardization because of colony issues. While the colony is being stabilized, the team is estimating substrate and larval volumes.

**Processing and sanitation were most consistent when accepted protocols fit local conditions.** Processing and sanitizing can be standardized using global protocols where local conditions allow. For

example, harvested larvae can be sanitized through the globally accepted step of submerging them in boiling water for about one minute. In Dadaab, KEBS-tested protein content was below 40 percent. The team experimented with washing-only and direct solar drying, but the workshop recommended a return to boiling water. The low protein content was attributed mainly to higher moisture content in the end product and to substrate composition. All pilots used solar dryers of varying designs: a walk-in greenhouse-style unit at Dadaab, smaller wooden structures with greenhouse paper at Dzaleka, and metal tabletop dryers at the Zimbabwe sites. Average drying time is two to three days, depending on weather. Kenya has the most developed tracking and standardization, packaging product in sealed, labeled 5 kg bags and producing 15 to 20 kg of dried larvae per two-month cycle.

**Business models and operating-cost data remained incomplete until the final pilot phase.** All pilots lacked a fully developed business model until the last phase of the pilot. Operational cost data, break-even analyses, minimum viable production levels, and pricing strategies aligned to client segments were either missing or incomplete (see Box 4.2). This highlighted the value of integrating business modeling in the early phases of the project to support long-term sustainability and informed decision-making in project design. Governance arrangements varied across sites. The Kenya pilot showed the clearest division of labor between UNHCR and DRC, the Zimbabwe pilots showed clear roles between UNHCR and World Vision, and the Malawi pilot was disrupted by a partner change from CARD to Plan International.

**Product and market diversification followed local feed, fertilizer, and poultry opportunities.** Malawi distributes samples to poultry and pig farmers, sells wet larvae as starter kits, sells dried larvae directly to farmers, and uses wet larvae to feed its own chickens. Kenya runs a chicken-feeding rotation, with dead flies on Monday, wet larvae on Wednesday, and dried larvae on Friday, and sells packaged dried larvae to a large poultry farmer in Garissa. Zimbabwe prioritizes feeding its own layer hens because in-camp egg demand is high, and the team completed a 10-day feed-formulation training as a longer-term option for diversified income. Packaging strategies are still being refined. Malawi and Kenya are testing small package sizes for refugee households and larger bags for commercial buyers, and the Dadaab community has expressed strong interest in starter kits for household-level production. The distinction between starter kits and finished products clarified whether products would seed new household operations or serve as feed and fertilizer inputs. Across sites, three lessons stand out. Markets were often closer than expected, and the immediate environment, including neighboring pig and poultry farms, was often the first market to test. Demand could be characterized in terms of products, buyers, and volumes. In sites where all participants are chicken farmers, and where it is the most cost-effective use, feeding their own chickens before selling externally can be the strongest business decision.

**Frass strengthened the value chain by generating revenue, building demand, and closing the agronomic loop.** Sustainable frass utilization strengthens the entire value chain because it generates revenue, builds farmer demand, and closes the agronomic loop. Pest-proof demonstration plots were highly effective in stimulating demand because farmers responded to visible results on familiar crops. Frass potency requires clear user guidance to prevent overapplication, and nutrient inconsistency complicates standardization and pricing. Packaging, branding, certification, and labeling of frass are critical for market entry, especially when products move beyond the immediate beneficiary community. Storage capacity, pest control, and drying capacity directly influence product viability. The pilots identified several enablers for scaling byproduct systems: standardized handling, sieving, and drying protocols with flexibility for climate; crop-specific application instructions; consistent packaging and branding with storage, usage, and shelf-life

labels; segmented or graded pricing with smaller package sizes for affordability; expanded demonstration plots; stronger storage to reduce pest pressure; and financing access for packaging, certification, and marketing.

### Coordination, knowledge sharing, and financing

Coordination evolved from internal sensitization to joint governance, field missions, and regular cross-country learning. The initial phase focused on internal sensitization and stakeholder engagement. The World Bank report *Insect and Hydroponic Farming in Africa: The New Circular Food Economy*, launched on January 19, 2022, served as a key input in this process. A joint governance structure linked World Bank and UNHCR leadership, while UNHCR country operations led implementation, supported by technical specialists in Kenya, Malawi, and Zimbabwe and partner field staff. Weekly coordination meetings included headquarters and field staff. Joint UNHCR–World Bank missions were carried out to pilot sites twice yearly. The pilot program launched with a regional training week at CUT in Zimbabwe, with participation from all pilot countries.

Knowledge sharing combined global visibility with informal communities that helped spread BSF learning. The World Bank engaged private-sector and broader audiences through presentations on insect farming at the United Nations General Assembly in New York and in Addis Ababa, Antananarivo, Berlin, Harare, London, Nairobi, N'Djamena, Rome, Seoul, Aarhus, and Turin. Stakeholder interest has been consistent and strong. The first presentation took place in Malawi, where BSF farming uptake accelerated and an informal WhatsApp group on insect farming grew from zero to more than 270 members. These formal and informal channels helped move learning beyond the pilot sites.

Funding roles and budget timing shaped procurement, staffing, and handover planning. UNHCR financed field-level staff and implementing partners, infrastructure and equipment for BSF production, demonstration and production sites, and missions. The World Bank financed training, capacity-building, technical assistance, data collection, knowledge management, supervision, part-time staff in various locations, and missions. The pilots needed predictable and flexible funding, but delays in UNHCR-managed budgets affected planning, procurement, and staff retention. Funding modalities also shaped implementation because World Bank trust funds cannot finance infrastructure, even though infrastructure and production equipment are critical to BSF production. Governance arrangements required clear roles across headquarters, country offices, and local partners, and stakeholder engagement supported uptake. Sustainability planning covered start-up and scale-up more effectively when it began at the outset.

## 4.2 A Quantitative Assessment of the Insect Farming Pilot Program

**The baseline and endline surveys tracked the same participants across the four pilot sites.** The surveys covered Dadaab Refugee Camp in Kenya, Dzaleka Refugee Camp in Malawi, Tongogara Refugee Settlement in Chipinge, Zimbabwe, and Chibuwe, the host community adjacent to Tongogara. All participants who completed the baseline survey also completed the endline survey. This section distills the impacts documented at endline across income, agricultural integration, food security, and sustainability, with a closing reflection on the conditions that enabled them.

**Women made up most participants across the four sites, and the three refugee-site cohorts included only refugees.** More than half of the participants across the four sites are women, at 56 percent, and women

are particularly well represented at Dadaab, at 80 percent, reflecting deliberate inclusion in that refugee setting. All participants at the three refugee sites are of refugee origin: 98 percent of Dadaab participants are Somali and 2 percent are South Sudanese, Dzaleka participants are Burundian and DRC nationals, and all Tongogara participants are refugees from DRC. Mobile-phone ownership is essentially universal across sites, which enables instructional and market information to flow through digital channels.

**Beneficiaries gained BSF knowledge and practical team skills across all four sites.** The survey findings show measurable human-capital gains among beneficiaries. Respondents reported BSF-specific knowledge, record keeping, conflict-resolution skills, and team-management skills as primary benefits at every site. The findings also show evidence of cross-site peer learning. Examples include the spread of frass-driven banana cultivation at Dadaab and the willingness of Dzaleka participants to revise their expectations about frass after observing it in use.

**The Dadaab pilot used garden plots to generate income before BSF products could enter the market.** The pilot paired BSF training with 16 m² garden plots for every participant, building a productive base while the project worked to secure market access. Every participant had a garden plot by endline, up from 40 percent at baseline, and 63 percent earned project-related income from vegetable sales. Twenty-one participants cited fertilizer, or frass, as a current benefit. One participant's frass-driven recovery of a banana crop from pest damage triggered a fourfold increase in banana cultivation across the team. Ninety-five percent of beneficiaries expect income from BSF products to begin once certification is finalized, and an implementing partner appearance at a January 2026 trade exhibition generated strong interest from large-scale chicken farmers.

**Dadaab participants used BSF and garden-plot income to cover basic needs and invest in small assets.** Participant testimony on pilot benefits focused on income, children's schooling and nutrition, and skills. Fifty-five percent of participants linked income directly to vegetable sales, 45 percent reported feeding their families from their plots, and 15 percent said they could now pay school fees and improve child welfare. The team has used the insect farming pilot to launch a Village Savings and Loan Association, with one participant already accessing credit through it. In open-ended responses, participants said income from the garden plots had been spent on basic needs such as food, soap, and clothing; building a house; buying a motorbike used as a taxi; and sending children to school.

**Dzaleka had already turned BSF farming into a practical source of skills and income by the end of the reporting period.** All participants in Dzaleka Refugee Camp, Malawi, reported income generation as a current benefit. Half said they used earnings to meet basic needs, and 25 percent said they used earnings for household food. All participants also identified organic fertilizer as a benefit. Fifty percent revised their assessment after observing the effects of frass on the communal demonstration plot. All participants take vegetables home from that plot about twice a week on average. Knowledge gains were unanimous: all beneficiaries cited insect-farming knowledge as a benefit, one team leader highlighted management experience, and participants reported growing camaraderie within the small team. Dzaleka was the only project that had moved into commercial sales when the survey began in July 2025. Participants described the project as helping them buy food for the household and meet basic needs.

**Tongogara showed that BSF skills can feed into broader farm and enterprise activity.** Sixty-nine percent of participants cited insect-farming knowledge and skills as a current benefit. Expected future benefits for income and livestock feed each tripled relative to current levels, reflecting optimism supported

by new infrastructure. The project installed a solar-powered, climate-controlled 40-foot insect-farming container in 2025, directly addressing the temperature challenges that destroyed 480 kg of larvae in March 2024. Total livestock holdings rose from 41 to 375 head, linking future BSFL feed potential with poultry, goat, sheep, pig, fish, cattle, and duck production. Household insect consumption doubled from baseline to endline. One Tongogara participant captured the integrated nature of the gains, paraphrased here from the survey: the project taught them to run a home garden, substitute frass for fertilizer, manage a layer-poultry operation, formulate feed, and apply marketing skills to the small business they hope to launch. The description moves across crops, livestock, BSF, and enterprise skills, reflecting the most consistent theme of the Tongogara endline.

**Chibuwe had the strongest results by the end of the pilot, especially on income and food security.** The host-community site also shows what scaled BSF integration can look like. Total realized benefits at endline exceeded baseline expectations by 14 percent, and 90 percent of participants reported livestock feed, waste reduction, and organic fertilizer as benefits. Ninety-seven percent of participants reported earning income at endline, up from 43 percent at baseline, with average monthly earnings of US$136. Chibuwe also showed the strongest food-security gains across the sites: food consumption improved across all 16 categories, total category-days rose by 36 percent, households reporting 7-day food shortages fell by 88 percent, and only 7 percent reported shortages at endline compared with 57 percent at baseline. Total 30-day livelihood adaptations also fell by 73 percent. All 30 participants plan to continue BSF farming, and 70 percent plan to establish household operations alongside teamwork at the demonstration site. In open-ended responses, Chibuwe participants consistently cited income, employment creation, waste management, and the social cohesion that has grown around the team. Income was cited by 67 percent of participants, and employment creation was cited by 50 percent. Several participants also emphasized that BSF-derived organic fertilizer outperformed the traditional chemical fertilizer they had used before.

**Each site showed progress on income, but some sites had already generated sales while others were still building toward them while using the larva as feed for own animals and saving on feed costs.** At Dadaab, 63 percent of participants earned project-related income at endline, primarily from produce grown on the 16 m² garden plots. Commercial certification for BSF product sales was still pending, but a January 2026 trade exhibition had already generated confirmed buyer interest from large-scale chicken farmers. Dzaleka was the only site already selling BSF products, including larvae and frass, at endline, with all participants reporting income generation as a current benefit (see also Box 4.2). At Tongogara, knowledge and skills formed the foundation for future income and were the dominant realized benefit, cited by 69 percent of participants. At Chibuwe, 97 percent of participants reported non-project income at endline, up from 43 percent at baseline, a 123 percent increase, with average monthly earnings of US$136.

**Each site expanded the pilot from BSF farming to crop or livestock production.** Frass, the BSF biofertilizer, was the most widely realized agricultural benefit. Garden-plot coverage at Dadaab rose from 40 percent of participants at baseline to 100 percent at endline. Ground-crop cultivation grew at Tongogara and Chibuwe, and Dzaleka's communal demonstration plot supplied vegetables to participants twice per week on average. Frass contributed to realized agricultural benefits: 90 percent of Chibuwe participants, 53 percent of Dadaab participants, and all Dzaleka participants reported fertilizer benefits at endline. Livestock holdings also grew strongly at the Zimbabwe sites. Tongogara holdings rose from 41 to 375 head, a near-tenfold increase, and Chibuwe's chicken count grew by 74 percent, increasing the value of BSF larvae as feed.

**Chibuwe recorded the strongest food-security gains, while the other sites showed more targeted improvements.** At Chibuwe, food consumption improved across all 16 food categories, and total category-days rose by 36 percent. Households reporting 7-day food shortages fell from 17 to 2, an 88 percent decline, and total 30-day livelihood adaptations to manage food insecurity fell by 73 percent. At Tongogara, animal-protein consumption rose by 35 net days, and reliance on borrowing food from friends and relatives declined by 60 percent. At Dzaleka, all households reported positive consumption trends, and none experienced 7-day food shortages at endline. At Dadaab, garden-plot production widened diet diversity, and 30-day livelihood adaptations remained stable.

**Most participants planned to continue BSF farming, and many planned to extend it beyond the project team.** Survey findings show that 99 percent of participants intend to continue BSF farming after the pilot. More than 40 percent plan to continue both within the project team and at their own household. Continuation plans were concrete: participants in Dadaab plan to start household operations alongside teamwork, and participants in Chibuwe plan to do the same. Record keeping was near-universal across sites, and conflict-resolution and teamwork skills were strong. In every project, participants who found teamwork easier than expected outnumbered those who found it harder by at least two to one.

## Enabling factors for gains and prospects for scaling

**Five conditions drove the documented positive impacts across the four pilot sites.** These conditions appear repeatedly across the four sites and account for much of the documented impact. First, BSF was deployed not as a stand-alone enterprise but as the centerpiece of a circular farm system, paired with garden plots at Dadaab, communal vegetable production at Dzaleka, integrated horticulture, aquaculture, and poultry at Tongogara, and intensive livestock at Chibuwe. Participants realized the compounding benefits of frass as biofertilizer and BSFL as feed because they already had crops and livestock that could use them. Second, infrastructure investments matched the operating environment, including 16 m² garden plots in arid Dadaab, climate-controlled containers at the heat-vulnerable Zimbabwe sites, and a demonstration plot for the small Dzaleka cohort. Third, the pilots treated human capital as a primary outcome rather than a by-product. Knowledge, record keeping, conflict resolution, and team management were measured directly and grew strongly at every site. Fourth, market pathways are opening sequentially. Dzaleka has crossed into commercial sales, Dadaab is at the certification threshold with confirmed buyer interest, and Tongogara and Chibuwe have the infrastructure and team maturity to follow. Fifth, participants are committed to BSF production. Ninety-nine percent of participants plan to continue, motivated by income at Dadaab, the prospect of a successful business at Dzaleka and Tongogara, and the enjoyment of the work and benefits at Chibuwe. Together, these conditions show that the pilots proved the concept and produced a replicable evidence base across four different operating environments.

**The four site findings describe a positive case for BSF in refugee and host-community settings.** In arid Dadaab, BSF anchored a productive horticulture system that helped households send children to school. In densely populated Dzaleka, BSF reached commercial sales and helped participants buy food and meet basic needs. In Tongogara, BSF produced integrated agronomic skills and a livestock base ready to absorb BSFL feed. In Chibuwe, BSF supported the strongest food-security improvements in the program. The remaining institutional investments are modest relative to the impacts already documented. These include completing certification at Dadaab, expanding frass uptake at Tongogara, sustaining cross-project learning, and

supporting Chibuwe's scaling. The finding that 99 percent of participants intend to continue BSF farming is a strong sign of sustainability. The conditions for sustained scaled impact are in place.

## 4.3 Beneficiary Testimonies from the Insect Farming Pilot Program

**Participant testimonies show that the BSF pilots affected both livelihoods and daily well-being.** The qualitative assessment found that participants reported impacts across well-being, income, agricultural productivity, and skills. The testimonies illustrate the breadth of effects from an intervention that began as a technical pilot but became a multidimensional livelihood and social platform. The most common shift reported by beneficiaries was a change in self-perception from aid recipient to skilled producer and entrepreneur.

**The BSF sites gave displaced youth a safer place to work, belong, and build identity.** For displaced youth, the project functioned as a source of safety and purpose. Participants reported that the team had become a kind of family that looks out for one another. They also said the site offered an alternative to drugs, alcohol, harassment, and idleness. Several described a shift from sitting idle to having hope that their knowledge and experience would carry them forward.

**BSF-related income helped participants pay school costs, reduce expenses, and start small businesses.** Income came from multiple sources, including waste-collection payments in Kenya, larvae and frass sales, crop and chicken product sales, and savings on agricultural inputs. Participants reported using BSF earnings to pay school fees, substitute self-grown vegetables for purchased ones, open a retail grocery shop, buy pigs, and scale a household poultry flock from 7 to 20 birds. These examples show how modest income streams translated into practical household gains.

**Frass helped participants turn crop production into a stronger income source.** Participants reported that frass improved crop yields and quality. Some said fertilizer use enabled them to earn a living from crop sales. One banana grower described how frass eliminated the black-end disease that had previously prevented the fruit from ripening, allowing the crop to be sold. Beneficiaries also expressed pride in environmental stewardship and in the new culture of structured teamwork.

**Participants began using BSF experience as a professional asset.** One participant linked the work to a long-held aspiration of becoming an agronomist. Another participant, who had previously worked as a waste picker, now aspires to a BSF manager role. Several stated that they intend to develop the activity into a business after the pilot ends. New leadership potential has emerged within teams, and participants who had no prior agricultural experience are now training other farmers, including non-beneficiaries from the host community. Beneficiaries also described broader technical interests beyond BSF itself, including poultry husbandry, fish farming, permaculture, feed formulation, record keeping, and small-business administration.

**Beneficiaries described BSF impacts as linked, gradual, and social as well as economic.** Three observations recur across the testimonies. First, the reported impacts are interlocking rather than sequential. Income enables school fees, which sustain household participation, which in turn supports skill acquisition that opens further income channels. Second, participants experienced the impacts gradually rather than immediately. This contrasts with expectations shaped by short-cycle aid programs and reinforces the importance of clear expectation management at the start of the project. Third, social impacts emerged

alongside economic impacts and were valued by participants in their own right. These included belonging, safety, teamwork, and purpose. In Zimbabwe in particular, the project hub functioned as a protective space against substance abuse, harassment, and gender-based violence in addition to its livelihood role.

## 4.4 Conclusions and Recommendations

### Conclusions

**Three conclusions stand out from the BSF pilot program in Kenya, Malawi, and Zimbabwe.** These conclusions are relevant in a context of rising refugee self-reliance needs, reduced development aid from many high-income countries, climate change, and growing fragility and conflict. First, BSF farming is technically feasible and commercially promising in refugee and host-community settings, as shown by documented production volumes, income generation, frass-driven crop gains, and food-security improvements at all four pilot sites. Second, success depends on tailoring each pilot to its local context, particularly organic-waste availability, climate adaptation, and beneficiary selection based on motivation and entrepreneurial intent, not vulnerability alone. Third, long-term impact and sustainable commercial enterprise require explicit business-model development from the project design stage, so that cost, production, pricing, and market data guide decisions throughout implementation.

**The pilots produced multidimensional impacts across skills, food systems, livelihoods, and social well-being.** Refugees, host communities, and project staff acquired technical expertise across the BSF value chain. Beneficiaries earned income and reinvested it in small businesses, school fees, food, and savings. Participation strengthened a sense of purpose and belonging, with the Zimbabwe hub providing a safer space for youth and helping reduce exposure to substance abuse and harassment. BSF larvae lowered poultry feed costs, and frass improved crop yields and, in arid Dadaab, soil water retention. Across sites, participants moved from aid dependence toward business-oriented thinking. The pilots also showed that scaling is not a single pathway, but can take different forms, including horizontal and vertical expansion, replication-based growth, and household-level production.

**Structured learning helped teams use problem solving at one site to improve practice at others.** Learning evolved through structured training, peer-to-peer exchange, and adaptive responses to local environments. Global insect meetings convened every two weeks by the World Bank Group and UNHCR helped teams review production logs and bottlenecks across the three pilot countries. This structure allowed learning from one site to inform troubleshooting and adaptation in the others.

**The pilots had sufficient infrastructure, but stronger results depended on improving how facilities supported BSF production and farm integration.** Physical infrastructure was a clear strength across all sites, so the principal challenge was not the absence of infrastructure. The challenge was to optimize the facilities, production systems, and operating models already in place. Integrated circular farming, which combines BSF with livestock and crops, made the benefits of BSF visible through lower poultry feed costs, improved growth and egg laying, and better crop yields. This model generated multiple income streams, lowered production costs, and embedded BSF in agricultural practices that participants already understood.

**Beneficiary commitment extended beyond improving incomes and helped build social cohesion.** Commitment was particularly visible among youth and women, even where income remained limited.

Beneficiaries valued learning, food security, sustainability, environmental impact, skills, teamwork, and a sense of purpose. A largely unintended outcome was the creation of safe spaces and belonging, particularly for youth in refugee settlements, with the strongest effect reported in Zimbabwe. Women were especially strong participants in the BSF program, making up 56 percent of beneficiaries across the four sites and 80 percent of the Dadaab cohort, which the pilot deliberately designed for women and low-literacy populations. Women translated BSF and garden-plot income into school fees and household food and used Village Savings and Loan Associations to access credit and strengthen the social cohesion and sense of purpose generated by the program.

**Motivated participants took stronger ownership of the pilots than participants selected mainly for vulnerability.** Beneficiary expectations of compensation, rooted in long-standing aid modalities, required a shift toward enterprise thinking. The selection lesson was consistent across pilots: vulnerability-only criteria produced weaker ownership, while selection was based on motivation, interest, and entrepreneurial potential, while still considering vulnerability, increased commitment and performance. Project continuity also affected momentum. Staff, partner, and participant turnover in Malawi and Zimbabwe disrupted scaling opportunities and weakened institutional memory.

**Climate stress and technical bottlenecks limited BSF production across the sites.** Extreme climate created challenges across the pilots, and each site used a different adaptive response. Kenya used low-tech approaches, including flooded floors and fans. Malawi used air-conditioning units during hot periods. Zimbabwe used climate-controlled containers, although the containers created light-spectrum issues that affected mating. Critical production stages, especially hatching, breeding, and harvesting, remain bottlenecks. The transition from pilot to commercial operation will require stronger technical capacity, production planning, standard operating procedures, quality control, and monitoring.

**The pilots can evolve into independent enterprises only if business management catches up with technical production.** The core question is no longer whether BSF works, but how protected pilots can become resilient, market-oriented enterprises without losing their social, environmental, and development value. This transition requires a shift from a pilot mindset to a business mindset across beneficiaries, project staff, partners, and donors. Business training was done with all four pilot sites. The experience suggests that future projects can protect progress toward financial sustainability by integrating business training and business-model development earlier.

**Three scaling opportunities cut across the pilot sites.** BSF-poultry integration offers the most direct route to internal cost reduction because feed accounts for the largest share of poultry production costs. Frass markets are growing across all three countries, with documented quality premiums on horticultural crops that can be captured through branded products and graded pricing. The pilots have also built reputational capital that can support replication. In Kenya, KEBS certification in process for both dried larvae and frass and a registered facility position Dadaab to enter the commercial poultry market in Garissa. In Zimbabwe, the Government's transition from a camp to an integrated settlement model creates space for expansion into surrounding host-community villages. In Malawi, an active national WhatsApp group of more than 270 members provides a peer network for early replicators. Across sites, the underlying impact mechanism was a circular-economy logic that integrated BSF with poultry, fish, and crop production. Pilots that operationalized this logic earlier, especially Tongogara with its integrated demonstration plots and Dadaab with its emerging permaculture practices, showed faster internalization by beneficiaries than pilots that initially treated BSF as a stand-alone activity.

**Climate volatility and policy constraints will shape what scaled BSF models can achieve.** The El Niño-induced drought in Zimbabwe in 2024 and the heat events that caused colony collapse show that climate volatility will remain a standing operating condition. Political and institutional constraints will also shape commercialization prospects, including encampment policies in Malawi and Zimbabwe and the Shirika Plan in Kenya. These conditions affect what beneficiaries can commercialize, where they can operate, and how far BSF enterprises can scale without institutional support.

## Operational design steps for future BSF production

**This section sets out practical steps for teams designing BSF projects in refugee and vulnerable-population settings.** It is not the report's final recommendations section, which appears in the final chapter and focuses on broader actions for policymakers, IFIs, and development partners. The focus here is project design: how implementation teams can test assumptions, build viable business models, and manage operational risks before committing to larger investments. These site-level steps provide the operational foundation for the report's broader recommendations on substrate security, extension systems, financing, standards, and coordination.

### Design the business model before building the system

**Project teams should phase BSF design so each stage tests assumptions before the next investment.** The project design should follow a sequence of clearly defined phases, each with explicit objectives, assumptions to test, and decision points. Early phases should test the technical feasibility of BSF production in refugee settlements and confirm whether BSF can be farmed under the given conditions. They should also develop a preliminary business model and select and strengthen a committed participant team. Later phases should focus on building production volume, providing advanced training, and strengthening business foundations. Iterative learning cycles allow teams to adjust quickly rather than lock in design choices too early.

**Project teams should prepare a preliminary business case before they select beneficiaries or size the facility.** The business case should draw on a baseline assessment, preliminary market research, waste analysis, and expected operating costs and budget. It can inform decisions on facility size, beneficiary numbers, and complementary models such as decentralized units or household-level kits. Hybrid models that combine a centralized facility with decentralized units could accommodate the same participant numbers with stronger income prospects. Early business modeling should also guide investments in machinery and infrastructure, including whether participants can operate, maintain, and replace equipment after handover and what production and sales volumes are needed for viability. Business strategy is not the same as entrepreneurship training. Implementers and program managers should embed commercial viability in design from the start and co-develop the business model with beneficiaries.

### Select and train participants for enterprise

**Future BSF projects should select beneficiaries for motivation and enterprise interest alongside vulnerability.** The selection lesson is consistent across pilots and should be formalized in future programming. Vulnerability indicators remain valid as a screening filter, but selection should also weigh willingness to participate, time availability, expressed interest, entrepreneurial intent, and trust within the candidate pool. Two design choices supported strong cohorts. In Zimbabwe, recruiting alumni of the 10-week Transformation Innovation Hub entrepreneurship training delivered a youth group with clear roles, ownership, and structured teamwork. In Kenya, an open, demand-driven approach with two kick-off meetings attended by about 120 candidates produced a cohort of 40 self-selected participants with 100 percent retention. Selection and training should be designed and managed as an integrated package, with explicit expectation management on the timing and form of compensation.

**Box 4.3: Example of a 10-point implementation checklist for BSF farming**

1. Conduct BSF awareness sessions, including BSF use as food, feed, and fertilizer.
2. Conduct an organic waste assessment covering types, volumes, seasonality, economics, potential partnerships, transport options, and competing uses.
3. Conduct market scoping to identify local demand for protein, frass, and BSF services, along with competing products and their economics.
4. Design a preliminary business case based on the waste assessment, market scoping, and resources available within the project.
5. Develop a fit-for-purpose farm design based on available funding and the preliminary business model, including the proposed scale of operations, equipment, machinery, and infrastructure.
6. Identify and secure a site within feasible distance of the main waste source, with shade, water, safe storage, and biosecurity, and prepare a modular infrastructure plan.
7. Define the standard operating procedures, including the waste-preprocessing flow, contingency inputs, and triggers for when those inputs are used.
8. Set up a simple data-capture system covering volumes, quality, outputs, sales, and the production protocol.
9. Design and conduct marketing campaigns for products, including outreach to potential frass and larvae offtake partners, demonstration plots, and product sample handouts.
10. Assess business-model performance, review assumptions, and adapt where needed.

Source: Authors.

**Project teams should involve BSF specialists in facility design, waste-flow planning, and technical training from the start.** Capacity building should be layered across partners, government officers, and participants. Training should combine BSF skills with record keeping, agronomy, and entrepreneurship. Demonstration plots should be used as both training and marketing tools because they allow farmers to see

frass performance directly. Box 4.3 turns these early design choices into a 10-point implementation sequence for new BSF projects.

### Build technical systems that fit the site

**Each site should use Standard Operating Procedures and production metrics to stabilize hatching, feeding, harvesting, and climate control.** Each site should adopt a written set of standard operating procedures covering daily, weekly, and monthly activities, fixed substrate ratios per crate, fixed harvest days, and a love-cage turnover schedule. A BSF specialist can help determine the key metrics during a period of production trials under local conditions. Site teams should select climate adaptation measures locally rather than transfer them wholesale from one site to another. Low-cost cooling techniques, including flooded floors, soaked blankets, fans, and shade nets, have proven effective in Kenya at temperatures above 45 degrees Celsius. Air-conditioning units in Malawi and climate-controlled containers in Zimbabwe produced more mixed results, including light-spectrum issues that affected hatching rates.

**Project teams should design facilities that protect BSF production from heat, moisture problems, and weather exposure.** Facility design should include shade, ventilation, and weatherproof drying systems. Teams should adjust substrate moisture to climate because drier environments require wetter feed. Practical operational tools, including crate labeling, batch tracking, and a small set of well-defined key performance indicators, simplify management and reduce reliance on individual staff memory. Transport modalities should match terrain, distance, and repair capacity. Adaptive management should be explicit, including weekly review of indicators, quarterly review of agreements, and annual review of infrastructure and procurement plans.

**Project teams should align procurement with BSF production timing and the facility's actual stage of growth.** Technical specifications for cages, netting, shredders, fermentation units, solar dryers, trays, and storage should be developed early. Purchases should be sequenced gradually rather than committed in large upfront tranches. Procurement cycles should align with BSF biological timing so that equipment is ready when the colony reaches the relevant production phase.

### Develop markets and waste supply together

**Project teams should develop demand while they build production capacity.** Demand-side activities should be planned and resourced in parallel with production and included in business-case development. Specific actions include market characterization studies that identify product types, buyer segments, and required volumes; pricing strategies aligned to client segments and comparable benchmarks, including global average dried-larvae prices of about US$1.00 per kg and Kenyan industrial benchmarks of about KES 130 per kg; and branding and packaging tailored to buyers, including small packs for refugee households, larger commercial bags for poultry farmers, and starter kits for new household producers. Project teams should also pursue product certification, including the KEBS certification process at Dadaab. Demonstration plots can help potential frass buyers see results on familiar crops, while structured outreach can build links with commercial poultry farmers, schools, and other institutional buyers. Project teams should also assess value-chain extension in Dzaleka and Tongogara and adjacent product categories, including liquid frass fertilizer, and pet food channels in Kenya.

**Project teams should diversify waste suppliers and use agreements that clarify roles and accountability.** Supplier diversity across households, schools or public buildings, farms, markets,

slaughterhouses, and mills reduce dependence on any single source. Teams should build redundancy across suppliers and transport options because no single source proved sufficient at any pilot site. Collaboration with research institutions, including Chinhoyi University of Technology and ICIPE, can support frass analysis, feed formulation, and product development. Early government engagement can secure long-term ownership and potential cofinancing, as illustrated by the Government of Zimbabwe's commitment to assume tractor fuel and maintenance costs.

### Plan for governance, financing, and risk

**Implementers should define roles and decision authority before implementation begins.** Delivery structures should balance partner implementation with community engagement and embedded external technical support. Coordination mechanisms should allow rapid response to climate variability, waste fluctuations, and pest pressure. Implementation systems should also be flexible enough to adapt as conditions change.

**Project teams should plan multiyear budgets that cover recurring costs, seasonal variation, and gradual system expansion.** Budgets should cover recurring inputs, including maize bran, fuel, maintenance, and personal protective equipment. They should also cover predictable transport costs, often the costliest operational expenditure, and maintenance of climate-exposed infrastructure. Funds should be available early in the cycle to avoid rushed procurement. A phased investment approach, with equipment procured progressively as the operation matures, reduces the risk of unused or underused equipment.

**Project teams should build BSF sustainability around ownership, waste continuity, technical continuity, and market linkages.** Institutional and community ownership should be built through joint management structures, progressive transfer of operational responsibilities to participants and local institutions, and institutional anchors such as government commitments. Waste-supply continuity should be supported through value-exchange arrangements, such as waste for frass, and through lean-season fermentation and stockpiling that buffer seasonal dips. Technical continuity should rest on documented practices, peer-learning groups, routine coaching, and demonstration plots that anchor knowledge in the community. Market linkages should be supported through branding, packaging, and certification, and through diverse market segments, including poultry, horticulture, and pet food, so that the program is not exposed to a single buyer or use.

**Project teams should manage supply, logistics, quality, and institutional risks explicitly.** Supply risks include competition for waste, seasonal dips, and price spikes for complementary inputs such as maize bran. Logistics risks include fuel availability, vehicle downtime, and transport modes that prove impractical at scale. Quality risks include fluctuating substrate composition, contaminants in slaughterhouse residues, and pest pressure from house flies, fruit flies, and rodents. Institutional risks include staff turnover, weak enforcement of agreements, and funding gaps between cycles. Mitigation requires at least two primary feedstock sources plus one contingency per site; simple fermentation protocols and pest-proof storage; weekly performance indicators covering volumes, rejection rates, moisture, hatch rates, larval growth, and frass sales; and short, written service agreements reviewed quarterly.

# Chapter 5. Recommendations and Ways Forward

The report's final recommendations are for policymakers and institutions that can shape the conditions for responsible BSF scaling in sub-Saharan Africa. The recommendations build on evidence that BSF farming can link three food-system priorities: protein supply, organic waste recovery, and soil fertility. Nearly 300 million Africans face hunger, and the share is rising. BSF larvae convert organic waste into protein-rich biomass for animal feed, while frass creates a potentially high-value soil amendment. The evidence assembled in this report shows that four viable farming models exist and that African conditions favor adoption through tropical warmth, abundant organic waste, rising feed costs, and available labor. It also shows that BSF biology, while well understood in principle, becomes harder to run reliably as operations grow, and remains a frequent point of failure. Sound biology is a precondition for success, not a given, and the level of expertise required rises with the scale and ambition of the operation.

The final recommendations focus on the enabling environment, not day-to-day project implementation. Chapter 2 sets out shared lessons for development programs implementing BSF, and Chapter 4 sets out project design steps for implementation teams working in refugee and vulnerable-population settings. This chapter focuses on actions that governments, IFIs, financial institutions, development partners, and private sector actors can finance, regulate, or co-develop. The eight recommendations target the regulatory, institutional, financing, and knowledge-system gaps that constrain BSF sector development and investment. The recommendations also recognize that some sector-level infrastructure, including evaluation methods for frass, certification pathways, and regulatory advocacy in international forums, is most efficiently developed at the continental level rather than country by country. Where appropriate, the recommendations identify continental-level institutional gaps alongside national ones.

The eight recommendations work as a package rather than a sequence. Regulatory harmonization helps shared processing investments attract private co-financing. Substrate security assessments improve the hit rate of blended finance facilities by screening out proposals built on unrealistic input assumptions. Extension system integration and support for producer associations help ensure that financing reaches operators with the skills and institutional backing to sustain viable enterprises. The report's cross-cutting finding is that BSF farming is not a single model. Household, hybrid, centralized, and vulnerable-population models can each be viable, but each requires different financing, regulatory, training, and risk-management arrangements.

### Recommendation 1:

*Establish a Single Regulatory Pathway for BSF Production and Market Access*

**Gap:**

Fragmented or incomplete regulatory systems prevent many BSF operators from moving into formal feed, food, and fertilizer markets. African evidence already shows the contrast between effective and ineffective regulatory design. Ethiopia and Madagascar demonstrate that coordinated regulatory development is achievable without institutional complexity. Coordination has come from assigning a lead role to an existing authority rather than creating a new BSF-specific agency, which a market of this size would not justify. Single-pathway processes anchored by an existing lead agency given coordinating responsibility, narrow product scope, and formal government endorsement have produced actionable national standards. Kenya's

experience illustrates the cost of the alternative. Fragmented authority across the Kenya Bureau of Standards, Kenya Wildlife Service, and National Environment Management Authority has left most operators in an informal grey zone where compliance is logistically impossible for small and mid-scale producers. A single pathway does not mean a single set of requirements for every operation. The regulatory burden should be tiered to the model and its risk: household and subsistence-scale production, where output is consumed or used on-farm and formal compliance is largely impractical, should be regulated lightly, with basic safety guidance rather than full certification, while commercial producers selling feed, food, or fertilizer into formal markets should meet certification scaled to product risk. Fragmented regulation also leaves a more basic gap unfilled. Because larvae reared on clean and on contaminated substrates are indistinguishable to buyers and priced the same, a sector without quality assurance, contamination testing, and traceability gives producers little incentive to maintain substrate discipline, and invites adulteration and shortcut-taking that a few bad products can use to discredit the whole category. A credible compliance pathway has to make product quality verifiable, not only define what the rules are.

**Actions:**

African governments, with IFI and development partner support, should establish one BSF compliance pathway from production to market. The pathway should be tiered rather than uniform: it should exempt or lightly regulate household and subsistence-scale operations, and concentrate certification and quality-assurance requirements on commercial feed, food, and fertilizer producers, with food-grade production held to the strictest standard and frass standards developed as set out in Recommendation 6. Development partners and IFIs should make regulatory harmonization a standard component of BSF sector development operations and broader food system transformation operations. Technical assistance should support the designation of a lead regulatory authority from among existing agencies rather than the creation of a dedicated BSF body, the preparation of product-specific standards, and the dissemination of requirements in forms that small-scale operators can navigate. The pathway should also include quality-assurance and traceability mechanisms that let buyers and regulators verify what a product is and how it was produced, including substrate qualification and contamination testing scaled to end use and product risk. Because testing capacity is scarce and costly across most African food-safety systems, this verification infrastructure is best developed as a shared public good rather than required of each operator individually. Given the relatively small size of the BSF market, support should favor a lightweight navigation function over new institutions: a designated technician or focal point, housed within the lead agency or the extension system described in Recommendation 2, who helps small producers meet feed, food, and fertilizer requirements across the existing agencies responsible for each. Where regional harmonization is feasible, including within the East African Community or ECOWAS, IFIs should support regionally recognized standards that reduce the compliance burden on cross-border trade. Madagascar's NMG 132-13, the world's first national standard for dried BSF larvae for direct human consumption, demonstrates that regulatory leadership in this space is achievable and confers first-mover credibility.

### Recommendation 2:

*Integrate BSF Technical Training into National Agricultural Extension Systems*

**Gap:**

Most farmers lack the extension support needed to start and sustain BSF production. Farmers across Africa, including in Kenya, Ghana, the DRC, and Niger, consistently show high acceptance once they understand

the technology. Actual adoption rates, however, remain a fraction of willingness-to-adopt estimates because extension contact is the main constraint. Across African countries, empirical survey evidence shows that extension access is among the strongest positive predictors of both willingness to pay for BSF products and willingness to adopt BSF production. The Madagascar Biodiversity Center's sustained facilitation model, which combines local demonstration farms, peer-to-peer learning, and repeated technical follow-up across its network of 266 micro-farms, shows that one-off training is insufficient and that sustained engagement produces more durable operations.

**Actions:**
African governments, with IFI and development partner support, should integrate BSF training into national agricultural extension systems. Governments should embed BSF-specific curricula and technical capacity within existing extension systems rather than rely on parallel project implementation structures that prevent knowledge from becoming institutionalized. Extension workers should be trained not only in BSF biology and husbandry but also in the business disciplines that determine whether farms remain viable after external support phases out, including substrate cost accounting, frass valuation, and market linkages. Programs targeting youth and women's groups as primary extension audiences are likely to generate the highest adoption returns given documented patterns in awareness and uptake by demographic group. Extension should also be diagnostic, not only instructional. Because BSF is viable only under specific conditions, extension workers should be equipped to assess whether a given context suits it, screening for substrate availability and cost, market access, and model fit before encouraging adoption, rather than promoting BSF uniformly. This screening applies the same substrate-security and commercial-viability logic that Recommendation 4 requires before publicly financed BSF investments, at the farmer-advisory level. Extension that promotes BSF without regard to whether local conditions support it risks generating the disappointed adopters that follow when the model is applied where its preconditions are absent.

### Recommendation 3:
*Establish BSF Producer Associations and Coordination Mechanisms Early in Market Development*

**Gap:**
Competition among BSF producers can shift from healthy rivalry to secrecy and misinformation without early coordination. The African evidence documents a consistent pattern: competitive dysfunction, knowledge hoarding, and deliberate misinformation intensify as markets mature, while coordination and open knowledge-sharing are most prevalent in early-stage markets. This creates a time-sensitive window for institutional support that becomes harder to open as sectors develop. Kenya's relatively mature BSF sector exhibits competitive secrecy and documented misinformation among producers, while Uganda's earlier-stage sector maintained far healthier information exchange. Cross-country value chain analysis from Madagascar, Kenya, and Uganda identifies the same institutional gap: capable individual operators exist, but the associations, training networks, shared learning platforms, and financial instruments that translate individual capability into sector capacity are largely absent. The gap is also visible at continental level. North America, Europe, Asia, and Australia each have an industry body, NACIA, IPIFF, AFFIA, and IPAA respectively, that represents producers in regulatory development, coordinates standards, anchors knowledge infrastructure, and speaks for the regional sector in global forums. Africa is the only major region without an equivalent body, and African positions on insect agriculture are currently presented by

individual researchers, donor-funded projects, or international actors speaking on Africa's behalf rather than by an African industry coalition itself. Coordination mechanisms established before competitive dysfunction takes hold are far more effective than remediation efforts in mature markets.

**Actions:**
Governments and development partners should establish BSF producer associations before competitive dysfunction takes hold. Early-stage support should include technical and financial support for producer associations, industry councils, and shared research platforms designed with governance structures that prevent capture by any single commercial interest. Support should include secretariat functions, data collection on production volumes and prices, quality benchmarking among members, and joint representation to regulatory authorities. Research institutions, including ICIPE, IITA, ILRI, and national agricultural universities, could be supported to anchor knowledge-sharing networks that insulate technical learning from competitive dynamics. Alongside national associations, development partners and African institutions should support the formation of a continental BSF industry coalition, structured to federate national bodies and to provide cross-country coordination functions that national associations alone cannot deliver, including regulatory advocacy, standards harmonization, shared evaluation infrastructure, and representation in global forums. The existing African institutional base, including ICIPE, IITA, the Madagascar Biodiversity Center, the African Association of Insect Scientists, and the Africa Circular BUGS Africa initiative, could be federated rather than rebuilt from scratch. Governance should be designed to prevent capture by any single national interest or commercial actor, drawing on the NACIA Foundation and Frass Institute structure as one workable model for separating advocacy from research and evaluation functions. That window is currently open in most African BSF markets, and it narrows as sectors scale.

### Recommendation 4:

*Require Substrate Security, Commercial Viability, and Production-Capability Assessments Before Publicly Financed BSF Investments*

**Gap:**
BSF projects fail when they invest in sites or training before securing reliable, affordable substrate. The evidence on this point is unambiguous. Across EXA Feed's brewery contract in Madagascar, BSF Tamatave's diversified substrate portfolio, and the Jamjang pilot's negotiated waste collection agreements, substrate was secured first in every successful operation. Projects that selected sites and then searched for substrate inverted the operational logic and consistently underperformed. Project planners also need to account for how quickly free or low-cost waste streams can become priced inputs as competing buyers enter the market. Substrate sourced from agro-industrial facilities such as breweries increasingly commands a purchase price as the feed and composting sectors recognize its value. Substrate is not the only precondition that is routinely assumed rather than verified. Reliable production capability is equally decisive and equally often overstated. As the discussion of operator capability in Chapter 2 sets out, projects fail not only on substrate and markets but on the biology itself: operations that have never closed a production cycle, ventures where prior funding or recognition is mistaken for demonstrated capability, and consultants whose own training does not meet the demands of commercial BSF production. A project can secure its substrate and still collapse if no one involved can run the colony reliably at the intended scale.

**Actions:**

Governments and development partners should screen BSF investments for substrate security and commercial viability before financing. Substrate security assessments should become a formal screening criterion for publicly financed BSF investments, with analytical rigor equivalent to market feasibility assessments required for other agri-food investments. Assessments should document the volume of available substrate, its farm-gate cost under current and competitive market conditions, the reliability of supply across seasonal and market cycles, and the logistics cost of collection and transport. Substrate-security assessments should be paired with a preliminary business case that defines break-even and minimum-viable-production thresholds, benchmarks pricing against locally available alternatives, and estimates how many operators a given facility can support as profitable enterprises. For larger commercial investments, screening should extend to production capability. Financing for hybrid and centralized operations should be conditional on demonstrated biological capability, evidenced by a completed production cycle with documented yields rather than by prior funding, reputation, or a training certificate alone, and on a credible plan to retain technical staff through the vulnerable mid-implementation period when key personnel often depart. This condition is calibrated to scale and model. It applies most stringently to the capital-intensive centralized model, where a colony failure is an existential event, and it does not apply to vulnerable-population projects, where building production capability from a low base is part of the funded objective rather than a precondition. For those projects, the equivalent safeguard is a realistic capability-building plan, including sustained mentoring and the early recruitment of production expertise, as the Jamjang pilot's experience indicates. Substrate security, commercial viability, and, for larger operations, production capability should be clear before infrastructure or training commitments are made.

## Recommendation 5:

*Select BSF Operators Based on their Motivation Not Vulnerability*

**Gap:**

BSF projects underperform when participants are selected for vulnerability rather than motivation. Across the African evidence base, the operators who succeed in BSF are those who actively chose it, not those who were chosen for it. Selecting participants on the basis of vulnerability or need alone, without screening for genuine interest, motivation, and a realistic time horizon, consistently produces poor outcomes. Beneficiaries expect quick returns, disengage when profits do not materialize, and treat the operation as a transfer rather than a business. The four-country pilot evidence assembled by the World Bank and UNHCR in Kenya, Malawi, Zimbabwe, and South Sudan documents this directly. The Dzaleka pilot in Malawi dismantled its first cohort after eighteen months due to limited interest and weak ownership, then recovered durability after shifting to interest-based selection. The Dadaab pilot in Kenya adopted an open, demand-driven self-selection model. Two kick-off meetings drew approximately 120 candidates and produced a cohort of 40 self-selected participants with 100 percent retention. The Zimbabwe pilots recruited from alumni of an entrepreneurship training program, producing youth groups with clear roles and structural teamwork. The selection lesson is consistent across pilots: vulnerability indicators remain valid as one screening filter, but selection should weigh willingness to participate, time availability, expressed interest, entrepreneurial intent, and trust within the candidate pool. Operator selection is upstream of every subsequent design decision; substrate, infrastructure, financing, and extension all underperform when the operators running them did not choose to be there.

**Actions:**
Governments and development partners should screen for motivated BSF operators within each target group. Selection criteria should be embedded in project documents and participant-selection protocols rather than addressed at the implementation stage. Selection processes should combine open expression-of-interest mechanisms with screening for time availability, prior interest in agricultural enterprise, and realistic understanding of BSF's multi-cycle learning curve. Selection and training should be designed and managed as an integrated package, with explicit expectation management on the timing and form of compensation. Where programs target vulnerable populations as a policy objective, motivation-based screening should be applied within that target population rather than treated as a competing criterion. The household, hybrid, centralized, and vulnerable-population models each impose different demands on operator profile, and screening criteria should be matched to the model the project is supporting.

### Recommendation 6:
*Develop National Standards for BSF Frass as a Commercial Soil Amendment*

**Gap:**
BSF frass can determine whether BSF enterprises are profitable, but most markets lack standards to sell it as a premium product. Frass, the residual organic matter from BSF bioconversion, is not simply a by-product to be managed. Field evidence across Africa consistently identifies it as a revenue stream that can determine whether BSF enterprises are commercially viable. Producers, however, lack quality reference points, and off-takers lack procurement specifications because frass remains almost entirely unregulated and unstandardized in most African markets. The economic case for frass standardization is compelling. Survey data from 373 Kenyan BSF farmers shows that enterprises selling larvae alone generated negative returns on investment, while the combined larvae-and-frass enterprise yielded a 51 percent gross profit margin and a positive benefit-cost ratio. At BSF Tamatave in Madagascar, pelletized frass margins of 92.5 percent and bulk frass margins of 97.8 percent were the highest in the entire product portfolio, far exceeding the margins on processed larval products. Frass's agronomic performance in African field trials matches or exceeds comparable mineral fertilizer inputs when appropriately composted, and substrate amendment with sawdust or biochar can improve nitrogen and phosphorus retention substantially. Despite this evidence, the absence of national standards creates a regulatory vacuum that suppresses the premium pricing BSF frass can command relative to unprocessed compost.

**Actions:**
Governments and development partners should support the development of the scientific and regulatory infrastructure that frass markets require, in three sequenced stages. First, establish standardized testing methods and comparable datasets for frass quality across substrates and processing pathways, building on the work of bodies such as the NACIA Frass Institute and African research institutions. Second, develop tiered product categories that allow buyers to discriminate between frass types (composted versus fresh; agro-industrial substrate versus mixed waste) without imposing uniform compliance. Third, establish certification and labeling pathways accessible to small producers. Formal regulatory standards for product safety and trade can follow once the evidence base supports them. Premature standardization, in advance of the underlying science, risks either excluding small-holder production or codifying specifications the evidence cannot yet support.

**Recommendation 7:**

*Establish Blended Finance Facilities that Match BSF Cash-Flow Realities*

**Gap:**

Standard loans do not work well for BSF farming because operators must repay the loan before operations are stable and profitable. BSF operations require a multi-month learning phase before biological protocols stabilize and reliable revenue begins. Standard microcredit products, with short tenors, immediate repayment obligations, and no grace periods, impose debt service burdens at the stage when operators generate the least cash. Capital-intensive operations also require upfront investments in drying infrastructure, climate-controlled breeding facilities, and, in off-grid settings, renewable energy systems. These assets reduce operational risk but add to front-loaded capital needs. The absence of financing instruments designed around these cash-flow realities constrains sector growth. The appropriate instrument also differs by model. Credit suits the hybrid and centralized models, where external capital becomes genuinely relevant and assets can secure it; it is the wrong tool for the household model, which is typically self-financing and where loans risk creating dependency rather than capability; and the vulnerable-population model depends on grant and donor finance through its setup phase rather than credit it cannot yet service. A single financing instrument applied across all four models would systematically misallocate support.

**Actions:**

Banks, governments, and IFIs should structure BSF finance around the time operators need to stabilize production. Finance should be matched to the model rather than offered as a single product. Household operations are best supported through training and market linkage rather than credit; vulnerable-population operations through grants that fund the setup and training phase and are bridged toward a business model before donor exit; and hybrid and centralized operations through patient blended credit sized to their longer horizons and formal risk profiles. BSF Tamatave in Madagascar illustrates this sequencing: it self-financed its early-stage growth from reinvested revenue, took on modest staged repayable funding (US$5,000, then US$15,000) only once its biology was proven, and drew separate grant support for its public-good training function rather than for its commercial core, matching each instrument to the stage and purpose rather than applying one form of finance throughout. World Bank Group instruments, including the International Finance Corporation's blended finance windows, Development Policy Financing linked to sector reforms, and Project-Based Guarantees, are well positioned to catalyze commercial bank participation on terms aligned to BSF realities. Credit lines should have tenors of three to five years, grace periods of six to twelve months, and performance milestones tied to biological benchmarks, including cycle-on-cycle larval yield improvement and substrate conversion ratios, rather than revenue alone. Where operations generate verifiable climate co-benefits through waste diversion or methane reduction, carbon-credit revenue can serve as a credit-subsidy or first-loss mechanism that improves financing terms, particularly for waste-management-oriented operations, though on the evidence standard set out in Recommendation 8 such revenue should be treated as contingent in the business case rather than assumed. Financing should be conditional on a preliminary business case meeting the analytical standards described in Recommendation 4. Patient capital is warranted when operators demonstrate disciplined learning against measurable benchmarks. Financing that absorbs poor performance without that discipline is misallocated regardless of how the instrument is structured. Blended finance facilities can absorb first-loss risk and crowd in private capital at scale when they are linked to disciplined performance benchmarks.

**Recommendation 8:**

*Match Environmental Claims to the African Evidence Base and Build the Data Foundation for African BSF Assessment*

**Gap:**

The environmental case for BSF in Africa rests largely on evidence drawn from elsewhere. The largest life cycle assessments model temperate systems, whose energy mixes, supply chains, ambient temperatures, and processing scales do not represent Sub-Saharan African operations, and they show that BSF's environmental performance depends heavily on conditions. The handful of African assessments that exist all model small or research-scale operations, and where they find insect meal performing poorly, they attribute it largely to coal-heavy grid electricity and small-scale processing inefficiency, the conditions a well-located operation is best able to change. A smaller penalty comes from the biology rather than the conditions: most of the substrate's mass is lost in conversion, and even an operation on clean energy and genuine waste still carries it. No assessment exists of an African operation at full commercial scale on low-carbon energy, and the larger, apparently successful African producers that could anchor one have not been studied. The risk is that climate-finance eligibility, including carbon credits monetizing diversion or methane-reduction benefits, is claimed on evidence the African context does not yet support, exposing programs to misallocated finance and to reputational risk if independent assessments later fail to confirm the assumed benefits. The same proportionality problem runs in the opposite direction on biodiversity. Invasion-risk research has identified insect farming as a pathway for biological invasion, but that literature is calibrated to regions where BSF would be a novel introduction, and across most of sub-Saharan Africa, where BSF has been naturalized for decades, mass rearing does not introduce a species into an ecosystem that lacks it. Applying the novel-invasion standard uncritically could deny smallholders documented livelihood and nutrition benefits to guard against a risk the setting does not carry. The risks that do remain are narrower and governed by strain provenance: escapes from imported, farm-selected strains can introgress into local wild populations and can carry pathogens the local system has not encountered and rearing locally sourced BSF rather than importing exotic domesticated strains is the cheapest precaution against both.

**Actions:**

Development partners and IFIs should take a staged approach proportionate to the evidence rather than treat a completed LCA as an immediate precondition. In the near term, climate benefits should be presented as plausible but unverified, and any carbon-credit revenue in BSF business cases treated as contingent. Because commercial-scale operations already exist but go unassessed, the priority is to create the incentive to assess them: development partners can make data contribution and independent environmental assessment a condition of public co-financing, technical support, or carbon-finance facilitation, and can fund the assessment itself, so that representative operations are studied rather than left as gaps. Publicly financed operations should likewise collect the primary data an LCA depends on, including energy use, substrate flows, yields, and processing inputs, as a routine condition of financing, building on the benchmarking and viability screening recommended elsewhere in this chapter. As an independent evidence base accumulates, development partners, IFIs, and research institutions should commission purpose-designed assessments of representative African operations, specifying genuine-waste substrate, local energy, tropical conditions, realistic scale, transparent co-product allocation assumptions, concrete soy and

fishmeal comparators, and the composting or anaerobic-digestion counterfactual against which any diversion benefit is claimed. Because such an evidence base is non-trivial and costly to produce, its methods and datasets are best developed as shared continental infrastructure, for which the coordination body in Recommendation 3 is a natural host. On biodiversity, the compliance pathway in Recommendation 1 should treat strain provenance as the primary control, requiring commercial operations to rear locally sourced BSF, verify species identity at colony establishment, and obtain specific authorization before importing exotic domesticated strains. Containment appropriate to scale and basic colony-health management should be standard at all scales, delivered through the extension systems in Recommendation 2 and the producer associations in Recommendation 3 rather than through facility-level regulation alone.