Nature-Positive Solutions

Training Manual

INITIATIVE ON
Nature-Positive Solutions

Black Soldier Fly Farming for Feed and Biofertilizer: A Practical Guide

Noah Adamtey, Elijah Badu, Nicholas Ayimba, Fredrick Kimathi, and Solomie Gebrezgabher

February 2024

Acknowledgments

This work was carried out under the CGIAR Initiative on Nature-Positive Solutions, the CGIAR Initiative on West and Central African Food Systems Transformation, and the CGIAR initiative on Resilient Cities. We would like to thank all funders who support this research through their contributions to the CGIAR Trust Fund (www.cgiar.org/funders).

The Authors

Noah Adamtey, Senior Researcher – Resource Recovery and Agri-food System Expert, International Water Management Institute (IWMI), Accra, Ghana; **Elijah Badu**, Postgraduate student, Department of Crop Science, University of Ghana, Accra, Ghana; **Nicholas Ayimba**, Collaboration Partner Bondo Community Development Programme, Nairobi, Kenya; **Fredrick Kimathi**, Director, Protein Masters, Nairobi, Kenya; **Solomie Gebrezgabher**, Senior Researcher - Economics, International Water Management Institute (IWMI), Accra, Ghana.

Suggested Citation: Adamtey, N.; Badu, E.; Ayimba, N.; Kimathi, F.; Gebrezgabher, S. 2024. *Black soldier fly farming for feed and biofertilizer: a practical guide*. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Initiative on Nature-Positive Solutions. 50p.

Front cover photograph: Freepik | image by @freepik

About the CGIAR Initiative on Nature-Positive Solutions

The CGIAR Initiative on Nature-Positive Solutions aims to re-imagine, co-create, and implement nature-positive solutions-based agrifood systems that equitably support food and livelihoods while ensuring that agriculture is a net positive contributor to biodiversity and nature. https://on.cgiar.org/3rHjbRO

About the Guide

The aim of this guide is to facilitate the utilization of Black Soldier Fly (BSF) as an alternative protein and fertilizer source, contributing to employment generation and poverty reduction. It is designed to support farmers, small and medium enterprises (SMEs), Extension Agents, and other stakeholders in acquiring the necessary knowledge and skills to engage in BSF farming as a viable business opportunity. Serving as an all-encompassing guide, it systematically outlines the 'how' and 'why' behind each stage of the BSF production cycle, starting from initial startup (point zero) to the successful harvesting phase. The manual also delves into the science of BSF farming, elucidates the steps for establishment, covers best practices, and provides insights into potential challenges within the production chain, along with strategies for ensuring the sustainability of the BSF enterprise.

CGIAR Initiative on Nature-Positive Solutions (NATURE+)

NATURE+ is part of CGIAR's research portfolio that focuses on bringing environmentally friendly strategies to farmers in Burkina Faso, Colombia, Kenya, India, and Vietnam. Actions include increasing agricultural biodiversity on farmland (including more native crops and trees), improving water and soil management, and transforming biowaste into fertilizer, animal feed and energy, among others. The initiative aims to reverse natural resource depletion, enhance biodiversity, mitigate climate change impacts on farms, and augment food and nutrition security. Collaborating directly with farmers and communities is key to the NATURE+ initiative. By working closely with policymakers and influential stakeholders, the initiative aims to establish a comprehensive framework of incentives that not only encourages the widespread adoption of nature-positive practices but also facilitates the development of necessary skills and knowledge among individuals and communities. This approach empowers farmers and communities to actively participate in and contribute to the long-term success of sustainable practices.

CONTENTS

Chapter 1

Introduction

1. Background

In the face of escalating global challenges related to food waste, high feed cost and fertilizer scarcity, and unsustainable agricultural practices, the need for innovative solutions has become more pressing than ever. Approximately 30–40% of today's food production is lost or wasted along the production chain, forming a significant part of the global food waste generated annually (FAO, 2023; Zhu et al., 2023).

This mismanagement can pose a threat to the environment and pollute water bodies. There are significant increases in global demand for livestock products and by 2050 this is expected to increase by 60-70%, especially in developing countries (Makkar, 2018). This will clearly require increasing amounts of feed protein supplies to satisfy the growth in the human population.

Conventional means of producing livestock and poultry, particularly in developing countries, is challenged with high prices for animal feed, where protein costs alone can account for a substantial portion of the production expenses. For instance, the cost of chicken feed is around 60-70% of total production costs, while for pigs, this figure rises to around 80% (Amaral, 2023). There is therefore the need to look for alternatives sources of protein for feeding livestock.

Black Soldier Fly (BSF) larvae farming emerges as a beacon of hope, offering a multifaceted solution that addresses the negative impact of food waste on the environment and tackles the high cost of animal feed in the agricultural sector. Aside conversion of food waste, the production of BSF-based feeds exhibits a lower environmental impact compared to conventional livestock feed production. BSF is also reported to reduce greenhouse gas emissions. BSF solution promotes a circular economy principle and mitigates threats to public health and the environment.

In view of the above advantages, there is growing interest among farmers in using BSF technology to revolutionize the agricultural landscape and food systems. However, like any other technology, BSF farming also demands specialized knowledge and skills. Recognizing this need, it becomes imperative to provide a comprehensive guide and manual to assist not only aspiring BSF farmers but also to offer a brief overview of the BSF production process for other stakeholders, including investors, and decision makers.

Chapter 2

Understanding the Science of the BSF: Origin, lifecycle, description

2.1 Biology, origin, and classification

- The Black Soldier Fly, scientifically referred to as Hermetia illucens belongs to the class Insecta, order Diptera (true flies with two wings), and the family Stratiomyidae (soldier flies).
- BSF are prevalent in tropical regions, with their origin traced back to South America. Human influence has facilitated their spread to other tropical and sub-tropical regions.
- BSFs thrive in warm conditions. The survival and growth peak are at 27°C with the upper limit for BSF development falling between 30 and 36°C (Tomberlin et al. 2009; Chalermliamthong et al., 2023).
- BSFL can tolerate a range from 30 to 90% relative humidity (Sheppard et al. , 2002; Chalermliamthong et al., 2023), with the optimal range being 50 to 70% (Barry, 2004; Chalermliamthong et al., 2023).
- Unlike houseflies, BSFs are not pests as they neither bite, sting, nor transmit zoonotic diseases (infections that are spread between people and animals).
- Known for their adaptability, BSFs quickly adjust to diverse environments.
- By nature, the BSF is attracted to any place with organic waste and can decompose any kind of organic waste irrespective of the form. It is this nature of the fly that humans have leverages on and adopted in farming the insect.
- The BSF exhibits voracious appetites (i.e., like to eat a lot), consuming decomposing fruits, vegetables, and various types of animal manure.

2.2 Description of life cycle

The Black Soldier Fly (BSF) undergoes a life cycle consisting of five distinct stages: egg, larva, prepupa, pupa, and adult, spanning a total duration of about 44 days.

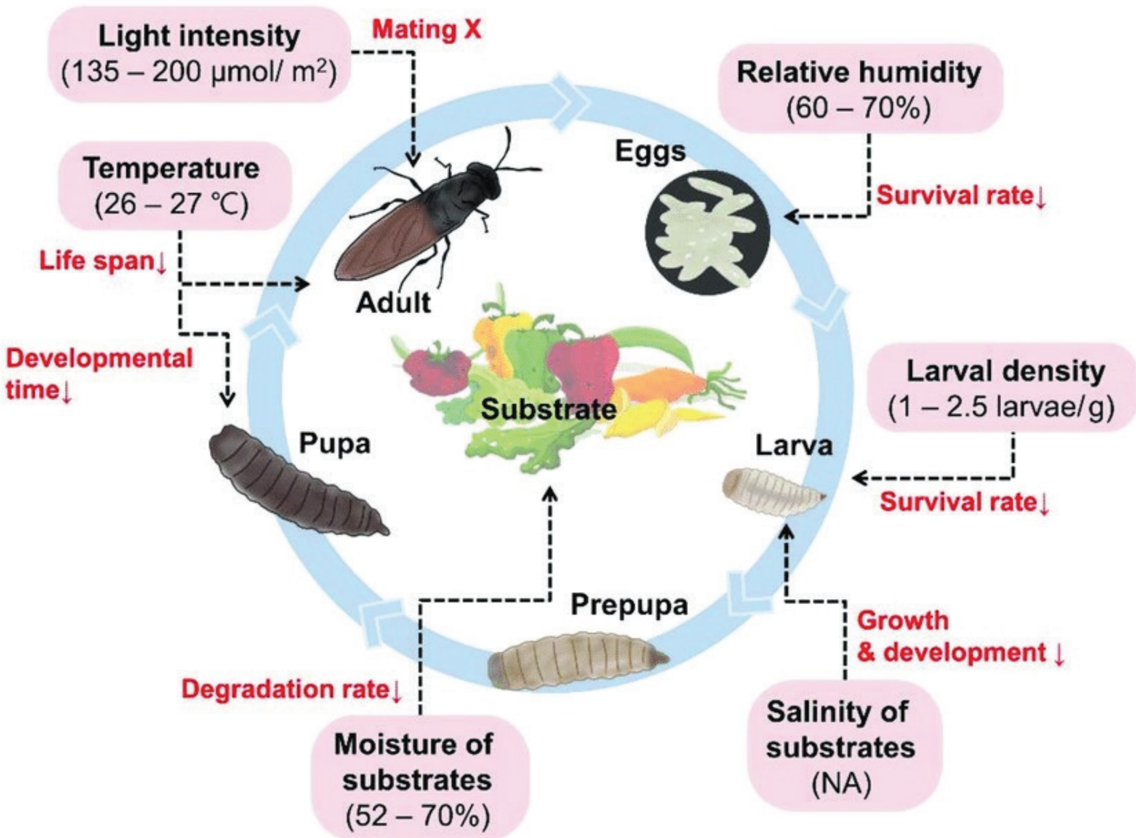


Figure 1: Life cycle of the BSF. Adopted from (Kim et al., 2021)

- Adult Stage: The adult BSF resembles a wasp, measuring between 15 and 20 millimeters in length. It does not possess a mouth and, consequently, does not engage in feeding. The flies have a distinctive buzzing sound during flight, often causing confusion with wasps. Typically, males emerge first from the pupa casing, with females following two days later. Mating occurs after an additional two days, leading to oviposition (egg-laying). Adult flies deposit eggs in dry crevices near decomposing organic matter. The insect is capable of laying eggs multiple times during its life cycle with an average of 206 to 639 eggs per time (Sonal, 2022).
- Egg Stage: Eggs hatch approximately four days after deposition, giving rise to larvae. Optimal hatchability requires temperatures ranging from 27 to 34°C and relative humidity between 60–70%. Lower temperatures below 27°C can hinder hatchability.
- Larval Stage: White in color, the larvae undergo five developmental stages known as first, second, third, fourth and fifth instars, feeding on organic waste over a span of 13 to 18 days (Figure 2). As they progress, the larvae molt their exoskeleton between instar 5 and prepupae. BSF larvae biomass is rich in protein, amino acids, fat, vitamins, and minerals. Dried larvae contain 37 to 63% protein and 7 to 28% fat, making them a valuable resource for farmers (Barragan-Fonesca et al. , 2017; Zulkifli et al. , 2022). The larvae exhibit remarkable resilience to variations in environmental conditions, thriving in diverse conditions such as temperature and humidity. Larvae grow slower and larger in cooler temperatures, whereas warmer temperatures result in faster growth but smaller size.
- Prepupal and Pupal Stages: White in color, the larvae undergo five developmental stages known as first, second, third, fourth and fifth instars, feeding on organic waste over a span of 13 to 18 days (Figure 2). As they progress, the larvae molt their exoskeleton between instar 5 and prepupae. BSF larvae biomass is rich in protein, amino acids, fat, vitamins, and minerals. Dried larvae contain 37 to 63% protein and 7 to 28% fat, making them a valuable resource for farmers. The larvae exhibit remarkable resilience to variations in environmental conditions, thriving in diverse conditions such as temperature and humidity. Larvae grow slower and larger in cooler temperatures, whereas warmer temperatures result in faster growth but smaller size.

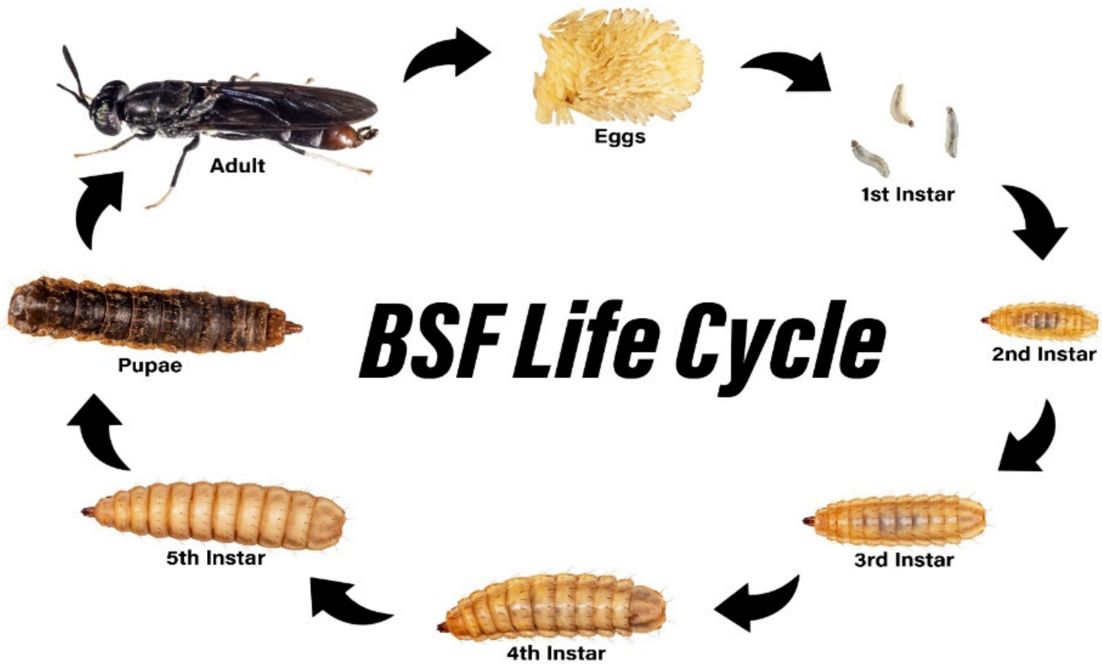


Figure 2: BSF life cycle showing the larvae stage from instar and pupa (Terrell and Ingwell, 2022)

Chapter 3

Requirements for BSF farming

3.1 Things to Consider for a BSF Facility Establishment

There is the need to provide an environment that best mimics the natural habitat of the BSF. Therefore, site conditions are among the major factors that determine the success and sustainability of the BSF enterprise. The following should be taken into consideration when selecting the site for a BSF processing facility:

- Capital is required. Capital refer to funds that are invested in resources to run the BSF project for example to buy all necessary tool, equipment and containers for production or even hire land.
- Sources of organic waste. The closer the facility is to the source of waste, the lesser is the need for transport and logistics of waste sourcing.
- Availability of sufficient fresh organic waste in huge amounts and on a regular basis at a low cost.
- Routes for delivery and pickup of waste should be well maintained and easily accessible throughout the year.
- Densely populated neighborhoods and areas where adjacent land users may find a waste processing facility inappropriate should be avoided.
- Access to water and electricity supply and wastewater management systems.
- Adequate environmental buffers that separate the facility from the surroundings should be maintained (e.g., open areas, trees, fences, etc.).
- Flat land is preferably the best because the larvae tend to flow by gravity and escape from the rearing trays/crates/troughs.
- The facility should be preferably located downwind from the residential areas.
- For a concrete floor building, you should keep a minimum of 250m^2 of floor space in mind, with a maximum of 400m^2 and a minimum of 50m^2.
- The facility should be enclosed but well-ventilated and should allow sunlight in especially to the love cage areas.
- Space is needed for office and laboratory establishment.
- Toilet and hygiene facilities should be provided.
- Accessibility to market. The closer the facility is to the customers, the easier it is to maintain suitable market channels and enhance customer relationships while reducing transport costs.

3.2 Construction of BSF facility

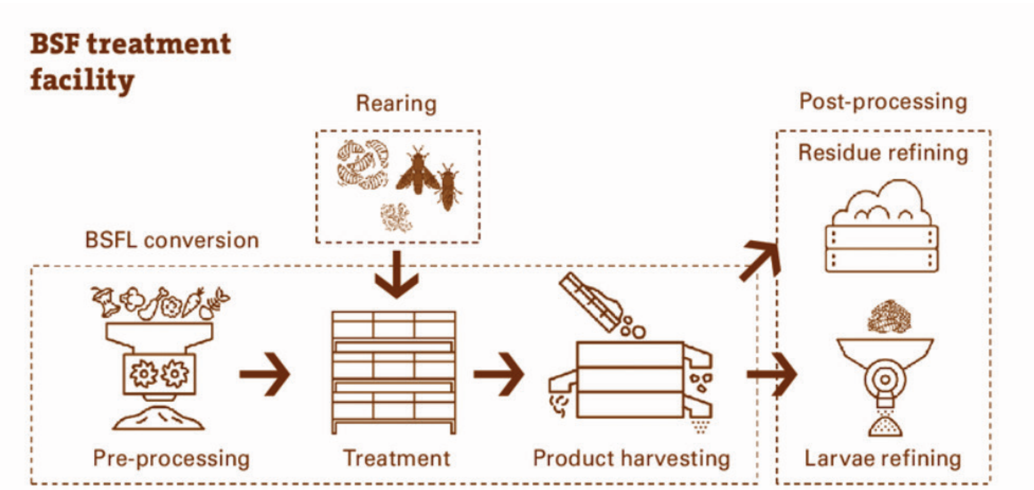


Figure 3: Schematic diagram of BSF facility at a glance

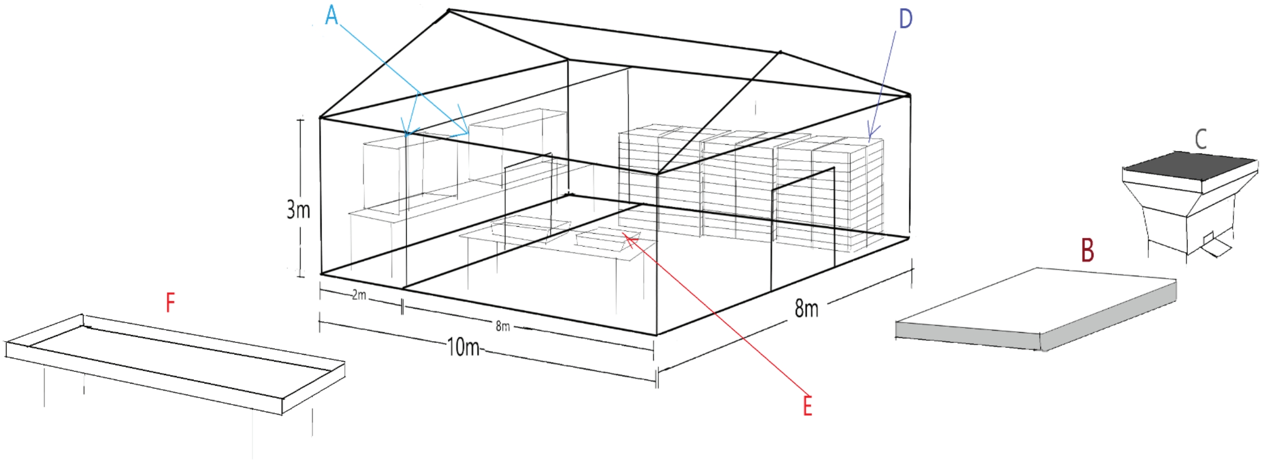


Figure 4: Plan of BSF facility showing (A) Love Cages (BSF Rearing Unit); (B) Raised Concrete Slab (Waste receiving Unit); (C) Hammer Mill (Pre-Processing Unit); (D) Metal racks & Crates (Pre-Processing Unit); (E) Trays and Sieve (Product harvesting unit); and (F) Post-treatment unit (larvae refining and residue processing)

a. *BSF mating unit:* This unit comprises of love cages (Figure 5A). The primary goal of this unit is for reproduction by creating a conducive environment for mating and laying. This step is crucial to ensure steady supply of eggs to hatch into larvae to guarantee continuous treatment of the daily bio-waste at the facility.

Figure 5: BSF rearing unit

b. *Waste receiving and pre-processing unit:* The waste receiving unit consists of a concrete slab (Figure 6A and 6B). The size is dependent on the intendent scale of operation. The concrete slab should be raised above the ground. It is critical that the waste received at the facility is suitable for feeding to the larvae. This step involves controlling of the waste to ensure that there are no hazardous materials like pharmaceuticals, pesticides and inorganic substances like paints solvents and household cleaners in the waste. The pre-processing unit consists of a hammer mill (Figure 4C and 5 b). At this stage, the substrates are fed into the hammer mill to shred or crush aggregate material into smaller particles. The waste if it has too high moisture content should be dewatered under a shade. Uncaptured inorganic waste should be removed, thereafter the different waste can be blended to create a suitable balanced diet and moisture content of 70-80% for the larvae.

c. *Bioconversion /waste treatment unit:* This unit is dedicated to the growth and development of the larvae, the larvae convert nutrients in pretreated bio-waste into its biomass leaving behind residue (known frass).

Figure 6a: Waste receiving unit

Figure 6b: Waste treatment mill

d. Product harvesting unit: This unit consists of mesh-like sieves and a basin / trays (Figure 4E and 7a-c). Shortly before turning into prepupae, the larvae are harvested from the larveros. The waste residue itself is also a product of value that is taken out.

A B C

Figure 7a-c: Waste harvesting units

e. Post processing unit: This unit consists of a solar dryer (a fruit solar dryer can also be used, Figure 8). At this stage, both products, larvae, and residue, can be further processed if required by the local market demand. This is called "product refining". Typically, a first step will be to kill the larvae using the eco-friendly method of drying using solar while still maintaining nutrients. Other steps of larvae refinement include freezing or drying the larvae, or separating larvae oil from larvae protein. A typical step for residue refinement is composting or feeding the residue into a biogas digester for fuel production.

Figure 8: Fruit Solar dryer

3.3 Setting Up Love/Adult Cage

The following items are required for a successful setting of love or adult cage (Figure 9).

• Cage frame	• Water containers for BSF
• Net	• Cotton wool/cotton cloth
• Pupa	• Water spray bottle
• Smelly substrate	• Water container placed on the legs of the cage frame.
• Eggies	• Good ventilation and good area with natural light

Cage frame: The cage frame can be done either using wood frame or metal frame and measurement depends on the size of the area. For example, a 4ft * 4ft * 4ft or 4ft * 6ft *4ft can be done but remember these measurements are just to give a guidance. Alternatively a walk-in love cage can be done, in which case there is a need to ensure that the floor is cemented to avoid foreign/unwanted insects getting access. Furthermore, ensure that there is no introduction of any insecticide in the love cage even if there are unwanted insects crawling in. In such instances, use clean water at where the insects find access and wash them away.

Figure 9: Cage frame and walk in love cage (Source: World Economic Forum)

Net: For the net, No. 04 size of insect net can be used or even use the normal mosquito net if it is **not treated**, because if it is treated the flies will die, as this is organic farming. The size of the net will be determined by the size of the frame. For a 4ft * 4ft * 3ft frame 11 meters of insect net is needed. Other things to bear in mind is to have one side of the net to have an opening to be able to give access to putting the pupa, smelly substrate, water containers and eggies inside the love cage. The colour of the net does not matter so much but preferably white will be good to be able to tell well when it gets dirty, and can be removed and washed. It is important to wash the love cage net once it gets dirty to allow flies to be in a clean area and not affected by the excretions excreted by the flies around the net, as it might have some bacteria in them.

Pupa: BSF larvae have seven stages which are instar 1, 2, 3, 4, 5 (Figure 2). Insta 5 has high protein levels and is good for feeding to chicken, fish and other livestock. From 1st to 5th instar the color is **beige**. Then from instar 5 to **pre-pupa** and **pupa**, these are **black** in color. The difference between pre-pupa and the pupa though both are black in color is that the **pre-pupa** is still **mobile**, and the pupa has no **mobility**, its **back is bent** and does not feed. when you look at a pupa you might think it's dead but not, but it's where the BSF is about to pupate from. You can even pick the pre-pupa and pupa together and put them in the cage even if you leave the pre-pupa in the food with the rest of the larvae it does not feed.

Smelly substrate: Smelly substrate is something that has a very bad smell that is used to give direction to where the female BSF should lay its eggs. Remember one female is able to lay between 500-900 eggs. If there is no smelly substrate, then female BSF will lay her eggs on the net or any other place inside the cage which makes it difficult to harvest. The life span of BSF is between 7-14 days then it dies but it is possible to prolong the life span of the fly to around 20 days and it can lay an extra eggs. Once the flies die, they are not thrown away, but they are still nutritious food for the chicken. The smelly substrate can either be **fish intestine, rotten meat, chicken droppings** that have been soaked in water and then let to ferment for 14 days or any other waste that is smelly. Then you cover it with a net. Other smelly substrates that can be used include millet porridge mash, pig manure, and fermented fruit or sliced rotten fruit.

Eggies: These are materials that are used to harvest the BSF eggs, and they can be either:

a. Conduits
b. Pieces of small cutting of a carton
c. Pieces of 15cm length by 3cm width sanded wood. (Three pieces of the wood are then joined together with a rubber band.) These are placed on top of the net which holds the smelly substrate so that when the female fly comes to lay her eggs they can lay in between the small spaces on the wood which are the size of a small crack or the carton pieces and conduits.

A

B

C

Figure 10: Conduits (A), wooden (B) and carboard (C) eggies

Water container: These are plastic containers that are placed inside the love cage, filled with water for the black soldier flies to consume. It is important to highlight that no food is supplied in the love cage during this phase as, the flies, although not feeding, rely on their fat reserves andand water for sustenance. Since black soldier flies are poor swimmers, when adding water in the containers, it should be the same level as the cotton wool or cotton cloth placed inside the container. This allows the flies to suck the water from the cotton material without the ability to swim.

Figure 11: Water container with cotton wool/cloth

Cotton wool / cotton cloth: This is placed inside the water containers (Figure 11) to help the flies not to drown because they are poor swimmers and yet they still need water to live long. These cotton woold need to change regularly when they get dirty..

Water spray bottle: This helps to spray round the love cage net to allow the flies to drink water apart from the water containers. The water that is sprayed on the net also helps in raising the humidity which also helps the BSF to be productive.

Water containers placed on the legs of the cage frame: This is to help the rodents and other foreign insects entering the love cage. It is important to highlight that the love cage should be protected at all costs as that is the core of BSFL farming.

Good ventilation and good area with natural light: BSF thrive well in a place that has good ventilation and also has good natural light. A place that has around 25-37 °C would be favorable to the flies and also with a humidity of between 50-80% Three to four protective clothing and other essentials are also required.

Personal Protective Items: Prioritize the safety and hygiene of personnel by providing necessary equipment, including gumboots, gloves, and overalls (Figure 12a-b). The usage of the mentioned items are essential for those working within the unit to prevent contamination of the working environment.

Digital Weighing Scales: Utilize digital weighing scales for precision in measuring both eggs and juvenile larvae. There is also the need to have a separate scale for weighing substrates and larvae before and after harvest to accurately monitor growth.

Figure 12A: Goggles

Figure 12B: Overall dress

Figure 12C: Digital weighing scale

Record-Keeping Materials: Maintain organized records with at least three dedicated books for substrate delivery, egg collection/harvest, and larvae harvest. Use writing pens and marker pens for clear documentation.

Soap and Disinfectant: Ensure an ample supply of soap and detergent for thorough cleaning of personnel, equipment, and tools. Use these for disinfecting crates, nets, and other relevant items to uphold hygiene standards.

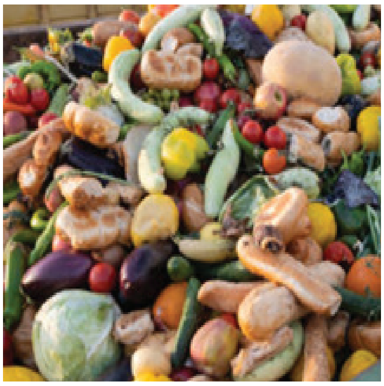
Tools: Shredder, hand fork, cutlass, sieve , dryers, etc.

Chapter 4

Substrates for larvae feeding

4.1 Mapping and Sourcing of Organic Waste

At this stage all possible potential waste sourcing for the BSF substrate is identified and assessed for their availability. Mapping involves strategically identifying and assessing potential locations within the vicinity where organic waste is suitable (state and quality), abundant and accessible. The primary target areas should include the municipal market, hotels, restaurants, slaughterhouses, boarding schools, and agro-food industries. Proper mapping is needed to ensure a consistent supply of high-quality feedstock for preparing the feed substrate. In some regions, there may be well-organized waste collection services that the farm can opt to outsource. Priority should be given to areas with less-contaminated food waste, optimizing the quality of substrate. Following mapping, the next step is sourcing which refers to collection or acquisition of organic waste from the identified locations. To facilitate this process, the farm should have access to a reliable means of transportation, whether it is a motorcycle, truck, or tricycle. This is essential to efficiently convey the feedstock to the farm or production unit. Records should be kept on the waste collection as per the template provided in section 8.0.



a. Food waste

b. Market waste

c. Agro-industrial waste

d. Slaughter waste

e. Manure

f. Spent grain

Figure 13: Common feedstock in the environment

4.2 Potential feedstock for substrate

When establishing a cost-effective BSF bio conversion and processing business, the key challenge is the inconsistency of substrate and the low digestibility of substrates containing high cellulose and lignin.

Table 1: Nutritional composition of different substrates (%) for feeding BSF larvae

Substrate	Protein	Fat	Total carbohydrate	Ash
Digestate	246*	NA	779*	299*
Restaurant waste	157*	NA	700*	45*
Vegetable waste	86*	NA	1121*	108*
Fish meal	69.3*	6.9*	NA	12.2*
Digested waste (methane)	51.35	21.20	9.07	NA
Palm kernel meal (fermented)	47.34	4.31	33.34	13.18
Cow manure (fermented)	46.64	4.47	35.45	11.14
Market waste	46.52*	NA		10.08*
Hotel waste	45.29*			9.03*
Almond by-products	40.1–67.7	14.6–31.0	56.85–341.73+	NA
Milk fish offal	38.95	10.08	44.45	6.33
Poultry slaughterhouse waste	37.3	42.9		
Raw food waste	36.93	26.9	7.77	
Rice straw	34.62	8.00	39.45	17.92
Canteen waste	32.2	34.9	NA	
Barley + brewer's yeast	31.99*	5.39*	NA	4.74*
Barley + sorgum + brewer's yeast	31.39*	9.48*		4.32*
Barley + malt + brewer's yeast	30.22*	6.96*		4.41*
Maize distillers	29.5*	94.9**		5.40*
Nursery pig manure	28.92	3.37	5.69*	NA
Chicken manure	28.91	4.37	NA	NA
Corn starch + malt + brewer's yeast	27.72*	6.04*		5.14*
Vegetable waste + fruit waste	27.5–35.9	0.9–1.4	16.8–27.3	2.6–6.8
Secondary sludge of slaughter waste	26.60*	27.38*	NA	3.49*
Pig manure	26.60*	1.2*	NA	13.7*
Kitchen waste	25.41	13.37	28.92	10.52
Spent grain	24.5*	2.9*	NA	NA
Soybean curd residue	23.24	9.19	4.33	30.15
Kitchen waste	22.86*	20.77*	42.16*	NA
Brewer's waste	22.06*	5.8*	NA	3.7*
Growing pig manure	22.60	3.64	5.49 +	
Sorghum + barley + molasses + brewer's yeast	21.69*	5.18*		4.71*

NA: Not available
* : Dry matter,
** : Total amount of fat and carbohydrate on dry basis,
+ : Total amount of starch and sugar,
++ : Soluble carbohydrate on dry basis

Adapted from Siddiqui et al. (2024).

Substrate	Protein	Fat	Total carbohydrate	Ash
Chinese cabbage	21.42	1.42	45.71	NA
Dairy manure	20.18	2.04	NA	NA
Kitchen waste	20.0*	NA		7.2*
Coffee grounds + bio pulp with husk	19.78-	20.74-	38.60-	6.34-
Fruit + vegetable + barley + brewery	19.66*	8.26*	41.33+	4.16*
Malt + corn starch + molasses + brewer's yeast	19.10*	3.42*		4.31*
Fast food waste	18.09*	27.74*	NA	3.13*
Wheat bran	15.10	2.73	61.6	NA
Vegetable waste + sheep manure	16.43	3.87	41.61	20.45
Vegetable waste + horse manure	13.89	3.51	37.40	21.80

NA: Not available
* : Dry matter,
** : Total amount of fat and carbohydrate on dry basis,
+ : Total amount of starch and sugar,
++ : Soluble carbohydrate on dry basis

Adapted from Siddiqui et al. (2024).

These impact the efficiency of the process. When selecting feedstock, it is important to note that feeding the BSF with high quality substrate rich in fats, proteins, and starches improves the growth, and nutritional composition of the larvae are largely influenced by nutrition, specifically the type and quality of feedstock substrates.

The common sources of feedstock used to feed the larvae are kitchen or restaurant waste, food waste, fruits, vegetables, livestock manure, market waste, spent brewery waste, rice bran, spent grains, soy cake, etc. (Table 1). These wastes can contribute to higher survival rates (Table 2). The nutritional composition of different substrates can be used as guide for feeding BSF larvae.

Bioconversion rate and feed conversion rate

Process performance and bioconversion of agri-food wastes are decisive for affordability, economic viability and sustainability of BSF farming. Bioconversion rate is the amount of dry larvae biomass produced per unit of waste (i.e insects' ability to convert organic waste materials into biomass). Substrates with low bioconversion rate (LBR) are animal, 1.9-6%; brewery waste, 5%; fruit and vegetables waste, 4-5%. BCR are comparatively high for food waste, 13-21%. The greater the conversion efficiencies, the more optimal the sustainability outcomes of the system.

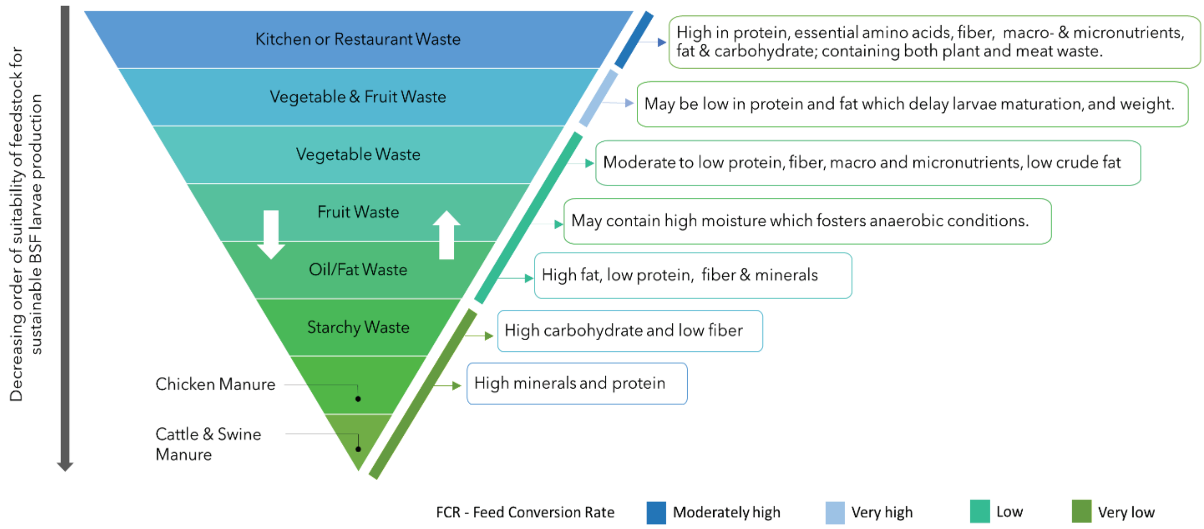
Bioconversion rate can be determined as follows:

$$FCR = \frac{(Total\ biomass\ of\ larvae)}{(Total\ amount\ of\ feed)} * 100$$

Feed conversion rate (FCR) is the efficiency of feed utilization when assessed on dry matter. The FCR value is the ratio between feed consumption and body weight gain obtained within a certain period. The FCR value through the formula below should ideally be close to 1 and always above 1. A lower FCR indicates a more efficient conversion of feed into insect biomass, which is desirable in BSF farming, as it means less feed is wasted and more biomass is produced for various applications. The FCR formula can also be calculated in % units, so a high percentage will indicate a high level of feed use efficiency. The commonly available waste arranged according to their Feed Conversion Rate (FCR) are shown in Figure 14. Feeding the same kind of food waste consistently to the larvae results in low levels of nutrients such as protein, fats, and amino acids in the larvae. To optimize for business, it's crucial to feed the larvae with a mix of different types of food waste instead of sticking to just one type. Section 4.4 gives a guide on how to mix the waste. It is also important to note that the feeding/nutritional requirements of the larvae vary across its growth cycle. Due to this variation, different substrates comprising various feedstocks need to be formulated for the different phases of the larvae production chain (see section 5).

$$FCR = \frac{F}{wt - wo}$$

F = Amount of feed consumed during the maintenance period (kg)
Wt = Final biomass (kg)
Wo = Initial biomass (kg)



Source: Adamtey et al. forthcoming

Figure 14: Locally available feedstock, major nutrient they supply, and decreasing order of their suitability for sustainable production of BSF larvae.

Table 2: Survival and bioconversion rates as well as treatment durations of substrates for feeding BSF larvae

The survival and bioconversion rates as a percentage, and durations of treatments of BSF larvae with changing substrate types and/or amounts is as shown in Table 2.

Substrate	Survival rate (%)	Bioconversion rate (%)	Treatment duration (day)
Abattoir waste	101.5	15.2	12
Aquaculture waste	101	23.9	12
Spent coffee	98.6	38.7	14
Chicken manure	98.35	9.88	18.34
Oat pulp	98.2–99.5	3.0–18.8	
Soybean curd residue (Lactobacillus burnerii)	98	6.9	16.1
Poultry feed	97.9	21.0	
Vegetable canteen waste	97.5	22.7	

Adapted from Siddiqui et al. (2024).

Substrate	Survival rate (%)	Bioconversion rate (%)	Treatment duration (day)
Pig manure (high temperature anaerobic)	97.33–98.67	7.01–7.32	
Abattoir, fruit and vegetable	96.3	14.2	12
Human feces	96.2–99.1	18.8–22.7	
Spent grain	95.7–98.9	3.1–11.5	
Fresh pig manure	95.67	4.94	10
Soybean curd residue	95.4	5	17.7
Dewatered sludge + wheat bran	95.00	13.84	
Wheat bran	94.27–98.00	6.71–9.17	17.5–19
Pig manure (aerobic)	94.00–94.33	3.81–4.34	
Chicken manure + biochar	93.33–96.67	6.87–8.31	
Poultry manure	92.7	7.1	14
Sewage sludge: fruit waste (30:70)	92.67	9.19	22
Canteen waste	92.3	15.3	
Digester sludge + wheat bran	92.00	14.60	
Household food waste	92.00	9.98	
Dairy manure + chicken manure	91.86–96.41	5.88–7.90	18.57–21.36
Human feces	91.8	11.3	12
Chicken manure	91.33	5.21	10
Cow manure	91.1–96.1	1.6–3.8	12–16
Poultry slaughterhouse waste	90.7	13.4	
Food waste	89.1	18.9	
Food waste	87.2	13.9	14
Sweet potato	87.0	23.0	
Soybean curd residue: kitchen waste (30:70)	81.50–99.50	13.04–18.54	12

Adapted from Siddiqui et al. (2024).

4.3 Pre-treating and processing of feedstock

The size of the food particles can affect how well larvae can consume nutrients. Larger particles can be harder for larvae to eat and might lead to uneven nutrient distribution, potentially causing variations in larval size. Similarly, some organic waste materials e.g., the brown materials or crop residues are high in crude fibre (lignin and cellulose) content and because of that they are poorly digested by the larvae. Others such as vegetable and fruit waste can produce a lot of water which decrease degradation of substrates, consequently killing the larvae due to anaerobic condition.

Therefore, after waste collection it is advisable not to provide the feedstock directly to the larvae. Instead, the feedstock should be pre-treated (Figure 15). These may include breaking down of the waste into smaller pieces. The most common and straightforward approach involves chopping/cutting or milling the substrates into smaller particles. Chopping or shredding or milling helps to reduce the energy and time required by the larvae to break the feedstock down. The save energy is used by the larvae for growth, development, and reproduction. Tools like knives, cutlass, grinders, choppers, or shredders are used to break down the waste materials into very fine particles to diameter of < 2mm to 5 mm. This increases the surface area making it easy for the larvae to break down. Thermal or heat treatment of the substrate can also be done at a specific temperature above 100 °C with processing time ranging between 15 to 120 minutes. The main goal of the thermal treatment is to increase solubility of the organic matter, thereby improving biodegradability and efficiency of composting. Excess water in vegetables and fruit waste can also be reduced through dewatering under a shade. Other treatments include the addition of yeast, fungi, or mixtures of microorganisms to the waste for the decomposition of hard plant materials. It is therefore important for the larvae production unit to include such setups in the facility.

Figure 15: Shredding machine

4.4 Mixing of substrate with manure, molasses, and yeast

The development of BSF larvae relies on the optimization of the mixing ratio, where nutritious organic waste can be effectively introduced as co-substrates. The weight of the larvae is determined by their diet during the larvae stage, therefore the combination of feed stock and how the substrate is prepared depends on the stage of the larvae. If the larvae consume a diet that lacks sufficient nutritional value, the duration required for development into pre-pupae may be prolonged by up to a maximum of two months.

A diet abundant in protein or waste material greatly expedites the development of the larvae, as they rapidly accumulate the essential protein needed for their growth and save significant amounts of energy in the process. Table 2 shows that the survival rate of larvae could be enhanced by combining different substrates, with aquaculture and abattoir waste given the superior survival rates, followed by spent coffee, chicken manure, vegetable canteen waste, and fruit waste. In waste blending, attention should be paid to the ratio between lignocellulosic materials and feedstock that is rich in protein (C/N). The same applies to the selection of protein sources to be mixed with agricultural leftovers. Example of protein sources for BSF are captured in Table 1.

In the case of a 6-day old larvae, kitchen waste is pre-treated and mixed thoroughly with manure to create the final substrate. Molasses and yeast should be added to speed up fermentation, enhancing aerobic conditions for the substrate.

Table 3: Example of blended substrates for BSF larvae feeding at different growth stages

Feed Type	Feed stock Combination	Feeding Rate	Considerations/Notes
Neonate Feed	Maize bran + Wheat bran + Yeast and molasses	-	Substrate should be wet
5-day-old larvae	40% Kitchen waste + 60% Manure	7-8 kg of substrate to 250g larvae	Substrate should be neither too wet nor too dry
14-day-old larvae	Kitchen waste + Manure	7-8 kg of substrate to 250g larvae	Substrate should be neither too wet nor too dry
21-day-old feed	Kitchen waste + Manure	7-8 kg of substrate to 250g larvae	Substrate should be neither too wet nor too dry
Neonates – 21 day-olds	Sorghum + Barley + Brewer's yeast + molasses	500g at every 3 days until the fifth instar	Substrate should be wet up to 10% moisture content.
Attractant for adult eggs	Cow manure + Rotten meat	-	Not for feed, serves only to produce hard odour to attract insects.
Attractant for adult eggs	Intestine of fish + organic waste		Not for feed; serves only to produce hard odour to attract insects.

Source: Generated by Authors from their own practical work experience
NB: feed stock listing above does not restrict a producer to a particular type of waste but encourages the producer to identify similar types of waste and utilize. For example, cow manure can be replaced with pig manure.

4.5 Storage of substrate

Proper storage is crucial to maintaining the quality and integrity of the formulated substrate until they are being used. The prepared substrates are stored under certain conditions (dry environment, moderate humidity, cold storage, air tight containers, exposure to sunlight, and protection from pests) until the appropriate time to introduce it to the larvae.

Dry environment: This is to is to prevent growth of mold and fungi as moisture can lead to spoilage and reduce the quality of the substrate. Regular checks on moisture levels and quality should be conducted during storage to ensure that the substrates remain viable for feeding the larvae.

Moderate Humidity: The Optimal humidity content level should be between the range of 40 -70%.

Cold Storage: While it's not necessary to refrigerate the substrate, storing it in a cool environment can help extend its shelf life.It is recommended to store the substrates in a cool, dry place to deter the growth of undesirable microorganisms and maintain their stability.

High Temperature: Exposure to high temperatures should be avoided which may promote the growth of harmful microorganisms.

Airtight Containers: The prepared substrates should be stored in suitable plastic containers or bins to prevent contamination and preserve their nutritional content (Figure 16). Airtight containers or bags should be used to seal the substrate and prevent exposure to air. This helps in maintaining the quality and preventing the substrate from becoming contaminated.

Airtight Containers: The prepared substrates should be stored in suitable plastic containers or bins to prevent contamination and preserve their nutritional content (see Figure 16). Airtight containers or bags should be used to seal the substrate and prevent exposure to air. This helps in maintaining the quality and preventing the substrate from becoming contaminated.

Direct Sunlight: Exposure to direct sunlight should be avoided: Substrate should be kept away from direct sunlight, as exposure to UV rays can degrade the nutritional content and quality of the substrate.

Protection from Pests: Substrates should be stored in a location where they are protected from pests, such as rodents and insects, which could compromise quality.

Proper Handling: Substrates should be handled with clean hands and equipment to avoid introducing contaminants during storage.

Storage Period: The storage period for substrates may depend on the specific type of material used. Some substrates, such as food waste, may have a shorter shelf life compared to processed substrates. It's essential to monitor and use substrates within a reasonable timeframe.

Regular Inspection: Inspect stored substrate for any signs of spoilage, mold, or pests. If any issues are detected, take corrective actions promptly.

Figure 16: Airtight Containers for storing substrate

Chapter 5

BSF production cycle

5.1 Obtaining a starter colony

The first step in the BSF production cycle is to acquire a starter colony, which could be in the form of eggs, larvae or pupa. The larvae are more convenient and are recommended, especially to inexperienced farmers looking to start production. There are two commonly adopted options for obtaining starter larvae: either hatching BSF eggs obtained from wild BSFs in your vicinity or purchasing larvae from a local supplier.

a. *Hatch from Wild Flies - How to attract BSF found in the wild to start your colony:* This method is appropriate in areas where there are no local sources of purchasing the starter larvae. The goal is to attract wild BSFs using natural bait like intestine of fish, rotten meat and waste or rotting fruit or kitchen scraps to attract wild BSF colonies in nearby areas to lay their eggs. BSF can be attracted using the procedure below:

   i. *Prepare an attractant:* Organic waste, including intestine of fish, rotten meat, rotten fruit, or kitchen waste, and animal manure, is initially crushed or chopped into pieces. Subsequently, water is added to create a moist mixture, which is then placed in a polybag and left in a warm location for approximately six days for decomposition/fermentation.

Figure 17: Container with an attractant

   ii. *Place the attractant:* Position the container with the attractant in an outdoor spot in a shady area where BSFs are likely to visit (Figure 17). The shady area prevent the wild around it from causing it attracted to dry.

   iii. *Provide a surface for egg Laying:* Create a surface for female BSFs to lay eggs by stacking wooden blocks over the container (Figure 16). Use wood pieces with cracks and crevices. Secure the stacks with rubber bands and place toothpicks between the layers to create space for egg laying.

   iv. *Monitor for eggs:* Watch the wooden stacks for eggs. If you don't see eggs after 3 days, it is likely there are few or no wild BSF populations around the attractant. Relocate the container to areas with potential BSF populations such as areas with a lot of organic waste (for example near swine waste dump).

   v. *Hatch the eggs:* For hatching, use a mating enclosure (Figure 18). This setup allows you to produce eggs within the enclosure rather than relying on wild BSFs. Alternatively, you can leave the attractant out for about 30 days for the eggs to naturally hatch so you can get your larvae and pupa for rearing as you start up.

Figure 18: BSF mating enclosure

b. *Purchase Locally:* This method involves acquiring starter larvae from a local supplier or purchasing directly from a nearby BSF farm (Figure 19). Local suppliers typically package larvae in 5kg containers, offering them in a ready-to-use form. This makes it an ideal option for beginners who may not be well-versed in the complexities of hatching. Some suppliers also offer the BSF stater-kit with about 5 bags packaged of 5-day old larvae (5 DOL) and other essentials such as crates, an overall, a sieve and a pair of non-dispatchable rubber gloves.

Figure 19: Starter larvae

5.2 Raising of adult fly

The pupa is transported in containers to the love/adult cage just before emergence. For timing purposes, it is crucial to know that the adult emerges approximately two weeks after transitioning into the pupal stage. At the adult stage, the adult BSF does not require any feed. The adults do not possess a mouth for feeding or seeping water; however, it requires water. Water is provided to them through a moth dipped in water.

Setting up adult cage for post mating

The adult cage is enclosed in a net that prevents the adult fly from escaping (Figure 20A). For medium and small-scale production setups, a cage with dimensions of 1m * 1m * 1.5m is suitable. The cage is elevated about 2 feet above the ground, with legs placed in a bowl partially filled with oil. This is done to prevent mites (+ants) from moving into the cage. Soil spreads inside the surface/base of the cage, and a potted plant can be added to create a natural environment for the flies. The cage must be exposed to enough sunlight, as adult BSF have special light receptors, and successful mating occurs only when they are exposed to light.

To facilitate easier egg collection after oviposition, a conducive condition is created within the cage for them to lay their eggs. This is achieved by placing a bowl with decomposing organic matter, such as fish intestine, rotten meat, fruit, or kitchen waste, and cow dung or poultry manure (referred to as the oviposition substrate/BSF attractant) (Figure 20B). Wooden planks (roughly 25cm * 5cm, size may vary based on the bowl) are stacked on top of each other held together with a glue or a rubber band and placed on top of the attractant/container/bowl.

The strong odor from the bowl attracts the flies when they are about to lay eggs (The stronger the odor, the better). After the mating (Figure 20C), the adult flies do not lay the eggs directly on the substrate; instead, they tend to lay them on the surface and inside the crevices between the stack of wooden planks on top of the bowl (Figure 20E). As an alternative to wooden planks, other materials such as cardboard (roughly 15x 6cm) or conduits can be used. Similarly, like wooden planks, the cut pieces of cardboard should be stacked on top of the oviposition substrate, while conduits are placed inside the substrate horizontally. The bait materials placed inside in case for the adult fly to lay their eggs is referred to as "eggies".

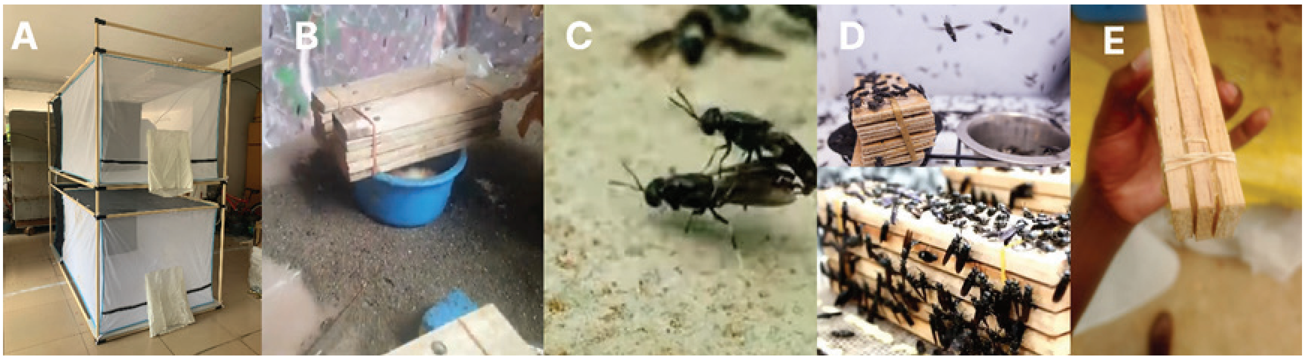


Figure 20: A-Adult cage; B-BSF attractant; C- Mating; D and E; Stack of wooden planks for laying eggs

Guide for optimal egg production in adult cage/mating net/love cage

- *Space Consideration:* Make sure there's enough space for flies in the love cage. As guide, use a maximum of eight crates (sized: 60cm * 40cm * 12cm), in a 4ft *4ft * 4ft area/cage. This allows the flies to move around freely from one corner to the next. Availability of sufficient fresh organic waste in huge amounts and on a regular basis at a low cost.

- *Shading for Egg Deposition:* Shade half of the love cage, particularly on top, using a carton. This creates a dark area for egg deposition and enables flies to regulate their temperature by shifting between covered and uncovered sections during varying temperatures.

- *Energy Boost for Reproduction:* Supply molasses or sugar crystals and sprinkle sugar syrup on moist cloth surfaces to enhance the flies' energy for reproductive activities, ensuring a prolonged lifespan and increased egg production.

- *Dead Flies Management:* Routinely remove dead flies in the morning and evening to prevent unpleasant odors and ensure live flies lay eggs only on intended attractants, not on deceased flies.
- *Cleaning and Disinfecting:* Regularly wash and disinfect love cage nets to minimize disease-causing pathogens, maintaining a clean and towels hygienic environment.
- *Humidity Maintenance:* Ensure humidity by spreading moist blankets on the love cage floor and placing containers of water with face in them. Sprinkle water on the love cage net when the temperature is relatively high.
- *Labeling and Data Tracking:* Label the love cage and pin a data entry form to track activities, including pupa introduction dates, egg collection, cage cleaning, and emptying.
- *Egg Collection Procedure:* Collect eggs every three days, removing everything, including the attractant, into the BSF neonate hatching crates. Clean the attractant holding dish.
- *Pupa Crate Emptying:* Empty pupa crates from the love cage after a maximum of 14 days. Remove everything and clean the net for optimal hygiene and egg production.

5.3 Egg management and hatching

Egg collection

In the adult stage, it takes 2 to 4 days for the flies to start emerging. Once eggs start emerging, they are collected every two to three days (Figure 21). This is because the eggs take about 3 days to hatch and should be collected just before they hatch in the adult cage.

After the removal of 'eggies,' ensure that the nets are tied up or closed to prevent adult flies from escaping. Regularly monitor and be on the lookout for clusters of small, white to yellowish eggs on the eggies. Adults are expected to start laying eggs about 3 days after mating, and farmers should check the cage every day onwards to inspect the wooden planks (eggies) for eggs.

BSF **neonates** refer to the newly hatched larvae of the Black Soldier Fly (BSF).

Figure 21: Inspection and monitoring of wooden planks for eggs

Preparing substrates for newly hatched eggs (neonate)

Once your eggs hatch, you need to provide your newly hatched larvae (neonates), with a nutritious substrate. It's crucial not to use just any waste; instead, it is advisable to select waste that is rich in protein for preparing the substrate (Table 1). Maize bran and wheat bran, two nutritious feedstocks, are commonly used for this purpose. In the absence of these, any other waste (captured in Table 2) with a similar nutritional profile including blood meal can be used as substitute. Soak the maize and wheat bran in water in a container, cover it, and leave it for about 6 days to ferment. Yeast and molasses are added to the substrate before fermentation begins to help break down the waste and release nutrients for BSF neonates. The molasses provides the neonates with extra energy. In the absence of molasses, the neonates would have to spend extra energy on breaking down the substrate.

Introducing neonates to feed

After collecting the eggs, they are placed in a favorable environment for hatching. It's worth noting that hatching typically occurs approximately four days after deposition, giving rise to larvae. The collected eggs are introduced into the prepared substrate (Figure 22A). However, the eggs are not placed directly on the substrate; instead, they are positioned on a goose wire (or similar) above the substrate (Figure 22B). Placing the eggs directly above the substrate may result in a significant reduction in mortality/low hatchability, as they could root and be consumed by mold. If you choose to place your eggies directly on the substrate, ensure that the side where the eggs are, faces upward to prevent direct contact with the moist substrate.

After placing the eggies, the crates (with substrate) must be covered to prevent nearby houseflies from laying their eggs in the same substrate (Figure 22C). Additionally, covering the crates help maintain warmth, which is favorable for hatching. After six days the eggs are removed from the nursery unit and transferred into the larvae rearing unit to introduce neonates to the main waste. Out of the six days, the first three days are for hatching, while the next three days are for the BSF neonates to feed and get ready for transfer. After six days, you would observe a lot of husks on top, and the substrate will no longer be dry due to feeding by the neonates.

Figure 22: Introducing neonates to feed

5.4 Rearing larvae

Introduction of 5 to 6-day-old larvae to feeding substrate

The approximately 6-day-old larvae (neonates) from the nursery are transferred, along with the remains of the feeding substrate, to the rearing unit to introduce them to the main feeding substrates. In farming systems without a mating unit for egg production, an alternative approach involves acquiring larvae from a local supplier. These suppliers typically offer packaged 5-day-old larvae for sale. In this kind of production, farmers feed the larvae to optimum weight, harvest the larvae (mostly used as livestock feed), and then purchase the packaged larvae again to begin the cycle.

Feeding the larvae on substrate

The feeding of substrate to the larvae is conducted in three consecutive phases, each based on the growth stage of the larvae. The **first feeding phase** lasts for about 8 days, while the **second phase** lasts for 7 days, followed by the **third phase**, which also lasts for 7 days. A phase ends when the larvae consume the given substrate, so the 7 day period assumes optimal conditions. The length of each phase may vary based on temperatures. Around 26°C is the optimum temperature required for the larvae to complete the feeding phase on time. For farms in warmer areas, opening windows and allowing for optimum ventilation help to decrease the temperature. Pouring water on the floor can achieve relative humidity of 40-80% (optimal humidity for growth) when it evaporates. The goal is to do this in the shortest time possible. Always turn the food after every 3 days. This helps to oxygenate the substrate, allowing the larvae that have burrowed into it and are underneath to have access to oxygen. This helps the larvae feed efficiently. If left without turning, they may take a very long time, possibly even beyond 9 days. The appearance of substrate will change, looking unlike what was initially placed, resembling soil, which is termed as frass. It would be dry. Don't add any food on top, sieve them to separate larvae from frass, and feed them again. This marks the second phase for another 7 days. After the second phase, it is sieved again before introducing them to the 3rd feed, referred to as the 3rd phase.

Feeding Rates

During the first phase, about 250g of larvae is added to 8 kg of feeding substrate in a crate. As a tip, about 3 handfuls equal about 300g of larvae if the remains of the previous compost it came from weigh about 2g. Subsequently, during the second phase, the quantity of feed is reduced to 2kg against 250g of larvae (already fed, we have a lot of instars 3, 4, and 5). In the third phase, it is further reduced to about 1 kg. At this third phase, most larvae would be in instars like instar 5, prepupa, and pupa; some may even prepare for pupation and may not need food, emphasizing the need for rearing substrates along the phases. The larvae are efficient feeders, requiring 4.5 to 10kg of organic waste to produce 1kg of larvae biomass.

Substrate for larvae

An amount of prepared feeding substrate is weighed into a container. Ensure the substrate being used has the right moisture content, being damp but not overly wet. Secondly, make sure to use a suitable container, such as a crate, with proper ventilation. The most suitable and commonly used container is the plastic crate. The feedstock combinations for the different stages of larvae development are captured in Table 3. Table 2 and the notes in section 4.4 and 4.5 can be referred to blend the substrates.

Based on the weight of the feed substrate weighed into the crate, the number of larvae required is estimated and added. For starters, it is generally recommended that 250g larvae require about 12kg of feed. The number of larvae per crate can vary based on several factors, including the size of the crate, the depth of the substrate, the quality of the substrate, and environmental conditions. After initially introducing the larvae to the feed, feeding does not end there. The feeding process is done in three phases for efficient larvae growth and development. In the initial phase, spanning 8 to 9 days, 10kg of substrate is provided.

The second phase follows, lasting 7 days with 4kg of substrate. After each feeding phase, a sieving process is implemented twice using coffee and goose wire to separate the larvae from the frass, the waste byproduct. Feeding for larval feed production lasts for the initial 9-day phase. However, when it comes to pupa development, the feeding extends to the third phase. During this period, it's important to regularly turn the substrate in the crates. This simple practice ensures good aeration and helps maintain optimal temperature conditions for the larvae and pupae.

Why do you need to estimate larvae per crate?

The above method is particularly crucial during feeding activities. Knowing the approximate larval population helps in determining the quantity of additional feed to provide, ensuring it is sufficient for the larval density in the crate. The method is also useful when determining the weight of the substrate-larvae mixture. By estimating larvae per unit weight, you can scale up to the entire crate and calculate the overall weight of larvae and substrate.

How do you estimate the larvae per crate?

- *Sampling: Take a small representative sample of the larvae and substrate mixture, approximately 100g.*
- *Observation and Counting: Within this sample, carefully count the number of larvae present. This provides a snapshot of the larval density within that specific quantity of the substrate.*
- *Extrapolation: Use the counted number of larvae in the sample to estimate the larval population per unit weight. For example, if you have 100g of substrate and counted 50 larvae, you might estimate that there are 500 larvae per kilogram of substrate.*

How to maximize larvae growth and development for optimum yield?

- *Drainage optimization: Drill 6 mm diameter holes at the container's bottom for efficient drainage. Place a screen layer between feedstock and drainage holes to prevent pest entry. Collect leachate from drainage for valuable use as fertilizer.*
- *Container conditions: House larvae in suitable containers with proper ventilation for optimal airflow. Maintain temperatures between 25°C to 35°Cto support larvae thriving. Ensure adequate lighting; larvae are attracted to light, aiding in effective harvesting.*
- *Nutrient-rich substrate: Confirm a balanced mix of pretreated kitchen waste, manure, molasses, and yeast in the substrate. Regularly monitor and adjust substrate moisture, aiming for dampness without waterlogging.*
- *Feeding Practices: Feed larvae consistently on time with the appropriate amounts. Avoid overfeeding to prevent overcrowding and resource competition among larvae.*

5.5 Harvesting of larvae and all by product from the production chain

Products from BSF Farming

In the process of Black Soldier Fly (BSF) farming, every element of the production cycle is utilized, resulting in a closed-loop system where nothing is discarded or wasted. The primary product of a BSF farm is the larvae. However, beyond the larvae, various by-products such as frass, pupa casing, pupa, and dead flies hold economic value and can be sold Table 4.). All products harvested are 100% organic and serve as valuable resources in various agricultural applications.

Table 4: Application of harvested products from BSF in Agriculture and pharmaceutical industry

	Harvested Product	Possible Uses In Agriculture
A	Larvae	Animal feed for livestock poultry , pet and aquaculture. Supplement in aquaculture and poultry diets. High-protein fertilizer when left to decompose. Oil and biodiesel production.
B	Frass	Organic fertilizer for crop production; Soil conditioner; Composting agent to accelerate
	Pupa	Animal feed for livestock; Biodiesel production; Extracts can be used in cosmetics and pharmaceuticals.
C	Pupa Casing	Soil amendment; Composting material; Mulching material
D	Dead Flies	Animal feed for small animals Composting material

Larvae | Frass | Pupa casing | Dead flies

Figure 23: Products from BSF farming

When to harvest for larvae intended to be used as livestock feed

The larvae are harvested before maturity (just before prepupae stage, coinciding after larvae completes first feeding) when their protein content is highest, identifiable by a beige color (Figure 24). Before the harvesting stage, larvae are white. Once beyond the harvesting stage, larvae transform into a black/grey color and are prone to escaping from crates. Under optimum growth conditions, which includes both high-quality and sufficient substrate, as well as accurate temperature and humidity levels, the larvae can be collected / harvested within a span of two weeks. In the absence of these conditions harvesting can be delayed by an additional one to two weeks.

NB: Larvae intended for raising adults for mating are not harvested at this stage. Instead, they are fed again and left to go through the pupation stage for the emergence of the adult.

Source: Tanga and Dorothy, 2022

Figure 24: Harvesting larvae for livestock feed

How to harvest the larvae?

The harvesting of the larvae is done by separating the larvae from their feeding substrate. The feeding substrate is passed through a sieve. A 5mm wire mesh can be used for this purpose. The degraded larvae substrate is shaken and poured into small containers at a time over the sieve. The big size larvae are prevented from passing through the sieve. By this time, the remains of the feeding substrate would have a finer texture due to the larvae feeding, allowing it to pass through the sieve.

Immediately after harvesting, the harvested larvae are weighed and recorded together with the number of crates harvested (Figure 25). The remaining material after sieving (appearance: dark, finer, looks like soil) contains a mixture of frass (larvae excrement and exoskeletons) and residues of the organic material fed to the larvae. It is rich in essential plant nutrients such as nitrogen and potassium, making it a valuable source to be used as an organic fertilizer. Due to several regulation requirements, it is advisable to compost the frass before use. For larvae intended to be directly fed to livestock, separating the larvae from the substrate is optional.

Figure 25a: Harvesting of larvae

How to sort larvae?

After harvesting the larvae, they are sorted into various sizes. During the separation or sieving process, some larvae may not meet the required harvestable size. In this sorting step, the larvae that have already transformed into the pre-pupal and pupal stages but did not pass through the sieve are separated and subsequently allowed to develop into adult fly for mating. Secondly, smaller sized larvae that were not able to penetrate the sieve, are separated and are subsequently fed again.

There are two main methods for sorting larvae to ensure uniformity:

- Wet harvesting: This method involves using water to carry larvae through larger screens, allowing smaller food debris to pass through finer screens. This process effectively isolates (from substrate debris and smaller sized) the larvae for feed.
- Dry harvesting: In this approach, the mixed contents are moved or shaken on screens until larvae are separated from large and small food particles (Figure 25). Sorting can be done by hand or with mechanized shakers, similar to technologies used in vermiculture systems.

NB: BSF farms with additional value addition units such as frass fertilizer production has 5 to 15 folds net income compared to sole BSF larvae farming. For example, a production of 1 ton of dried BSF larvae can generate 10 to 34 ton of frass fertilizer

Figure 25b: Efficiency of BSFL biowaste conversion. Depending on the waste type, the stage of larvae harvesting, the initial waste volume can be reduced by 35-66.5 % (wt/wt)

5.6 Preparing larvae as feed for livestock and poultry

The larvae need to be harvested before it can be used as feed for livestock. In occassions such as for chicken the larvae can be fed alive. The following procedure can be adopted to process the larvae into ready feed to be utilized by livestock.

- *Step 1. Cleaning of larvae:* The larvea is first washed in clean water to remove all remaining particles of feeding substrates and other impurities on its surface.
- *Step 2. killing of larvae:* The most cost-effective approach to terminate BSF larvae involves immersion in hot boiling water at temperatures ranging between 70-80°C, maintained for approximately 15 seconds, while enclosed in a sack. This not only ensures that the larvae are killed but also sterilized by eliminating a significant portion of disease-causing microbes.

  Alternatively, to the steam method, roasting can be employed for larvae termination. However, it's crucial to exercise caution with the roasting method, as inadequate control over time and heat may compromise the nutrition content of the final products. Additionally, roasting can be perceived as time-consuming.

  Another technique involves subjecting the larvae to extremely cold temperatures within a freezer for termination. Nevertheless, this method might be expensive for many farms, particularly those operating on a smaller scale. Consideration of the most suitable method should be made in alignment with the resources and scale of the farming operation.
- *Step 3. Drying the larvae:* After killing the larvae, they are then dried in the sun for about two weeks. After which the dried larvae can be fed to the livestock. Using a solar dryer can shorten the drying period but again it is dependent on the scale of operation and affordability.
- *Step 4. Packaging and storage:* The dried larvae can be packaged inside a plastic container and stored in a freezer until it is time to be given to the livestock.
- *Step 5. Final Stage- Cleaning and Hygiene:* After larvae processing, thorough cleaning of the crates is essential. This process minimizes risks, ensures a hygienic environment, and eliminates possible transfer of pathogen to the next cycle. Wash the crates with warm water and soap, thereafter use disinfectant to eliminate bacteria and other pathogen. Allow the crates to dry for at least one day before their next use.

5.7 Transition from larvae to pupae : raising pupae for reproduction

- The prepupa-pupa life stage takes a minimum of 14 days with feeding phases extending up to the third phase to ensure high-quality pupa.
- To facilitate faster fly development during the pupa stage, a dark room is necessary. BSF instinctively migrate from their food source to find a dark and quiet location for transformation into mature flies.
- Sieving is crucial at this point to separate the pupa and substrates before introducing them into the love cage for mating. It is vital to adhere to a four-day allowance for introducing pupa transformed from prepupa into the love cage to prevent fly emergence outside.
- Unconsumed substrate obtained after sieving during this stage can be used to feed other stages.

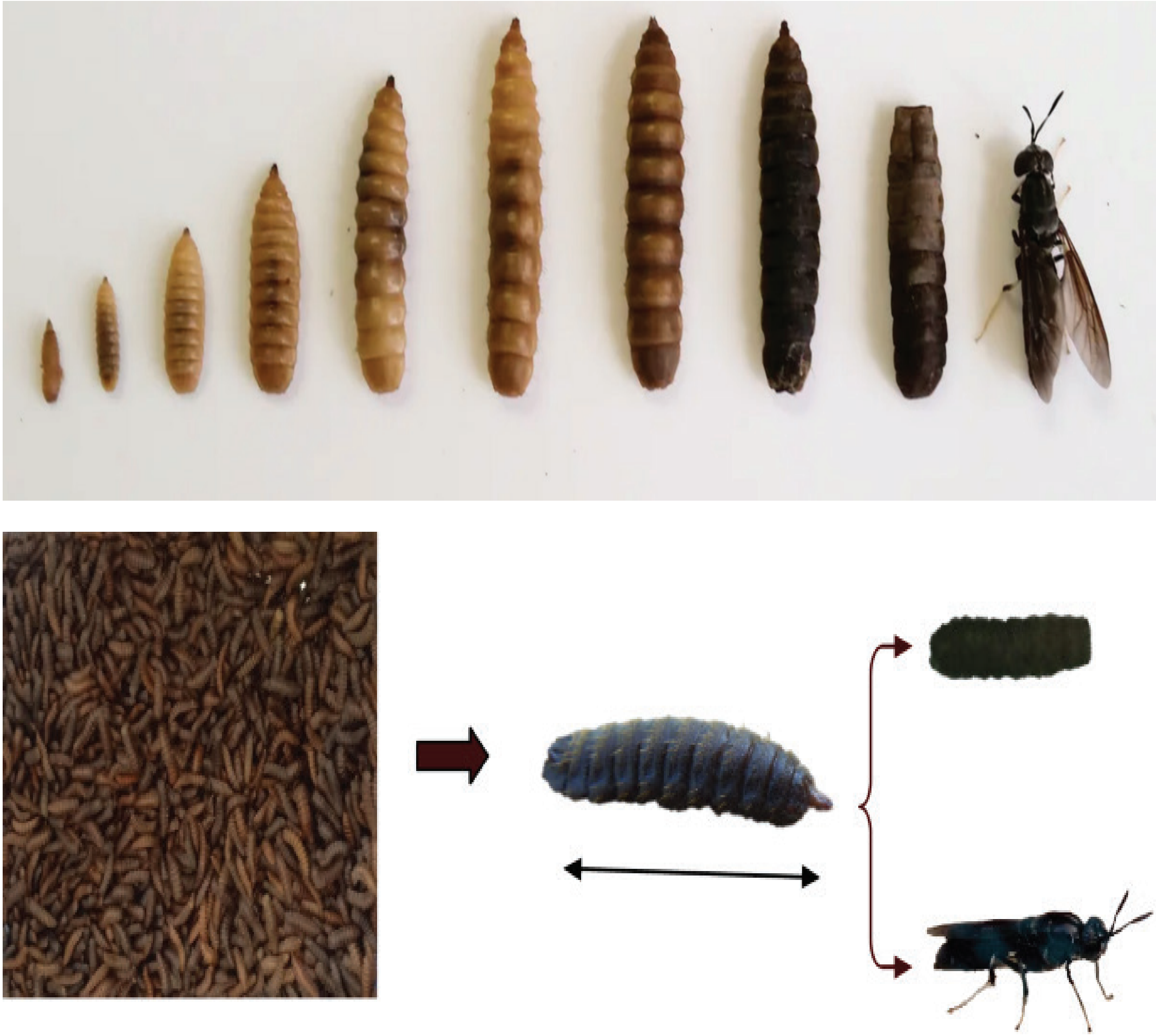
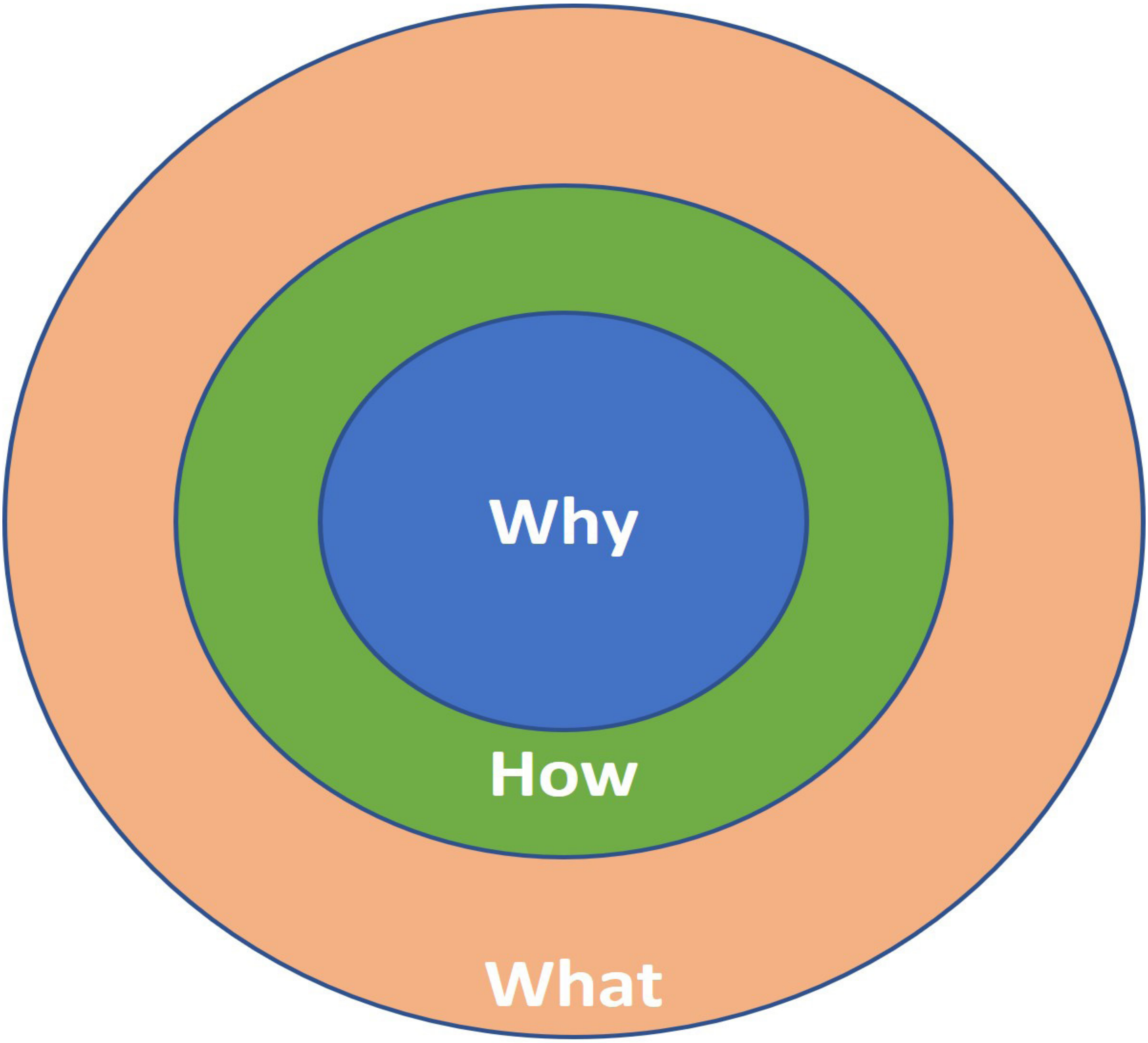


Figure 26: Transition from larvae to pupae and adult fly

Chapter 6

Production challenges



6.2 Risk of Pests infestation

Pest infestation is one of the major challenges in larvae production. During the design it is important to include installation of screens and nets to keep out unwarranted pest interferences (and decrease risk). Various pests, including birds, rats, mites, and houseflies, have been identified as potential production pests that need to be considered during the design, construction, and setup of larvae production units.

- Birds are naturally attracted towards the larvae and may consume them when given the opportunity. In order to prevent this threat, install protective nets on top of crates where the larvae are being reared (Figure 27a).
- Mites attach themselves to the body of the larvae, where they feed on the blood of the larvae. They can be identified by their distinctive red color (Figure 27b). To prevent contamination of the BSFL along any of the developmental stages, regularly inspect for mite infestations. In cases where mites are detected, thorough cleaning with disinfectants and proper drying of the crates should be done immediately after harvest.
- Houseflies (Figure 27c), when present at site may lay their eggs inside the same substrate and this can get mix up with the BSF larvae or eggs. While houseflies themselves are not a direct threat to the larvae, they compete for resources with BSF, as they share the same feed substrate. Pupa of housefly can be recognized by their shape and size as they appear different from that of larvae. Given that housefly larvae have a shorter development time, they can outcompete BSF larvae for resources. Covering the crate with nets can help to prevent nearby housefly from laying their eggs inside the BSF substrate.

a. Birds

b. Mites

c. Housefly

Figure 27: Pests of BSF larvae

6.3 Unpleasant/Foul Odour

The foul odour associated with BSF farming presents a significant challenge in establishing production units in urban areas. Residents in proximity are often opposed to it due to the unpleasant odours they must endure in their homes. The odour creates bad perception and could deter potential clients and stakeholders.

Foul odour from BSF farms can arise from various sources, most notably, decomposition of organic waste, anaerobic conditions, accumulation of excess moisture, inadequate waste management practices and presence of pathogens. Several food wastes, including those with high-moisture content like fruit and vegetable scraps, can lead to anaerobic conditions within the system.

The prevention of anaerobic conditions is therefore important to reducing the foul odours for maintaining positive perceptions among neighbors and clients. Implementing drainage solutions, and incorporation of absorbent materials such as bran or flour can help manage excess moisture, and break up any feed clumps to facilitate optimal consumption by the larvae.

6.4 Premature Larval Migration

Insufficient feedstock can cause larvae to prematurely exit the system, crawling out of enclosures in search of food. To prevent this, regularly monitor larvae and their surroundings and ensure a consistent and ample food supply.

6.5 Quality and safety concerns due to varied substrate sources

Lack of control over the various sources where the feedstock/waste is obtained from makes it difficult in controlling quality of substrate. Potential contamination of waste heavy metals and pathogens from the source which the is farmer has no control of places the entire production chain at risks, leading to questions about safety being raised. Implementing strict quality control measures such as collaborating with reliable waste sources and pretreatment of waste can help mitigate this risk.

Chapter 7

Storage, Packaging and Transport

7.1 Why the need for storage?

After the harvesting of Black Soldier Fly Larvae (BSFL) and its associated products, storage and transportation of these products in a short or over extended periods and distances is crucial for the success of the enterprise. The objectives for storage are to:

- Preserving the nutritional integrity of black soldier fly larvae is crucial for their effectiveness as feed for livestock, poultry, and aquaculture.
- Ensures constant and uninterrupted supply of larvae to the BSF farms, to be used in composting, and in the production of fish and livestock feeds.
- To meet the demand and maintain pricing stability, thereby avoiding shortages and surplus in market at a particular point in time. Store larvae makes the larvae production more cost effective to the farmer.

7.2 Forms BSFL can be stored

BSFL can be stored either live, dead/killed and in a processed form. The choice of form to store the larvae is influenced by the intended used. For instance, live insects serve as high-value food for poultry because of their rich protein and fat content and should be stored in a refrigerator. The same applies when the larvae would be used as a stock material to ensure constant and uninterrupted supply to the BSF farms.

7.3 Storage techniques

The techniques adopted for the storage of larvae can be divided into short-term or long-term methods based on the desired length or duration intended for preservation. Short-term storage is done when farmers need to keep the larvae alive for a brief period (usually 3-7 days) at a temperature of about 15°C. Long-term storage is required when farmers need to store the larvae for extended periods (1 week- 3 months). Refrigerators and cold room are used for long term storage (see freezing). The technologies applied during storage are drying and freezing.

Drying

Drying insect products has many advantages since it improves preservation by reducing microbial growth and spoilage-enzyme activity. Several drying methods can be applied to the larvae which have different effects on the final dry product. Indeed, the method can affect the colour, water activity, proximate composition, lipid oxidation and protein solubility. Sun-drying, oven-drying, freeze-drying and microwave-drying are the most frequent methods used in larvae processing.

- Sun drying: Sun drying is a traditional low-cost drying method, considered as a low temperature and extended-time treatment, which has been applied to many insect species including grasshopper, caterpillar, termite and maggot.
- Oven drying: Oven drying has been shown to have a great potential as a drying method. Temperatures between 50 °C and 120 °C are generally applied from an hour to a few days, but lower temperature is favourable in order to maintain protein solubility and to reduce Maillard reaction, shrinkage and tissue collapsing. Drying at 60 °C appears as the optimal drying temperature to prevent those effects while reducing the drying time.
- Freeze drying: This method is done by transferring frozen BSFL (without letting it melt) into a freeze dryer machine to remove the ice directly from larvae without turning it back into liquid. Freeze-drying is a non-thermal treatment frequently used in insect processing, but is relatively expensive and requires a minimum of 24-53h. It is one of the best drying methods to maintain insect colour since it does not induce Maillard reaction resulting in the whitest powder. However, it also induces a slight protein solubility reduction of 10%. Moreover, freeze-drying induces the greatest lipid oxidation resulting in

important quality loss, but blanching prior freeze-drying was able to reduce by half the oxidation. In addition, it can enhance BSF larvae customer acceptability since the whole freeze-dried larvae appears inflated instead of shrank.

- **Microwave drying:** Microwave is also expensive but is the fastest drying method for insects requiring only 10 to 15 min depending on the microwave parameters. It also produces inflated whole dried larvae but allows browning to occur. Microwave drying of BSF induces protein polymerization resulting in a lower digestible amino acid score and digestibility, and in a powder of bigger particle sizes compared to oven-drying at 60 °C.
- **Packaging dry larvae:** After drying plastic containers with screw lid or polyethylene bags with holes are preferable to keep the larvae at a room temperature and to exchange air (oxygen and carbon dioxide levels) to slow down deterioration process.

Freezing

BSFL can be stored in cold temperatures between 10 to 15°C, preserving them for 2-3 months. Placing larvae in the freezer at certain temperatures can induce a hibernation state, halting their growth into adult flies. During the dormant phase, their metabolism slows down, resulting in reduced activity and a noticeable decrease in size. Some individuals extend storage periods to 6-8 months. Although more than half of the larvae may die during this time, the nutritional quality of the dead larvae remains unchanged after being removed from the freezer. Selecting the right refrigerator is imperative. Avoid storing BSFL in a standard household refrigerator, as the temperature (typically between -4 and 8 degrees Celsius) can be excessively cold, leading to larval mortality. Instead, opt for a specialized refrigerator commonly found in grocery stores, such as wine or beer coolers designed for selling soft drinks. These refrigerators maintain a more suitable temperature range of 3 – 15 degrees Celsius, providing an ideal environment for the larvae to hibernate for extended periods. Another important consideration is choosing the appropriate storage bag or container.

- **Packaging for live larvae:** It is recommended to package the larvae in Chewy Zip bags before freezing. The larvae require 1-2 days to initiate the hibernation process. Adding a small amount of liquid food into a Zip bag allows the larvae to sustain their nutrition for the initial 1-2 days before entering hibernation. When you want to use the BSF larvae, gradually expose them to sunlight. Choose low-light areas with gentle shade to prevent heat shock and avoid larval mortality. As the ambient temperature increases, the larvae will respond by resuming their bodily functions.

Figure 28: A zip bag

Figure 29: Vacuum freeze dryer

7.4 Transport under cold environment

The larvae are packaged or transported in a controlled environment to reduce any quality losses during distribution. Two common technologies used to modify the atmosphere during distribution of living and killed BSF larvae are controlled atmosphere packaging (CAP) and storage (CAS). For CAP, the larvae are stored by modifying the container or package in which they are stored to extend the shelf life of the contents. This involves adjusting factors such as oxygen and carbon dioxide levels to slow down deterioration processes. On the other hand, in Controlled Atmosphere Storage (CAS), the entire atmosphere during transport or storage is modified. Selecting whether to use CAP or CAS depends on the scale. For instance, CAP is employed for fresh larvae products, delaying microbiological spoilage. Meanwhile, CAS for fresh produce enables transportation without significant quality losses

Chapter 8

Record & labelling keeping

A BSF production cycle is a very time sensitive process and as such timing and tracking of activities is very key to the success of operations in the BSF farm (missing a window can result in major loss). Table 5 shows the types of records to be taken.

Table 5: Types of data to be collected in BSF farming

Type of Record / Name of Table	Table Columns	Production Stage(s)	Significance of Record
Biowaste waste source collection	Date, Source, Type of Waste Available, Quantity collected, Competing Users, Cost, Comments	All stages	To ensure state and regular flow of feedstock
Love Cage and Nursery Records	RecordID, DateEggSet, QuantityEggsCollected, ExpectedSplittingDate, NoOfCratesIntroduced, DateCratesIntroduced	Nursery	Managing nursery activities and ensuring proper egg development.
Recording Books and Writing Materials	BookID, BookType, RecordDate, RecordDetails	Substrate Delivery, Eggs Collection/ Harvest, Larvae Harvest	Comprehensive log of various farm activities.
Larvae Rearing and Harvest Records	RecordID, FirstFeedingDate, ExpectedSecondFeeding, ActualSecondFeedingDate, ExpectedHarvestingDate, ActualHarvestingDate, QuantityHarvested	Larvae Rearing, Harvest	Critical for monitoring larvae growth and facilitating harvesting.
General Inventory Records	InventoryID, NoOfCratesOccupiedWeekly, CratesHarvestedWeekly, TotalCratesMonthly, ToolsEquipmentRecordDate, OtherToolsEquipmentMonthly	Weekly and Monthly Monitoring	Provides an overview of inventory status, aiding in resource management.
Harvesting Records	HarvestID, DateOfHarvest, NoOfCratesHarvested, WeightOfLarvae	Harvest	Essential for evaluating harvesting efficiency and productivity.

REFERENCES

- *Adamtey, N., Baidu, E., Somorin, T., & Cofie, O. (forthcoming). BSF and Agri-food system Transformation: A Systematic Review on Trends, Gaps, and Scaling Opportunities.*
- *Amaral, R. (2023). Nutrition for production animals: What it is and why it is important. Optimal Tecnologias. https://optimal.com.br/en/resources/nutrition-for-production-animals-what-it-is-and-why-it-is-important/*
- *Barry, T. 2004. Evaluation of the Economic, Social, and Biological Feasibility of Bioconverting Food Wastes With the Black Soldier Fly (Hermetia illucens). (Ph.D. dissertation), University of Texas, 176 pp.*
- *Barragan-Fonseca, K.B., M. Dicke, & van Loon, J.J.A. (2017). Nutritional value of the black soldier fly (Hermetia illucens L.) and its suitability as animal feed – a review. Journal of Insects as Food and Feed. 3(2):105-120. https://avingstan.com/wordpress/wp-content/uploads/2019/08/Barragan-Fonseca-et-al-2017-Nutritional-value.pdf. Accessed 13 Jan 2023.*
- *Terrell, C. & Ingwell, L. (2022). Vegetable Insects Black Soldier Fly Composting Guide Department of Entomology, Purdue University*
- *Chalermliamthong, S., Trail, P., Walle, R., & Motis, T. (2023). Black soldier fly larvae production. ECHO Technical Note No. 99.*
- *Etuah, S., Ohene-Yankyera, K., Liu, Z., Mensah, J. O., & Lan, J. (2020). Determinants of cost inefficiency in poultry production: Evidence from small-scale broiler farms in the Ashanti Region of Ghana. Tropical Animal Health and Production, 52(3), 1149–1159. https://doi.org/10.1007/s11250-019-02115-6*
- *FAO. (2023). Estimating Global and Country-level Employment in Agrifood Systems. FAO Statistics Working Paper Series. Issue 23/34. Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/Cc4337en*
- *Forager's Feed. (n.d.). Amazon.Com. Retrieved December 15, 2023, from https://www.amazon.com/stores/ForagersFeed/Homepage/page/DD5C4726-6116-477B-9881-26C5D54E5845*
- *Kamau, E., Mutungi, C., Kinyuru, J., Imathiu, S., Affognon, H., Ekesi, S., Nakimbugwe, D., & Fiaboe, K. K. M. (2020). Changes in chemical and microbiological quality of semi-processed black soldier fly (Hermetia illucens L.) larval meal during storage. Journal of Insects as Food and Feed, 6(4), 417–428. https://doi.org/10.3920/JIFF2019.0043*
- *Kim, C. H., Ryu, J., Lee, J., Ko, K., Lee, J., Park, K. Y., & Chung, H. (2021). Use of Black Soldier Fly Larvae for Food Waste Treatment and Energy Production in Asian Countries: A Review. Processes, 9, 161. https://doi.org/10.3390/pr9010161*
- *Kimmy Farm. (2020). How To Storage BSF Larvae In The Refrigerator? https://kimmyfarm.com/en/can-black-soldier-fly-larvae-be-refrigerated-in-the-refrigerator*
- *Larouche, J. (2019). Processing methods for the black soldier fly (Hermetia illucens) larvae: From feed withdrawal periods to killing methods. MSc Thesis, University of Laval*
- *Makkar, H. P. S. (2018). Feed demand landscape and implications of food-not feed strategy for food security and climate change. Animal, 12(8), 1744–1754.*
- *Meneguz, M., Schiavone, A., Gai, F., Dama, A., Lussiana, C., Renna, M., & Gasco, L. (2018). Effect of rearing substrate on growth performance, waste reduction efficiency and chemical composition of black soldier fly (Hermetia illucens) larvae. Journal of the Science of Food and Agriculture, 98(15), 5776–5784.*
- *Obie's BSFL Black Soldier Fly Life Cycle. (n.d.). Obie's Worms. Retrieved December 18, 2023, from https://obiesworms.com/blogs/news/obies-worms-black-soldier-fly-life-cycle*
- *Pavankumar, E., Baskaran, S., Prithivirajan, R., Vinoth Kumar, S., & Karpagaraj, A. (2021). Development of multi-functioning organic waste shredding machine for natural compost. In A. Arockiarajan, M. Duraiselvam, & R. Raju (Eds.), Advances in Industrial Automation and Smart Manufacturing (Lecture Notes in Mechanical Engineering). Springer. https://doi.org/10.1007/978-981-15-4739-3_90*
- *Peguero, D. A., Gold, M., Vandeweyer, D., Zurbrügg, C., & Mathys, A. (2022). A Review of Pretreatment Methods to Improve Agri-Food Waste Bioconversion by Black Soldier Fly Larvae. Frontiers in Sustainable Food Systems, 5. https://www.frontiersin.org/articles/10.3389/fsufs.2021.745894*
- *Sheppard, D. C., Tomberlin, J. K., Joyce, J. A., Kiser, B. C., & Sumner, S. M. (2002). Rearing Methods for the Black Soldier Fly (Diptera: Stratiomyidae): Table 1. Journal of Medical Entomology, 39(4), 695–698.*

- *Sheppard, D. C., Tomberlin, J. K., Joyce, J. A., Kiser, B. C., & Sumner, S. M. (2002). Rearing Methods for the Black Soldier Fly (Diptera: Stratiomyidae). Journal of Medical Entomology, 39(4), 695–698. https://doi.org/10.1603/0022-2585-39.4.695/*
- *Shumo, M., Osuga, I. M., Khamis, F. M., Tanga, C. M., Fiaboe, K. K. M., Subramanian, S., Ekesi,S., Huis,A,V., & Borgemeister, C. (2019). The nutritive value of black soldier fly larvae reared on common organic waste streams in Kenya. Scientific Reports, 9(1), 1–13.*
- *Siddiqui, S. A., Süfer, Ö., Çalışkan Koç, G., Lutuf, H., Rahayu, T., Castro-Muñoz, R., & Fernando, I. (2024). Enhancing the bioconversion rate and end products of black soldier fly (BSF) treatment – A comprehensive review. Environment, Development and Sustainability. https://doi.org/10.1007/s10668-023-04306-6*
- *Saucier, L., M'ballou, C., Ratti, C., Deschamps, M.-H., Lebeuf, Y., & Vandenberg, G. W. (2022). Comparison of black soldier fly larvae pre-treatments and drying techniques on the microbial load and physico-chemical characteristics. Journal of Insects as Food and Feed, 8(1), 45–64. https://doi.org/10.3920/JIFF2021.0002*
- *SNAS Biotech. (2023). How to Preserve Black Soldier Fly Larvae: Effective Long-Term Storage Techniques - SNAS Biotech. https://snasbiotech.com/how-to-preserve-black-soldier-fly-larvae/*
- *Sonal, S. (2022). Black Solder Fly | Design Innovation Center. Black Soldier Fly. https://vadic.vigyanashram.blog/2022/07/16/black-soldier-fly/*
- *Tanga, C., & Dorothy, N. (2022). Black soldier fly production: Farmers guide. http://hdl.handle.net/10625/60970*
- *Utmost Precision. (2022). Harvesting BSF and all the byproducts from BSF rearing [Video]. YouTube. https://www.youtube.com/watch?v=W8G8wjKUn8Y*
- *Utmost Precision. (2022). How to feed your Black-soldier fly larvae from eggies to maturity [Video]. YouTube. https://www.youtube.com/watch?v=4Yi_p28eAIg*
- *Wong, A. (2020). Black soldier fly of the Frangipani Langkawi Organic Farm. ECHO Asia Notes 41:7-9.*
- *zenyr garden. (2020). Storing Black Soldier Fly Larvae in the Fridge: Some Tips. Zenyr Garden. https://zenyrgarden.com/can-you-put-black-soldier-fly-larvae-in-the-fridge/*
- *Zulkifli, N.F.N.M., A.Y. Seok-Kian, L.L. Seng, S. Mustafa, Y.S. Kim, & R. Shapawi. (2022). Nutritional value of black soldier fly (Hermetia illucens) larvae processed by different methods. PLOS One 17(2):e0263924.*
- *Zhu, J., Luo, Z., Sun, T., Li, W., Zhou, W., Wang, X., Fei, X., Tong, H. & Yin, K. (2023). Cradle-to-grave emissions from food loss and waste represent half of total greenhouse gas emissions from food systems. Nature Food, 4(3),247–256. https://doi.org/10.1038/s43016-023-00710-3*

Noah Adamtey, Senior Researcher, N.Adamtey@cgiar.org

We thank all funders who support this research through their contributions to the CGIAR Trust Fund: www.cgiar.org/funders.

To learn more about this Initiative, please visit this webpage.

To learn more about this and other Initiatives in the CGIAR Research Portfolio, please visit www.cgiar.org/cgiar-portfolio

INITIATIVE ON
Nature-Positive Solutions