

MAKERERE



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**PRODUCTION PRACTICES AND TRAIT PREFERENCES OF
BLACK SOLDIER FLY IN SELECTED AGRO-ECOLOGICAL
ZONES OF UGANDA**

BY

OJUNGU MARK (BSc BAPTM)

2021/HD17/2646U

**A DISSERTATION SUBMITTED TO THE DIRECTORATE OF RESEARCH
AND GRADUATE TRAINING IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER
OF VETERINARY MEDICINE (FOOD ANIMAL HEALTH
AND PRODUCTION)- (MVMF) DEGREE OF
MAKERERE UNIVERSITY**

AUGUST, 2025

DECLARATION AND APPROVAL

I, **Ojungu Mark**, declare that this dissertation has not been submitted for a degree in any other University and that no part of it is plagiarized work.

Signature: .....

Date: 26/08/2025.....

This work has been submitted for examination with the approval of the following supervisors:

Signature: .....

Date: 26/08/2025.....

Bob Mali (PhD)

Department of Wildlife and Aquatic Animal Resources,
School of Veterinary Medicine and Animal Resources,
College of Veterinary Medicine, Animal Resources and Biosecurity,
Makerere University, P. O Box 7062, Kampala.

Signature: .....

Date: 26/08/2025.....

Sadhat S. Walusimbi (PhD)

Department of Animal of Agricultural Production
School of Agricultural Sciences
College of Agriculture and Environmental Sciences, Makerere University
Makerere University, P. O Box 7062, Kampala.

Signature: .....

Date: 26/08/2025.....

Grum Gebreyesus (PhD)

Center for Quantitative Genetics and Genomics, Aarhus University, Denmark

DEDICATION

This work is dedicated to my beloved wife Cicelia Ejang, who, despite the loneliness occasioned by my absence, not only trusted and believed in me but gave me the impetus to go on. To my lovely child, Jethro Odur, for whom I endeavor to live and strive. To my loving parents John Ocaga and Ketty Ocaga, who encouraged and supported me all through this level of education, to my beloved siblings, Okwir Aron, Odur Solomon (RIP), Opio Andrew, and Opio Emmanuel. Above all, God, the creator of all beings, provided the strength, health, and favor to enable me to see this output.

ACKNOWLEDGEMENTS

The almighty God, through whom all things are possible, gave me the strength and dedication I needed even when times were enormously tough.

My supervisors, Dr. Bob Mali, Dr. Sadhat Walusimbi and Prof Grum Gebreyesus. Thank you for taking me on, guiding me, and igniting my interest in my topic.

I am forever grateful to Prof Dorothy Nakimbugwe, Dr. Geoffrey Ssepuya, Dr. Cathrine Ndagire, and the entire Flygene research team.

I would also like to acknowledge the FlyGene project, funded by the Ministry of Foreign Affairs of Denmark under grant 21-09-AU, for support with the scholarship and the necessary logistics to collect data.

To my dear parents, who consistently probed my progress in writing this thesis and always supported me with my dreams and ambitions financially and through prayers. May God bless you.

To Dr. Deborah Ruth Amulen, Lecturers and fellow students at the College of Veterinary Medicine, Makerere University, thank you for your intellectual stimulation and encouragement and all the guidance you have given me throughout this process.

Most importantly, I thank my wife, Cicelia Ojungu, and my sons, Jethro Odur and Okwir Emmanuel, for enduring the emotional rollercoaster while I was away from home for extended periods, but you never stopped believing in me. This one is for you, my beloved family.

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LIST OF SYMBOLS AND ACRONYMS

°C	Degree celcius
%	Percentage
ABL	Above sea level
AEZs	Agro-ecological zones
ANOVA	Analysis of variance
BSF	Black soldiers fly
BSFL	Black soldier fly larvae
CBOs	Community Beneficiaries Organisations
ESG	North eastern savannah grassland
FAO	Food and Agricultural Organization
HI	<i>Hermetia illucens</i>
IBF	Insect based feed
IPIFF	International platform for food and feed
LVC	Lake victoria crescent
MD	<i>Musca domestica</i>
NGOs	Non-governmental organisations
SDGs	Sustainable development goals
TM	<i>Tenebrio molitor</i>
WSG	Western savannah grassland

ABSTRACT

Black soldier fly (BSF) larvae production is one of Uganda's fastest-growing insect value chains, with the potential to lift 4.53 million people over the poverty line and provide annual employment to up to 563,302 people. This study aimed to enhance the BSF value chain by characterizing black soldier fly production practices, identifying the preferred traits of black soldier fly larvae, and examining the factors influencing the productivity of these larvae in selected Agro-Ecological Zones (AEZs) of Uganda. The findings are intended to inform the design and implementation of a breeding program focused on improving the production of black soldier fly larvae. A cross-sectional study was conducted in which BSF farmer-households (n=83) from three agro-ecological zones (AEZs), including North-Eastern Savannah Grasslands (ESG), Lake Victoria Crescent (LVC), and Western Savannah Grassland (WSG), were interviewed using a questionnaire with semi-structured and structured questions. The main production objectives and traits preferred for potential genetic improvement were identified using ranking approaches with a Likert scale ranging from 1 (not important) to 5 (most important). Descriptive statistics were used to analyze data on socio-demographic information, production practices, morphometric traits sampled, and production challenges. The chi-square test examined the association between demographics and other characteristics of farmers with the production objectives, practices, and preferred BSF traits. Lastly, a linear regression model was used to determine factors affecting the yield of black soldier fly larvae produced. Results indicate that the main production objective for BSF farming was to feed farmers' own livestock, mostly poultry. Males dominated BSF farming (67.5%), with slightly over half of the respondents aged between 18 and 35, and most (75.2%) having attained tertiary-level education and having received technical training in BSF farming (80.7%). The production scale of BSF farming was generally still low, with the majority (54.2%) producing less than 100kg/week of fresh larvae, mainly under the vertical rearing system (68.7%). BSF breeding stock was mainly obtained from fellow producers (59.04%) who offered training. Market waste was the highest-yielding substrate reported (38.5%), yet it was less (20.5%) preferred and used than brewery waste (26.5%). Most farmers purchased substrates off-farm (56.6%), and only 25.3% used on-farm waste generated. Sieving (50.06%) and manual picking (36.14%) were the two common BSFL larvae harvesting methods practiced, while separation (83.33%) of the pre-pupa from larvae prior to

pupation was the main post-harvest handling practice carried out, whilst a few washes of BSFL (16.67%) prior to feeding and selling. The most important trait preferred and significant in all AEZs was high protein content larvae (20.3%), although ranked third (Median rank= 5, $p < 0.043$). Other important traits were big larvae girth (18.8%), which ranked highest (Median rank = 5), followed by long larvae length (15.3%), which ranked second (Median rank 5). Substrate sourcing was the main production challenge observed in all AEZs and positively influenced the BSFL yield. Overall, most farmers participating in black soldier fly farming are still producing at a small scale due to an inadequate supply of substrates, and they mainly obtain substrate from off-farm sources to enhance their production. Farmers who farm black soldier flies are well-educated and trained in BSF farming, with experience ranging from 1 to 2 years. They mainly produce BSFL under vertical rearing systems and non-permanent structures. Farmers are mainly interested in producing big girth larvae with high protein content and adaptability to high-temperature farming conditions. However, they are limited by inadequate substrate supply, which significantly influences the yield of larvae they produce ($p < 0.012$). This study's findings can guide further studies aimed at developing breeding programs, better understanding farmers' production practices under different rearing systems, and guiding the navigation of the production challenges faced by black soldier fly farmers to realize efficient and increased production.

Keywords: *Hermetia illucens, Trait preferences, production characteristics, production challenges*

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

The current and projected future demand for animal products by the burgeoning human population has increased pressure on global food systems, especially the feed for livestock (Sogari *et al.*, 2019). Over 60 billion land animals supply meat, eggs, and dairy products, which is expected to exceed 100 billion by 2050 (Yitbarek, 2020). Projections indicate significant increases in pig meat production by 290%, sheep and goat meat by 200%, beef and buffalo meat by 180%, milk by 180%, poultry by 700%, and egg production by 90% (Yitbarek, 2020). Consequently, global feed demand is projected to almost double by 2050 as compared to 2000, with farm animals consuming 1.3 billion tons of grain annually (Yitbarek, 2020). Therefore, to meet the current and future demand for food and feed without increasing our carbon footprint, there is a need to choose feed production systems that are socio-economically and environmentally sustainable.

In recent decades, insects have been explored as alternative feed resources that can sustainably bridge the gap between animal feed supply and human food demand. Insects such as the black soldier fly (*Hermetia illucens*, HI), the yellow mealworm (*Tenebrio molitor*, TM), and the common housefly (*Musca domestica*, MD) have been profiled and farmed (Sogari *et al.*, 2019), and as well categorized as farmed animal (Nayak *et al.*, 2024), commercially used as part of livestock feeds in several countries (van Huis *et al.*, 2020a), especially as a protein source to replace fish and soybean. The larval stages have emerged as a promising protein source for livestock feed (Meena & Meena, 2024). In addition, nutrient-rich frass can be utilized as a biofertiliser, thereby replacing synthetic fertilizers, which contribute to climate change through carbon dioxide CO₂ emissions during production, nitrogen oxide (N₂O) emissions during usage, soil health degradation, and water pollution. Hence, using insects as a feed ingredient and for waste management supports nutrient recycling in agricultural systems and could reduce greenhouse gas emissions from growing crops that provide protein to livestock and reduce pressure from human competition.

Insects, particularly the black soldier fly (*Hermetia illucens*, HI), have attracted much interest from researchers (van Huis *et al.*, 2020a), as well as producers (Beesigamukama *et al.*, 2022), compared to other insect species (Sogari *et al.*, 2019). The black soldier fly larvae (BSFL) are recognized as a promising alternative source of animal feed (Nayak *et al.*, 2024). The BSFL is polyphagous and less susceptible to pathogens than other insects, making it the most preferred insect for mass rearing (Hoc *et al.*, 2019). Moreover, BSF rearing is vital in ensuring feed safety, livestock feed, and livestock feed ingredients, in addition to other values evidenced in waste management and environmental protection. BSFL feeds on various organic waste, such as vegetable residues, municipal waste, fish offal, restaurant waste, and industrial waste (Hudson *et al.*, 2019), making it a farmer's choice. Consequently, the BSF industry is gaining traction from researchers, and other stakeholders, such as producers and feed manufacturers, have tailored many efforts towards BSF.

Investment in BSF farming is projected to increase because of its versatility in products and applications. Noteworthy, the production and demand for BSF products are growing exponentially. The global market of BSF was valued at 308.4 million USD last year, and it is projected to reach 2 billion USD by 2030 (Abro *et al.*, 2022). The BSFL market is expected to grow by 37% annually to reach 8,004 tons by 2033 (Abro *et al.*, 2022). In Uganda and wider eastern Africa, insect meals are also predicted to grow exponentially (Abro *et al.*, 2020). The economic benefits of insect-based feed (IBF) are substantial, totaling USD 0.73 billion annually, which is enough to raise approximately 4.53 million people above the poverty line and create 563,302 new jobs annually (Abro *et al.*, 2022). The national and global growth in the market of BSF products provides an opportunity for smallholder farmers to engage, and produce at a greater scale to benefit from BSF farming economically.

According to the International Platform of Insects for Food and Feed (IPIFF), the insect industry must considerably scale up to enhance its full potential exploitation. Indeed, the current trading price of insect meals still needs to be competitive enough (Ahmed *et al.*, 2023). The production volumes of fishmeal, soybean meal extract, and soybean meal are hundreds of times larger than those of insect protein products (Sogari *et al.*, 2019). Therefore, there is a need for possible options for the scale of insect production to increase their price competitiveness.

To benefit from BSF production, farmers must rear these insects in mass quantities to yield the desired product. Efficient mass rearing of insects requires sufficient substrates or a combination of substrates with desired nutrient content and measured abiotic conditions. The quality of BSF products is highly dependent on the type and quality of substrates used (Hosseindoust *et al.*, 2023). Traditionally, BSF rearing has focused on optimizing abiotic conditions, nutrition, and management practices to increase survival rates and productivity (Hansen *et al.*, 2024), but little has been done to improve production and productivity by focusing on improving desired traits. Whereas changes in environment and nutrition can influence desired products, taking advantage of genetic variation and short life cycles of insects makes them ideal candidates for selective breeding (Miranda *et al.*, 2019) as a tool to increase production and productivity. The success of selective breeding is mainly attributed to the phenotypic traits of individuals with high genetic importance that can be passed on to the next generation (Hansen *et al.*, 2024). Therefore, there is an opportunity to understand the rearing conditions and desired traits to support the development of strategies for improved production.

1.2 Problem statement

Black soldier fly (BSF) farming is an emerging enterprise with diverse products and applications that hold immense potential to alleviate poverty (Abro *et al.*, 2022), especially in smallholder farms, which dominate Uganda's agricultural landscape. The versatility of BSF products, ranging from feed for livestock to organic waste management, makes it a valuable addition to sustainable farming practices (Chia *et al.*, 2019). However, Key aspects of BSF farming, such as the scale of production, farming systems and practices, trait priorities, and challenges faced by farmers who have adopted BSF farming in different agro-ecological zones, remain largely unexplored. This lack of information hinders efforts to optimize production efficiency and formulate effective strategies for improvement. No systematic studies have been conducted in Uganda to assess how these AEZ differences affect BSF production outcomes

This study aims to investigate BSF farms across various agro-ecological zones in Uganda to characterize BSF farming systems, identify desirable traits of the black soldier fly, and assess factors influencing BSF productivity. The insights gained will not only provide a foundation for selective breeding programs but also guide the

optimization of BSF production practices, ultimately enhancing efficiency, productivity, and the overall economic potential of BSF farming in Uganda.

1.3 Objectives

1.3.1 General objective

To generate agro-ecological and performance-based evidence to inform region-specific strategies for improving BSF production and productivity in Uganda.

1.3.2 Specific objectives

- i. To characterize black soldier fly production practices in different agro-ecological zones.
- ii. To document the preferred traits of black soldier flies in the different agro-ecological zones.
- iii. To establish factors affecting the productivity of black soldier flies in the different agro-ecological zones.

1.4 Research questions

1. How do resources used in BSF farming and production practices differ across various agro-ecological zones?
2. How different are the traits prioritized by BSF farmers in different agro-ecological zones?
3. What factors affect the production of black soldier fly in different agro-ecological zones?

1.5 Justification

Black soldier fly (BSF) larvae production is one of Uganda's fastest-growing insect value chains, potentially lifting 4.53 million people over the poverty line and providing annual employment to up to 563,302 people (Abro *et al.*, 2020). Uganda has a diverse ecosystem and rich agricultural potential, which generates a variety of biowaste, and therefore, diversity in the type of climate and substrates available poses peculiar challenges to BSF production. For this reason, the study was conducted across several

agro-ecological zones (AEZs). Organizations and institutions have promoted BSF farming and trained several farmers from different parts of the country. Therefore, it is necessary to assess and examine to what extent farmers have adopted BSF farming and the challenges they face. The study addresses the critical knowledge gap by generating data on BSF performance across different agro-ecological zones. It aligns with Uganda's National Development Plan (NDP) III objectives on agro-industrialization, waste management, and job creation especially for youths and women. Contributes to regional and global efforts to promote climate-smart, resources, and inclusive agricultural practices, also in line with

1.6 Significance of the study

Uganda, like many other countries, is concerned about food security. The BSF, *Hemertia illuceans*, is a long-term solution because of its rapid growth and high nutritional content (Miranda *et al.*, 2019). Contribute to filling knowledge gap in agro-ecological zones practices, informing region-specific BSFL farming practices, leading to sustainable feed sector development. Its production practices and trait preferences must be explored to optimize its potential as a feed source for livestock and aquaculture, which will significantly contribute to Uganda's food security. Furthermore, by identifying desirable traits such as high protein content, low-fat composition, and rapid growth, size of the larvae, adaptability to micro-environmental conditions, amongst others, farmers can improve their productivity, thereby increasing income and livelihoods through the provision of employment opportunities to youths, women, and vulnerable groups. Providing rich protein and an excellent feed source for livestock and fish could revolutionize Uganda's animal husbandry and aquaculture sectors. Researchers have proved BSF larvae to be rich in proteins, essential amino acids, and micronutrients (Starcevic *et al.*, 2019). Integrating BSF-based feeds into livestock and aquaculture diets can enhance the nutritional quality of meat, eggs, and fish (Hudson *et al.*, 2019). This study is consistent with Uganda's commitment to ensure environmentally sustainable production methods in line with sustainable development goals (SDGs), which include SDG 1, No poverty, through commercial production of BSFL, SDG No. 2. Zero hunger, through providing food and feed for livestock production, SDG No. 11, Sustainable cities and communities, SDG No.13, Climate action, through reducing emissions resulting from waste (MAAIF, 2018). Lastly,

studying the production practices and trait preferences of BSF in the specific context of Uganda adds valuable scientific knowledge, providing the foundation for future research and promoting academic and scientific developments in the field of commercial insect rearing.

1.7 Limitations of the study

1. The study intended to cover more than three agro-ecological zones; however, due to limited documentation of farmers across the country, the population of farmers used to select a sample was derived from farmers trained by Makerere University and Amarula Protein.
2. The limited sample size of the respondents and uneven distribution of black soldier fly farmers across the Agroecological zones posed constraints, hence not allowing deeper investigation of the differences in practices, trait differences, and factors influencing productivity across the three agro-ecological zones studied.
3. Thirdly, ranking of importance rather than choice experiments was used as an analytical tool to derive the most preferred traits in determining the trait preferences.
4. The lack of adult fly stages in western savannah grassland limited meaningful comparisons of the morphometric traits of the different stages of the BSF.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of insect benefits

Insects have been identified as an important future source of sustainable raw materials for animal feeds (FAO, 2013). First and foremost, insects meet animals' dietary requirements regarding nutritional composition, providing a high-quality and sustainable source of nutrition for livestock (Nampijja *et al.*, 2023; Starcevic *et al.*, 2019). Secondly, it has less ecological footprint due to low emission levels of greenhouse gases (Muinde *et al.*, 2023; Miron *et al.*, 2023; Sogari *et al.*, 2019). On the other hand, using insects in the bioconversion of waste materials constitutes a novel approach and a remarkable example of a sustainable circular economy (Beyers *et al.*, 2023; Čičková *et al.*, 2015). Other benefits are evident in reducing the disposal costs of organic side streams (Eawag & Sandec, 2018). Overall, insects are one of the most important integral parts of the ecosystem's functioning, and they provide essential benefits to sustainable agriculture, biodiversity, conservation, and human beings. In particular, the black soldier fly (*Hermetia illucens*, HI) has attracted much interest from researchers compared to other insect species, consequently promoting developments for its mass rearing to optimize the utilization of its benefits.

2.2 Origin of black soldier fly

The black soldier fly was first discovered in South Africa in 1914 and later in Liberia in 1945 (Kaya *et al.*, 2021). Malta was the first country to report its presence in Europe in 1926 (Kaya *et al.*, 2021). The black soldier fly has the most extensive distribution of all stratomyids globally, as Badenhorst and Rhode reported in 2017 and Kaya *et al.* (2021). It can be found across tropical, subtropical, and temperate regions, as noted by Hoffmann *et al.* (2021).

2.3 Black Soldier Fly, *Hermetia illucens* biology

Hermetia illucens, also known as black soldier fly (BSF), belongs to the Hermetiinae subfamily of the Diptera order, along with four other genera: Patagiomyia, Chaetosargus, Notohermetia, and Chaetohermelia. *Hermetia illucens* is the most

common species. It is a large, slender black species with brownish wings and tentacles on the head. The abdomen has five segments with white spots. Males are longer than females but have smaller genitalia and wings. Females have body lengths between 12 and 20 mm and wings between 8 and 14.8 mm. The life cycle of BSF consists of five stages: egg, larva, pupa, and adult. The cycle of black soldier fly varies mainly between populations (wild or domesticated) and environments (temperature, humidity, light intensity, quality, and quantity of available food) (Badenhorst & Rhode, 2017). The fecundity of females is about 320 to 1000 eggs, which they lay hidden from predators but with proximity to the substrate in humid media to limit water loss of the eggs (Meena & Meena, 2024). The incubation period lasts more than four days at a temperature of 27-29°C and about 3.5 days at 30°C. As soon as the larvae hatches, they feed on the surrounding organic matter. The larval stage lasts about 4 weeks to 5 months, depending on food availability and environmental conditions (Diogo & Hesselberg, 2019). The growing larvae perform successive molts, separating into five larval stages, then reaching the pupal and imago stage, the last stage before pupating into adult flies. Metamorphosis is generally completed within two weeks, and males often emerge earlier than females (Meena & Meena, 2024). Adult BSF do not possess a mouth, digestive system, or stinger and thus do not pose a threat to other organisms. Importantly, they do not exhibit an affinity towards the human body or fresh food and, as a result, do not act as vectors for disease transmission. Therefore, their harmless nature is key to understanding their role in the ecosystem. The knowledge of the BSF life cycle could form the basis for its breeding and understanding of rearing systems in captivity to optimize the productivity of black soldier flies.

2.4 Black soldier fly production systems

To date, clarity is still demanded on the BSF production system since different researchers have reported production systems based on different parameters, Such as production scale and larvae-rearing method. The black soldier fly (BSF) was initially found in the wild and later domesticated due to its favorable characteristics. The first system was developed in the 1970s and consisted of exposing substrates to naturally occurring BSF females for laying eggs and separating adult rearing systems for egg production (Sheppard *et al.*, 1995). This is consistent with a study conducted in West Africa by Kenis *et al.* (2018), which categorized BSF production systems into two

systems. The first system involves exposing substrates to naturally occurring BSF females for egg laying, while the second consists of separating adult rearing systems for egg production. The first production system, which involved exposing substrates to attract wild BSF, was found to be unsustainable in regular larvae production and waste management (Kenis *et al.*, 2018). The system used concrete basins built under layer poultry units or piggery units. However, this production system had delays and lower production. The second system involves mass rearing of the larvae through domestication. It is widely adopted by most producers, particularly those at medium- and large-scale, using separate adult-rearing systems for egg production (Nyakeri *et al.*, 2017). One unit maintains breeding colonies in this system, whereas the remaining unit produces larvae. Likewise, the study conducted by Abro *et al.* (2022) in Uganda revealed that farmers employed three production systems for insect-based feed (IBF) farming: a plastic drum system used by small-scale farmers, modified production systems by medium-scale farmers, and greenhouses by large-scale farmers. However, it was noted that oviposition performance in the present production system remains low, and further clarity is still required on how fecundity in production systems can be improved (Nguyen & Tomberlin, 2013). Therefore, a better understanding of the production systems is still required to inform management of practices to improve productivity.

2.5 Requirement for BSF rearing

Understanding the requirements for rearing black soldier flies is essential for ensuring a successful operation, from preparation for breeding to post-harvest handling. Each stage of the process demands different inputs, and navigating various environmental factors, such as temperature, humidity, and light, is critical, as these elements significantly impact system performance. Additionally, key resources like land, infrastructure, space, containers, water, electricity, labor, and substrate play a vital role in the rearing process. Thus, managing these resources throughout the various stages of the lifecycle is crucial to achieving a successful operation, from breeding to post-harvest handling.

2.5.1 Land

Land is an indispensable and essential natural resource for livestock production, categorized as either fixed or variable, depending on whether it is owned or rented. The global agricultural land area is projected to increase from 5.1 billion hectares to 5.4 billion hectares by 2030 (Wirsenius *et al.*, 2010). Furthermore, investments in black soldier fly production necessitate land for establishing infrastructure (Roffeis *et al.*, 2017). Therefore, it is essential to recognize land as a vital resource when initiating black soldier fly production.

2.5.2 Infrastructure

Like any other livestock-intensive production system, producing black soldier flies requires a rearing facility and storage plan for both inputs and products. In addition to housing, black soldier fly-rearing containers, rearing stands, weighing scales, threshers, motorbikes, and trucks, among others, are essential for BSF production (Eawag & Sandec, 2018).

2.5.3 Labor

Insect production necessitates the active involvement of human resources in various stages, including raw material sourcing, production, processing, and marketing of black soldier fly larvae. Laborers play a crucial role in tasks such as egg collection, manual waste processing, larvae preparation and rearing, harvesting, and product marketing.

Additionally, a study conducted by Mutuku (2022), reported factors influencing the profitability of black soldier fly farming in Kenya, which included labor, along with other factors, significantly impacting the enterprise's gross margin.

2.5.4 Substrate use characterization in black soldier fly production

Black soldier fly larvae are polyphagous; they feed on a variety of substrates from different sources. Research has shown that the productivity of black soldier fly larvae (BSFL) is significantly affected by the type and nature of the substrates provided (Yakti *et al.*, 2022). Elsewhere, experimental studies have documented variations in larvae's performance based on whether they are fed protein-rich substrates, plant-based

proteins, or industrial by-products (Leni *et al.*, 2024; Hosseindoust *et al.*, 2023; Yakti *et al.*, 2022). These substrates impact the morphometric characteristics and nutritional quality of the BSFL end product. Specifically, studies have indicated that substrates derived from animal sources tend to produce larvae of superior size and overall quality (Hosseindoust *et al.*, 2023; Hudson *et al.*, 2019; Spranghers *et al.*, 2017; Tschirner & Simon, 2015).

Therefore, the feeding program for the larvae is crucial in achieving the desired nutritional content. Several substrates have been recommended for rearing black soldier fly larvae, including industrial by-products like brewery waste, livestock manure (such as poultry, cow and pig manure), as well as household and fruit wastes (Yakti *et al.*, 2022; Dortmans *et al.*, 2021; Eawag & Sandec, 2018). In Uganda, commonly used substrates include fruit wastes (such as avocado, mangoes, pineapples, and oranges), market wastes, livestock manure, like poultry manure, and industrial by-products such as brewery wastes (Hudson *et al.*, 2019).

Production efficiency is significantly impacted by how substrates are sourced and the business model adopted by farmers. For example, a study by Beesigamukama *et al.* (2022), revealed that sourcing substrates from off-farm purchases is not sustainable, as it incurs additional transportation and labor costs, thereby increasing production expenses. Many researchers have advocated integrating black soldier fly production with other livestock farming to create a recycling approach. For example, a study by Chia *et al.* (2019), suggested rearing livestock such as poultry and using its waste to feed the larvae, while using the larvae produced as that particular livestock feed. This approach helps to reduce the extra costs associated with purchasing and transporting substrates from outside the farm.

On the other hand, the forms of substrates fed to the larvae greatly influenced the performance of the larvae. Previous studies revealed two forms of substrates fed to the larvae, including feeding using shredded substrates and feeding substrates without further preparation. However, studies revealed that substrate preparation before feeding the larvae significantly contributes to larvae's utilization of the substrates. For instance, grinding substrates increases the surface area of the larvae utilizing the substrates (Barrett *et al.*, 2023). This is consistent with the study by Yakti *et al.* (2023), which

reported that the physical characteristics of substrates influenced the performance of the black soldier fly larvae.

2.5.5 Water

Water is one of the most important inputs in livestock production; it is considered an integral requirement, estimated to constitute 8 percent of the global water supply (Schlink *et al.*, 2010), used mostly in intensive livestock and feed-based production. According to Schlink (2010), approximately 98 percent of molecules in livestock are constituted by water. Water is required for several uses, including regulation of body temperature, growth, lactation, digestion, regulation of mineral homeostasis, lubricating joints, cushioning the nervous system, transport of song, and excretion. Similarly, mass rearing of BSF under intensive production systems requires water for cleaning and post-harvest handling of BSF larvae during normal BSF processes, especially in separating the larvae from residues (Roffeis *et al.*, 2017). Consequently, water is a vital requirement for BSF farming, and its sourcing should be planned before establishing a BSF rearing unit.

2.5.6 Other materials required for black soldier fly production

The materials necessary for black soldier fly production vary depending on the management stages: love-cage management, prepupa management, egg and 5-DOL management, nursery management, general laboratory equipment and tools, machines, consumables, waste receiving and pre-processing equipment, waste treatment, product harvesting, and post-harvest treatment. The materials required are adult cage net, adult cage frame, shading basket, water bowl, cotton cloth, egg media, eggies, ant trap, dark cage, pupation container, pupation substrate, hatchling container, sieve (mesh 1 mm & mesh 3-5 mm), precision weighing scale, calculator, masking tape, spoon, and scoops, shredder, pallet, screen, bucket, cut jerricans, drying table, stove, and cooking pan. Understanding BSF rearing requirements enables smooth operation and time management while executing routine management practices.

2.5.7 Optimal rearing conditions for black soldier fly

Like other flies, BSF is sensitive to several environmental parameters, predominantly temperature, which is the most important non-biological factor (Salam *et al.*, 2022). Not only can it affect the development rate, season, and insects' daily cycle, but it also has a significant effect on the different features of insect biology, such as adult life expectancy, larval survival, fertility, growth, sex ratio, and population growth parameters (Chia *et al.*, 2018). The two fundamental factors that affect the black soldier fly's foraging, development, and life cycle are temperature and humidity. Moisture content plays an essential role in composting because it is a significant parameter for the survival of microorganisms, especially for the growth and development of BSF. The optimal water content of the feed varies between 65% and 90% (Liu *et al.*, 2021). Studies by many authors have shown that maintaining a relative humidity (approximately 60%) and a temperature of 27 °C at the site are the best conditions for mating and egg-laying (Singh & Kumari, 2019). The pH value is an inherent parameter that affects the life cycle and survival of BSF. Many studies on the black soldier fly revealed that a pH higher than 6 is the best condition for the survival, growth, and development of larvae. It is recommended that BSF be used for organic waste biotransformation with an initial pH of 6.0 to 8.0 (Meneguz, Gasco, *et al.*, 2018). The initial pH effect may be favorable to beneficial bacteria, thereby contributing to the survival, growth, and development time of the larvae; the gut microbiome of insects promotes weight gain, growth, and egg production of larvae (Meneguz, Gasco, *et al.*, 2018). Sunlight plays a key role in the mating events of the species in the natural environment (Zhang *et al.*, 2010). The study results demonstrated that sunlight with an intensity of 110 $\mu\text{mol m}^{-2} \text{s}^{-1}$ is required for almost 85% of mating events, which is the leading cause why mating in the winter season is highly restricted (Singh & Kumari, 2019).

2.6 Black soldier fly husbandry practices

2.6.1 Black soldier fly production objectives

Worldwide, several farming reasons for black soldier fly larvae have been reported and majorly tailored towards its potential benefits, most especially as an alternative protein source (Soma *et al.*, 2022), source of income (Abro *et al.*, 2020; Abro *et al.*, 2022) and

a source of frass fertilizer (Beesigamukama *et al.*, 2022; Lopes *et al.*, 2022; Basri *et al.*, 2022), and biodiesel (Hadj Saadoun *et al.*, 2020; Franco *et al.*, 2021; Rehman *et al.*, 2023). On the other hand, researchers reported farming black soldier flies for waste management purposes (Gasco *et al.*, 2020; Čičková *et al.*, 2015; and Dzepe *et al.*, 2023). Similarly, a study conducted by Surendra *et al.* (2020) reported the use of black soldier flies to manage waste from various sources, as evidenced by their waste volume reduction capacity. However, there is still limited documentation on BSFL production objectives in Uganda; yet this could guide, especially for new adopters of farming technologies, in increasing the overall productivity of black soldier fly larvae in Uganda.

2.6.2 Adult fly cage management

An adult fly cage serves as the housing unit for flies throughout their lifespan after emergence. During this time, adult flies are provided with water and an egg-laying attractant designed to entice female flies to deposit their eggs nearby (Eawag & Sandec, 2018). The components of the adult fly cage include a net equipped with a loop at the corner and a zipper, attractant containers, cotton wool moistened with water, a shading basket, a water bowl, egg trays, and an ant trap. The cage is designed to facilitate successful breeding by creating optimal conditions for mating and egg laying.

Black soldier fly cycle management relies on proper management of all stages, involving a consistent supply of substrate, and management of the rearing conditions to ensure continuation of the lifecycle (Eawag & Sandec, 2018). Replenishing through continuous feeding methods rather than batch feeding is encouraged to ensure larval activity to boost the colony size (Ribeiro *et al.*, 2022). Continuous feeding of larvae for the next two weeks, until pupation time, encourages colony continuation. Studies by Wang & Shelomi, (2017) have shown that black soldier flies can indeed be reared through complete life cycles, hence promoting self-replenishing.

On the other hand, early troubleshooting factors negatively impacting the performance of black soldier fly are fundamental to promote timely intervention upon immediate diagnosis of the problem associated with larval growth, adult fly behavior, and the impact of the larvae on waste breakdown. Namely, stunted growth due to poor feed quality, uneven growth because of non-uniform rearing conditions and pest infestations,

disease and predators, and bad odor. Hence, having clear documentation of black soldier fly farming activity is critical to ensure tracking and implementation of corrective measures to maintain the cycle.

Two key aspects of cage design are crucial for effective adult management: emergence and mating. Successful emergence is promoted by offering a dark, enclosed space that allows flies to exit their pupal cases, thereby minimizing the risk of early mating among immature flies and the associated stress (Eawag & Sandec, 2018). In contrast, successful mating occurs in a well-lit environment, ideally with natural light or artificial lighting (Tomberlin, 2016). Additionally, the adult fly mating cage should incorporate an attractant to encourage egg-laying in females, as well as basins or trays filled with water for hydration, given that adult flies derive their nourishment solely from water (Eawag & Sandec, 2018). Finally, the design must include management strategies for controlling rodents and other predators. For example, applying engine oil around the base of the adult fly cage frame can help deter ants, along with regular removal of waste from the cage.

2.6.3 Egg collection, weighing, and hatching

The BSF eggs are regularly collected after a given period. During egg collection, depending on the hatching method, the eggies are removed from the adult fly cage and hatch using various hatching methods, including the shower hatching method, wire mesh hatching, and tray-to-tray hatching methods, which involve scraping off the eggs before being directly inoculated onto the substrate under (Eawag & Sandec, 2018).

2.6.4 Management of the 5-day-old larvae (5-DOL)

The 5-DOL is removed from the hatching unit, and the manual sieve with a mesh size of 1 mm separates the larvae from the residue (Eawag & Sandec, 2018). During the sieving process, the small residual particles will fall together with the tiny larvae, whereas the larvae residue and larvae will remain on the sieve (Eawag & Sandec, 2018). The residual particles are scooped using a spoon as much as possible, and the remaining 5-DOL are weighed before being inoculated on the rearing substrate (Eawag & Sandec, 2018). The equipment for handling 5-DOL includes a precision weighing scale, a scoop, a sieve (mesh size 1 mm), containers for larvae and residue, and a measuring cap.

2.6.5 Black soldier fly larvae substrate preparation before feeding

The waste received at the facility is processed to ensure its suitability for feeding the larvae. The first step involves removing all hazardous materials, such as plastics and polythene bags. After this, the waste particle size is reduced by shredding, and excess water is drained from the substrate if it has too high moisture (Barrett *et al.*, 2023). Finally, different organic waste types are mixed to create a suitable balanced diet and a 70-80% moisture level for the larvae (Eawag & Sandec, 2018) and ready to feed the larvae.

2.6.6 Black soldier fly larvae and adult fly feeding

The study conducted by Banks *et al.* (2014) compared the growth of black soldier fly larvae (BSFL) using two feeding methods: the batch method and the continuous method. It reported significant differences between the larvae groups, with those fed using the batch method growing larger and heavier than their continuously fed counterparts, which exhibited slower maturation rates. According to Eawag & Sandec (2018), placing 10,000 5-DOL in a container measuring 40 x 60 x 17 cm and feeding them with 15 kg of wet waste (comprising 75% water) over 12 days allows for additional waste to be added to the container on days 5 and 8. This feeding strategy continues until the larvae grows sufficiently to be harvested after 12 days. The 5-DOL are reared on the waste for approximately two weeks before harvest, at which point the by-product is separated from the larvae.

2.6.7 Black soldier fly larvae harvesting

Harvesting is the process by which the larvae are separated from the residue. This can be achieved by using a manual or automated shaking sieve, which allows the larvae to be easily separated from the residue (Eawag & Sandec, 2018). Harvesting is done shortly before the larvae become prepupae (Barrett *et al.*, 2023). BSFL harvest is carried out every 12 days from the start of feeding the larvae with the substrate upon hatching. (Eawag & Sandec, 2018). Upon reaching the harvesting period, when the larvae have reached their maximum weight and optimal nutritional levels, the BSFL and by-product are separated. Several larval harvesting methods have been recommended in previous studies, including sieving, manual picking, and self-

harvesting. According to Eawag & Sandec (2018), the separation method depends on the nature and texture of the substrate during rearing. Dry mass residue can be separated from the larvae through shaking either a sieving stand with a mesh size of 3-5 mm, depending on the size of the larvae, or using a sieving basket. In contrast, a wet slurry with a sticky mass on the larvae would require washing with water during larval harvesting due to the difficulty of separating them using a sieve. Consequently, the choice of harvesting method should be guided by the nature of the frass during BSFL harvesting time.

2.6.8 Post-harvest handling

Effective management of prepupae is essential for maintaining continuous cycles. Following the harvest of the larvae, it is crucial to provide additional feeding for a minimum of two weeks to ensure that the larvae molt into prepupae (Sheppard *et al.*, 2002). These prepupae can either be removed from the nursery containers and placed into a pupation chamber or self-harvested by crawling out of the nursery container into the chamber.

Additionally, larva refinement is necessary before storage or sale, along with the processing of by-products from Black Soldier Fly (BSF) larvae production, prior to utilizing the residues as fertilizer. A sanitizing step can be employed, which involves immersing the larvae in boiling water. This effectively kills the larvae and prompts the evacuation of their guts.

After boiling, the larvae are then laid out on drying tables, which are regularly turned to accelerate the drying process. Once dried, the larvae can be stored or further processed through methods such as drying, oil extraction, grinding, and pelletizing. Consequently, the final product is prepared for the market. Hence, the processed product is ready for the market.

2.6.9 Impact of rearing conditions on the black soldier fly activities

Environmental conditions significantly influence the time of mating and oviposition (Tomberlin, 2016). The study results showed that the adult fly mating activity positively correlates with the light intensity, whereas light intensity had no

impact on the oviposition activity. Similar study findings also revealed that adult fly mating negatively correlates with the time of day. Hence, fly mating mainly occurs during the early time of the day when there is high light intensity.

On the other hand, the study conducted by Tomberlin (2016) revealed that temperatures significantly affect all stages of development of black soldier fly except for pupation time. For instance, temperatures below 15 °C are associated with low larval activity, resulting in reduced substrate reduction and, consequently, poor larval growth (Holmes *et al.*, 2016). These findings are consistent with the study by Salam *et al.* (2022), which reported that different stages of black soldier fly larvae can be affected by either increasing or decreasing the temperature. Also, temperature influence on the longevity of the adult black soldier fly was reported (Chia *et al.*, 2018), this study revealed that adult flies live longer in intermediate temperatures than at extreme temperatures. Moreover, hatching eggs from BSFL larvae incubated at high temperature takes less time than at low temperature. The development time of the larvae differed significantly between temperatures (Shumo *et al.*, 2019). Therefore, there is a significant influence of temperature on the development time of the larvae and overall activity of the adult fly.

Furthermore, a study by Tomberlin *et al.* (2016) showed that relative humidity significantly influences the oviposition of the flies. Most authors carried out related studies and concluded that most (approximately up to 99.6%) oviposition occurs at a relative humidity of 60% (Booth & Sheppard, 1984). Other studies suggested that maintaining a relative humidity of around 60% at the site is perfect for egg-laying and mating (Holmes & Vanlaerhoven, 2012). Consequently, understanding and observing optimal relative humidity is fundamental to ensuring good performance of the black soldier fly.

However, studies have shown that environmental conditions such as temperature, humidity, pH, and light intensity had no impact on the feed conversion ratio (Ribeiro *et al.*, 2022). The findings from this study revealed that temperature and moisture content had no significant impact on feed conversion ratio. On the other hand, other studies have proven that differences in substrate properties have an impact on the larvae's survival rate, growth, and feed conversion ratio (Guidini Lopes *et al.*, 2023; Yakti *et al.*, 2023). The study findings revealed that a low survival rate and longer growth

duration were observed over time with low particle size substrate and vice versa. In contrast, a high feed conversion ratio was observed with a low particle size substrate. Therefore, it is important to identify the desired physical characteristics of substrates for optimal BSFL growth.

2.7 Significance of selective breeding and knowledge of farmers' trait preferences

Enhancement of desirable characteristics in livestock has been based on quantitative genetics, primarily involving principles of heritability controlled by genes and environmental variations. The selection of individuals with desirable genotypic characteristics to participate in breeding programs has been previously studied (Facchini *et al.*, 2022). On the other hand, considering that the selection goal is fundamental, as it forms the basis for the desirable traits required for enhancement (Hansen *et al.*, 2014). Meanwhile, prioritizing those traits and using appropriate tools to develop a breeding program is necessary for achieving the breeding objective's success (Hansen *et al.*, 2014). For example, selection tailored to enhance the performance of a given herd will involve choosing individuals with traits that improve their production, increase disease resistance, and improve feed conversion rate. On the other hand, selection based on target production systems and the market would involve improving traits that will eventually thrive in those specific rearing systems, as well as traits responsible for the quality of the product desired by the market.

Most studies have focused on selective breeding for designing breeding programs (Eriksson & Picard, 2021). Several successes have been recorded as well in livestock species, including cattle (Ouédraogo *et al.*, 2019), goats (Tyasi *et al.*, 2022), and sheep (Abebe *et al.*, 2020). Similarly, selected breeding practices have been observed in BSF reared under an experimental setting (Hansen *et al.*, 2024). Selective breeding in BSF is mainly based on individuals' phenotypes such as larval weight, larval size, larval color, larval growth rate, quality traits such as protein content and fat content, and fitness traits such as fecundity, environmental condition tolerance such as temperature, relative humidity, and light variations (Hansen *et al.*, 2024; Nawoya *et al.*, 2024; Barrett *et al.*, 2023).

Trait enhancement has been achieved by breeding individuals with specific traits to pass those traits to the next generation. However, due to limited resources, prioritization of the most important characteristics is key to implementing successful breeding programs. The participation of key stakeholders who will benefit from the breeding program is at the core of the initial design steps. A study conducted elsewhere involved a participatory approach involving goat farmers in designing community-based breeding programs (Teklewold *et al.*, 2013), and the outcome showed enhanced productivity. However, no study has yet been conducted in Uganda that involves identifying the preferred traits of black soldier fly farmers. Knowledge of BSF farmers' trait preferences is crucial for implementing a successful breeding program to enhance BSF productivity, increase its potential in alleviating poverty, create more job opportunities, and improve its price competitiveness with substitutes such as soy meal and fish meal.

Studies have demonstrated the benefits of selective breeding in various livestock species and crops and have suggested similar applications for insect mass rearing (Van *et al.*, 2015). In comparison to livestock, insects are more suitable candidates for selective breeding due to their short life cycles, fecundity, protein-fat ratio, and temperature tolerance, making improvement through selective breeding more efficient than in livestock (Eriksson & Picard, 2021). Mating of black soldier flies in close spaces has also been reported by Facchini *et al.* (2022); the performance of the selected body weight line increased compared to the base population line. For example, under automated production settings, an average increase of +39% in larval weight, +34% in wet crate yield, +26% in dry matter crate yield, +32% in crude protein per crate, and +21% crude fat per crate was achieved in the selected line compared to the base population line. In addition to genetic improvement of the economic and fitness traits, other benefits realized from selective breeding of black soldier flies under industrial settings include reduced exposure to pathogens and diseases from the wild population and controlled breeding (Eriksson & Picard, 2021).

2.7.1 Morphometric trait characteristics

Studies have reported the impact of larval diets on larval life history traits and nutrient composition (Miranda *et al.*, 2019; Gobbi *et al.*, 2013; Tomberlin *et al.*, 2002). The life history traits reported that are significantly affected include the size of the larvae, larval

growth rate, weight, adult fly size, adult fly longevity, and survivorship. The differences are attributed to the variation in the amount of nutrients contained in particular substrates fed to the larvae (Gobbi *et al.*, 2013); for instance, Renault, Aubin-Horth, & Saucier, (2023) investigated the effects of phenotyping, adult selection, and mating strategies on the reproductive outcomes of *H. illucens*. Their findings suggest that selecting individuals based on specific phenotypic traits, including body size, can enhance reproductive efficiency. Larger individuals, particularly males, exhibited higher mating success and contributed to increased oviposition rates in females. Elsewhere, studies have demonstrated that the larval diet influences the population dynamics of BSFs, which is crucial in selective breeding. Variations in larval wings, egg development, and final larval weight have been reported (Gobbi *et al.*, 2013). A study by Miranda *et al.* (2019), reported high larval weight, adult fly size, shorter development period, and long lifespan in adult fly-fed poultry manure compared to cow dung and swine manure. Adult fly body size positively influences female fly mating and egg production (Cammack & Tomberlin, 2017). A similar study reported that early adult fly emergence occurs when larvae are fed protein-rich manure compared to carbohydrate-rich manure.

2.7.2 Nutritional trait characteristics

The body composition of BSF larvae varies among substrates and development stages in protein and fat content (Barragan-Fonseca *et al.*, 2017). Although BSF larvae, on average, contain both a high protein and fat content (Leni *et al.*, 2024). The body composition of the larvae depends on the quality and quantity of food ingested (Barragan-Fonseca *et al.*, 2017). For instance, larvae fed swine manure have higher protein content than cow manure, and diets based on spent grains produce higher protein content (Banks *et al.*, 2014). On the other hand, fat content accounted for about 30% of the BSF larval biomass fed on manures, but chicken manure supported maximal larval growth and crude fat content (Chia *et al.*, 2020). On the other hand, a study by (Nguyen & Tomberlin, 2013), found that larvae fed fish and liver contained more protein and fat than those fed chicken feed. Despite producers being well-versed in information documented for experimental studies on the effect of substrate feed and the development stage on chemical traits, there is no documentation of the preferred trait for the nutrient content of the larvae. Understanding the proffered nutrient content

would guide the production practices employed and form the basis for selecting the preferred nutrient content of the larvae for breeding.

2.8 Black soldier fly production challenges

Despite the potential above, there are opportunities for BSF production in the livestock sector and environmental protection through the circular economy (Siva *et al.*, 2022). BSF production has faced several challenges. Several factors, including biotic and abiotic factors, constrain black soldier fly production. For example, according to Holmes *et al.* (2012), BSF production requires warm environmental conditions, which have proved difficult and energy-consuming to sustain in temperate climates and during the winter period. The weather fluctuations, especially during periods of development, are also influenced by temperatures, the quality, and the quantity of the diet (Veldkamp *et al.*, 2012).

To date, fluctuation in the supply of BSF products limits its competitiveness with conventional protein feed ingredients. Consequently, the prices for insects and insect meals remain high. They cannot compete with other protein sources in this respect, making them too expensive compared with common sources of proteins used in poultry diets. Consequently, campaigns to promote the adoption of black soldier fly rearing and other efforts tailored towards scaling up its production to ensure a steady supply are key to successful BSF rearing.

Legislation currently needs to be improved on using insects as feed components. Thus, there is no standard or regulation for quality and safety aspects to be monitored (Dicke *et al.*, 2020). Like other countries practicing BSF, Uganda currently follows developments in legislation elsewhere, such as in the EU. In the EU, the use of insects in feed is currently permitted in aquaculture, and the types of substrates used for insect production are still subject to legal limitations (IPIFF, 2020).

Farmers need more knowledge, yet it is relevant for smallholder farmers who wish to venture into insect farming (Chia *et al.*, 2019). Training in BSF farming will enhance knowledge on how to grow BSFL on leftover streams, choose suitable substrates, and understand how to effectively and efficiently use the substrate to achieve optimum productivity (van Huis *et al.*, 2020b).

Likewise, in livestock production, where feeding accounts for approximately 60-70 percent of the overall production input, BSF production relies on a reliable supply of suitable substrates to ensure optimal production efficiency. For instance, purchasing and transporting substrates long distances from the BSF-rearing facility has proven not to be economical (Beesigamukama *et al.*, 2022). The study revealed that substrate accounts for 89-90 percent of the overall production costs of BSF; realizing a stable supply of constant-quality substrates may take time, depending on the scale of production and the logistics involved.

Environment-related issues, nasty odors (Dicke *et al.*, 2020). Production of BSF involves sourcing large volumes of waste, which are directly used or temporarily stored, awaiting substrate preparation, and later fed to the BSFL. Improper storage of waste may lead to infestation by houseflies, resulting in nuisance and foul odors, especially for people neighboring the BSF facility, which consequently limits the production of BSF.

High labor costs involved at different stages of BSF production present huge constraints in overall production, especially in the mass production of insects, where both trained and untrained workers are required in the operation (Dicke *et al.*, 2020). A study by Roffies *et al.* (2017) recently reported that the economic performance of insect-based feed (IBF) production in West Africa was primarily determined by the costs attributed to labor. Hence, understanding the labor dynamics required in BSF operations is key to developing insightful labor shortage solutions and promoting efficient production.

2.9 Factors influencing black soldier fly productivity

Understanding the factors that influence black soldier fly performance, ranging from genetics to environmental conditions, as well as the complex molecular and physiological mechanisms involved, is essential (Barrett *et al.*, 2023). Various elements such as resource availability, competition, predator presence, seasonality, humidity, and temperature play a significant role in determining an insect's growth rates.

The quality of nutrition, which can vary based on the species of black soldier flies or other insects and the substrate on which they are raised, is a critical factor. Research has indicated that the type of substrate provided to larvae can have a substantial impact

on the performance of the flies. For example, a study conducted by Chia *et al.* (2022) demonstrated that larvae-fed diets supplemented with brewers' yeast exhibited higher crude protein levels than those on alternative diets. However, when brewers' yeast and molasses were combined with spent grains, the resulting larvae had lower crude protein content compared to those fed diets mixed with water alone. This underscores the importance of understanding and managing these factors to optimize black soldier fly production.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

The study was carried out in three different agro-ecological zones: Lake Victoria Crescent (LVC), North Eastern Savanna Grassland (ESG), and Western Savanna Grassland (WSG) (Ogwal *et al.*, 2021).

3.1.1 Lake Victoria Crescent

The region receives rainfall evenly distributed, ranging from 1200 mm to 2500mm (Ogwal *et al.*, 2021). In the eastern part of the zone, there are two rainy seasons: the primary season, which is March to May and peaks in April, and the secondary season, between September and November. The temperature ranges from 15-30 °C, and the altitude ranges from 1000-1800m (Ogwal *et al.*, 2021). It has several districts. The humid climatic conditions supported by the bi-modal rainfall and consistent warm temperatures provide favorable conditions for agricultural activities, generating wastes which are utilize as substrate for feeding black soldier fly larvae.

3.1.2 Western Savannah Grassland

Average rainfall is about 1270mm, with high variability ranging from about 800mm in eastern L. Albert parts to about 1400mm in western L. Albert. It has two rainy seasons, mainly from August to November, with a peak in October, and a secondary peak from March to May, with a peak in April. The primary dry season is from December to mid-March. Temperature ranges from 1530 °C and altitude from 621-1585m above sea level (ABL) (Ogwal *et al.*, 2021).

3.1.3 The North Eastern Savannah Grassland

The rainfall ranges between 1215 and 1328 mm. It has two rainy seasons, with the southern part from March to May, with a peak in April, and the secondary from August to November, with a peak in October and November. The temperature ranges from 15 -32.5 °C. The Main dry season is from December to February, and the secondary dry

season is from June to July. The altitude ranges from 914 to 1800m above sea level (Ogwal *et al.*, 2021).

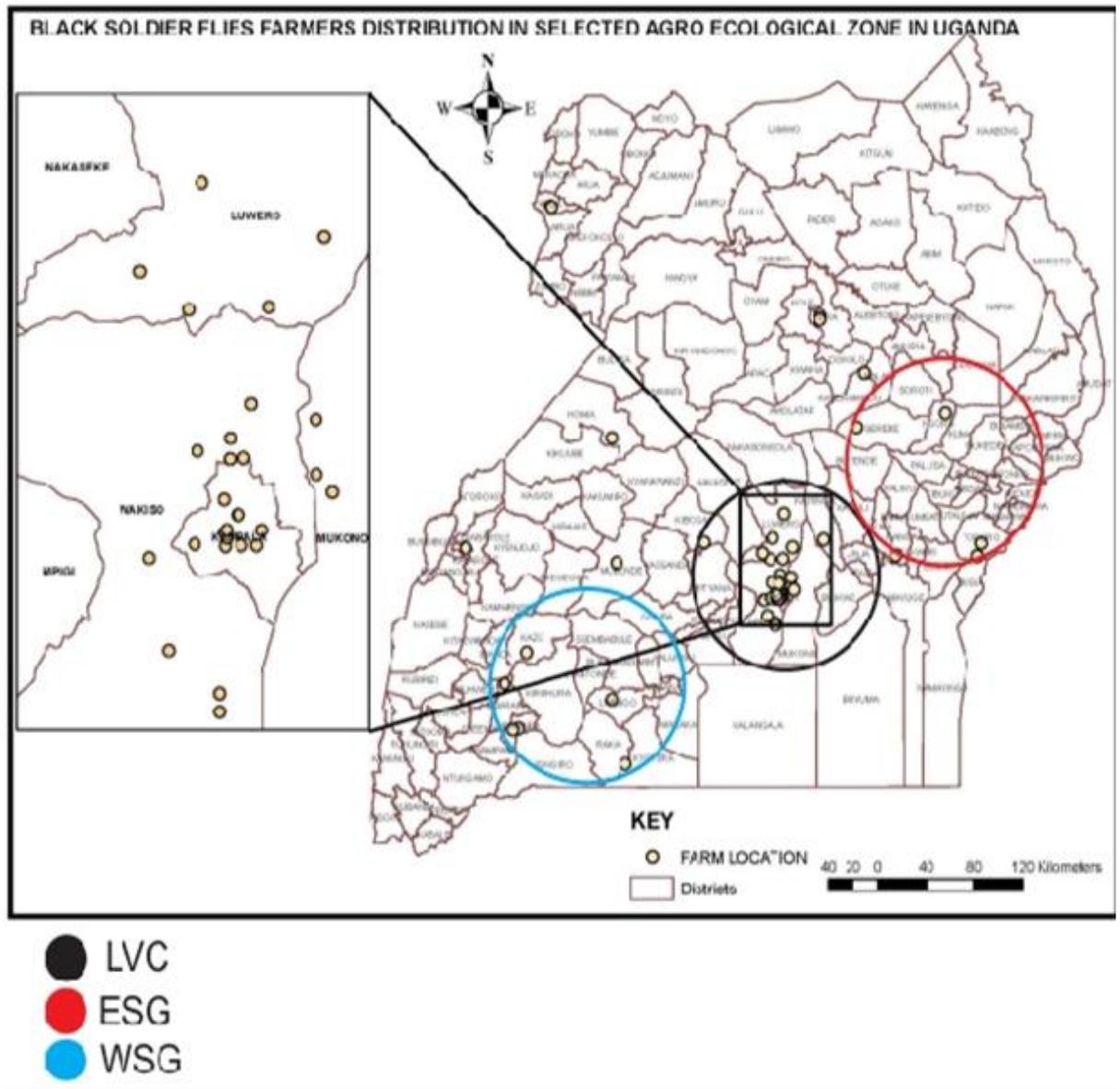


Figure 1: BSF Farmers Distribution

3.2 Study design

A cross-sectional study involving qualitative and quantitative data collection was conducted among BSF farmers across all three agroecological zones. A semi-structured questionnaire was administered through face-to-face interviews.

3.3 Sample size determination

This was established using the list of black soldier fly farmers provided by Makerere Research Insectary, located at the School of Food Technology, Nutrition and Bio-Engineering, College of Agriculture, Makerere University, Krejcie, and Morgan Table (Krejcie & Morgan, 1970).

Krejcie and Morgan formula,

$$S = \frac{X^2 NP (1-P) + d^2 (N-1) + X^2 P (1-P)}{d^2}$$

Where,

S= required sample

X^2 = the table value of chi-square for 1 degree of freedom at the desired confidence level (3.841)

N= the population size

P= the population proportion assumed to be 50 since this will provide the maximum sample size).

d = the degree of accuracy expressed as a proportion (0.05)

Using the above formula, out of 120 black soldier farmers, 92 were purposively selected for the survey. However, only 83 respondents out of 92 selected participated in the survey. Nine respondents declined to participate due to unknown reasons.

3.3.1 Sampling strategy

A multistage sampling approach was then employed during sampling. In the first stage, the black soldier fly farmers were categorized into agro-ecological zones, and the first three zones with the highest numbers of farmers were selected for the survey. The second and third stages involved purposive sampling of the districts and individual farmers within the chosen districts, using names and the contacts of the black soldier fly farmers shared on the lists. A total of 20 districts were sampled. Within LVC,

Kampala (16), Masaka (4), Mpigi (4), Mukono (9), Wakiso (18), Entebbe (2), Jinja (4), Luwero (2), and Kayunga (1) were sampled. Within North ESG, Lira (4), Gulu (2), Kaberamaido (1), Serere (3), Kumi (1), Mbale (2), Tororo (3), and Iganga (1) were sampled, and lastly, within WSG, Mubende (2), Mityana (1), Hoima (2), and Kiboga (1) were sampled. In the final stage, respondents were randomly chosen from the districts within the three selected agro-ecological zones. Out of the 83 respondents sampled, the majority (60 participants) were from Lake Victoria Crescent, followed by North Eastern Savanna Grassland (17 respondents) and Western Savanna Grassland (6 respondents).

3.3.2 Adult BSF, larvae, pupa, and prepupa sample sampling criteria

Out of 83 black soldier fly farmers who participated in the survey, 44 farmers (LVC=30, ESG = 9, WSG =5) were purposively selected for sampling larvae, prepupa, pupa, and adult flies; farmers who had fresh larvae ready for harvest, prepupa, pupa, and adult flies were sampled. Unfortunately, farmers within WSG agro-ecological zones never had adult BSF stages. During sampling, the black soldier farmer identifies at least one active adult cage. Different stages were sampled, including 10 adult flies, 10 larvae, 10 pupae, and 10 prepupa from each farmer. A total of 1710 samples (LVC= 1200, ESG= 360, WSG= 150) were collected. During sampling, the samples were placed in 5ml falcon tubes containing 75% ethanol, which served as a preservative. The samples were later labeled and placed in zip-lock bags before being transported to the laboratory for measurements.

3.4 Data collection

3.4.1 Survey

Eighty-three respondents were purposively selected for a cross-sectional survey to collect qualitative and quantitative data using a pre-tested questionnaire. The pre-testing involved purposive sampling of 7 black soldier fly farmers within Kampala; adjustments were made to the questionnaire to ensure accurate data was collected. Data collected included socio-demographic characteristics (age, sex, income level, level of education, years spent rearing black soldier flies, and their training in black soldier flies farming). Other data collected included socio-economic characteristics, production objectives, breeding knowledge, trait preferences, production practices, marketing of

products, and production challenges. The questionnaire was administered to the household head, but the farmhand and any other household member were interviewed if the household head was unavailable.

3.4.2 Measurement of the length, girth, and weight of the larvae

Samples of larvae at 10 days, pre-pupa at 30 days, pupa at 35days, and adult flies at 7 days from selected farms were sampled and preserved, and morphometric measurements were taken at the Nutrition Laboratory located at the College of Veterinary Medicine, Animal Resources and Biosecurity (COVAB), Makerere University. Specimens were delicately removed from the preservative solution and gently blotted dry using tissue paper prior to carrying out three measurements, namely weight, length, and width using Kern ABS-N analytical weighing scale. Weigh boats provided a controlled environment for weighing, while forceps facilitated precise manipulation. Tissue paper was utilized to blot specimens dry, minimizing any residual moisture that could affect measurements. The net weight of both larvae pupae, prepupa, and adult flies was determined using a precision analytical weighing scale. This scale provided measurements in grams, ensuring a high degree of accuracy. To ensure precise readings, specimens were gently blotted dry from any residual preservative solution before being weighed. A NHBS wildlife survey & monitoring vernier caliper was used for dimensional measurements. Specimens were placed on their dorsal side, and the height and girth were meticulously measured, while the width was measured from the midpoint of both larvae and pupae to ensure consistency.

3.5 Statistical analysis

The collected data was cleaned by auto-filling raw and column, removing duplicates and blank cells, correcting spelling errors, and validating data. Later, the cleaned Excel file version 2013 was imported into Statistical Package for Social Sciences (SPSS) version 23 and analyzed. Descriptive statistics were used to analyze data on socio-demographic information, production practices, morphometric traits sampled, and production challenges. The data collected to assess the production objectives for rearing black soldier fly larvae and trait preferences were ranked based on a Likert scale (5- Most important, Important-4, Least important -3, Indifferent -2, and not important -1. Furthermore, the Kruskal-Wallis test was conducted to test differences in the

characteristics and production objectives for farming BSF in selected AEZs. Chi-square statistics were used to compare the association between production objectives, practices, and farmers' black soldier fly trait preferences from the three selected agroecological zones. The frequencies and percentages were presented in tables and graphs.

Lastly, a linear regression model was used to determine factors affecting the yield of black soldier flies produced. The relationship between a dependent variable Y and independent variables (predictors) denoted X_1, X_2, \dots, X_n fitting a linear equation to the observed data. The general formula for a linear regression model equation used in the analysis is expressed below;

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n + \varepsilon$$

Where:

- Y is the dependent variable (the yield of BSFL produced).
- X_1, X_2, \dots, X_n are the independent variables (predictors).
- β_0 is the intercept, representing the value of Y when all X 's are 0.
- $\beta_1, \beta_2, \dots, \beta_n$ are the coefficients of the independent variables, indicating the change in Y for a one-unit change in each corresponding X , holding other variables constant.
- ε is the error term, accounting for the variability in Y that the linear relationship with X cannot explain. The predictor variables were age, gender, education level, and source of substrate

CHAPTER FOUR

RESULTS

4.1 Demographic characteristics of black soldier fly farmers

The characteristics of respondents by age, position at the farm, gender, and marital status were not significantly different across the selected agro-ecological zones except for education level ($p < 0.05$) (Table 1). Farmers participating in BSF production were mostly male (68%), 53% of the farmers were youths (age 18-35 years), the majority had attained tertiary education (74.39%), and the minority (4.88%) attained only primary education.

Table 1: Demographic characteristics of respondents across selected agro-ecological zones

Variable	Category(n=83)	Overall (%)	ESG	LVC	WSG	X ²	p-value
Age (years)	18-35	53.00	57.10	53.10	40.00	3.20	0.512
	36-59	42.20	42.90	42.20	40.00		
	Above 60	4.80	0.00	4.70	20.00		
Gender	Male	67.50	78.60	64.10	80.00	3.80	0.149
	Female	32.50	21.40	35.90	20.00		
Marital status	Married	60.20	64.30	57.80	80.00	1.06	0.586
	Single	39.80	35.70	42.20	20.00		
Education level	Primary	4.80	7.10	3.10	20.00	10.49	0.033
	Secondary	20.00	28.60	15.60	60.00		
	Tertiary	75.20	64.30	81.30	20.00		

4.2 Objective I: Characterization of black soldier fly production practices in different agro-ecological zones

4.2.1 Reason for black soldier fly farming in different agro-ecological zones

Overall, feed for livestock was the main reason for farming BSF across all the three selected agro-ecological zones. Also, in all three agro-ecological zones, there was a significant difference in ranking for feed for livestock, income from the sale of frass, and producing manure for one's farm. However, there was no significant difference in income from the sale of larvae, sales of breeding stock, and farming for pharmaceutical use.

Table 2: BSF production objectives across selected agro-ecological zones

BSF production objective	(n=83)	Score of importance					p-value
		Response (%)	ESG	LVC	WSG	Mean	
Income from BSFL sale	68.70	3.35 ^a	3.72 ^b	3.40 ^c	3.64	4	0.531
Income from frass sale	37.30	2.71 ^b	3.18 ^a	1.80 ^a	3.02	3	0.023
Farm manure for own farm	66.30	3.64 ^b	3.25 ^a	4.40 ^a	3.39	3	0.028
Sales of breeding stock	43.30	3.28 ^a	3.02 ^b	3.40 ^c	3.08	3	0.688
Feeds for livestock	80.70	4.50 ^b	4.14 ^a	5.00 ^a	4.02	5	0.045
For pharmaceutical use	2.40	1.92 ^b	2.02 ^b	2.00 ^b	2.00	2	0.860
Consume farm waste	56.60	3.39 ^b	3.26 ^a	3.42 ^b	3.36	4	0.450

^{a,b,c} Figures on the same row with different superscripts are significantly different

Likert scale: Most important-5; Important-4; Least important -3; Indifferent -2; Not important -1

4.2.2 Production characteristics of black soldier fly farmers

Most of the respondents (80.7%) had received training in BSF rearing; the majority had farmed BSF for less than one year (48.2 %) and were producing less than 100 kg for black soldier fly larvae weekly (54.2%). Overall, farmers used two rearing systems, vertical and horizontal rearing systems, with a few (9.6%) practicing both two rearing systems. In all three selected AEZs, vertical rearing systems (68.7%) and temporary rearing structures (72.3%) were mainly used for BSF farming.

Table 3: Production characteristics of black soldier fly farmers

Variable	Category (n=83)	Overall (%)	ESG	LVC	WSG	X ²	p-value
BSF farming experienced	<1 year	48.20	64.30	43.80	60.00	7.267	0.297
	1-2 years	38.60	21.40	43.80	20.00		
	3-4 years	6.00	0.00	7.80	0.00		
	>4 years	7.20	14.30	4.70	20.00		
Production level	<100basins	54.20	92.90	54.70	60.00	8.66	0.013
	>100basins	45.80	7.10	45.80	40.00		
Trained in BSF	Yes	80.70	64.30	82.80	100.00	3.80	0.149
	No	19.30	35.70	17.20	0.00		
Trainer	Farmer	69.90	64.30	70.30	80.00	1.19	0.879
	Institution	30.10	35.70	29.70	20.00		
Rearing system	Vertical	68.70	78.60	67.20	60.00	9.28	0.054
	Horizontal	21.70	7.10	26.60	0.00		
	Both	9.60	14.30	6.30	40.00		
Rearing structure	Permanent	27.70	21.40	26.60	60.00	2.92	0.009
	Temporary	72.30	78.60	73.40	40.00		
Frame material	Metallic	6.00	7.10	4.70	20.00	6.64	0.156
	Wooden	90.40	92.90	92.20	60.00		
	Both	3.60	0.00	3.10	20.00		
Cage material	Textile	91.60	0.00	90.60	80.00	17.56	0.001
	None	8.40	100.00	9.40	20.00		
BSF product sales	Eggs	15.70	0.00	20.30	0.00	20.19	0.446
	Larvae	62.70	35.70	73.40	0.00		
	Frass	22.90	14.30	26.60	0.00		
	BSFL meal	7.20	0.00	9.40	0.00		
Production scale	Large (> 300 kgs)	45.00	7.10	54.70	40.00	10.53	0.005
	Small (< 300 kgs)	54.20	92.90	45.30	60.00		

4.2.2.1 Characterization of black soldier fly attractant use

Most respondents (81.9%) used attractants in adult fly breeding cages. Wood was the most common egg-laying material used, whereas the rest used cardboard or plastic. Overall, mixed fruit waste (26.5%), followed by brewery waste, was used to stimulate the female fly to lay eggs, as mentioned earlier. Farmers were using different attractants across the three agro-ecological zones ($p < 0.009$). Variation in the attractant used might be due to accessibility and the impact of smell on attracting the female fly to lay eggs.

Table 4: Characterization of black soldier fly farmers' attractant use

Variable	Category (n=83)	Overall (%)	ESG	LVC	WSG	X ²	p-value
Use of an attractant	Yes	81.90	92.90	79.70	98.80	2.892	0.576
	No	18.90	7.10	20.30	1.20		
Attractant used	Chicken offal	9.60	28.60	4.70	20.00	51.22	0.009
	Cow dung	2.40	0.00	3.20	0.00		
	Goat manure	1.20	0.00	1.60	0.00		
	Brewery waste	10.80	0.00	14.10	0.00		
	Food leftovers	3.60	0.00	4.70	0.00		
	Mixed fruit waste	26.50	7.10	31.30	20.0		
	Pig manure	12.00	14.30	12.50	0.00		
	Poultry manure	30.10	42.90	25.00	60.00		
	Water hyacinth	1.200	0.00	1.60	0.00		
	None	12.00	7.10	0.00	0.00		

4.2.3 BSF Breeding Practices

The survey identified about 80% of black soldier fly farmers practicing breeding, 28% of the BSF farmers practicing breeding reported light as the major limiting environmental condition to adult fly mating. Other critical environmental conditions that affected fly breeding included temperature and humidity. However, a notable

proportion of farmers (18.29%) reported that all the environmental conditions, including temperature, light, and moisture, equally affect breeding. The most favorable time for female flies to oviposit was reported to be morning hours (44%). The fly oviposition time and laying material used were different across the three selected agro-ecological zones ($p < 0.05$).

Table 5: BSF farmers' breeding practices

Variable	Category (n=83)	Overall (%)	ESG	LVC	WSG	X ²	p-value																																																																																																																																		
Has breeding cage	Yes	81.9	14.5	61.4	6.0	1.455	0.483																																																																																																																																		
	No	18.1	2.4	15.7	0.0			Source of breeding material	Fellow farmer	59.04	10.8	45.8	2.4	2.74	0.841	Institution	34.94	4.8	26.5	3.6	Wild	6.02	1.2	4.8	6.0	Cage material affects	Egg laying	20.49	2.4	15.7	2.4	4.21	0.648	BSF mating	65.06	9.6	51.8	3.6	None	14.45	4.8	9.6	0.0	Microenvironment that affect breeding	Light	28.05	3.6	22.0	2.45	32.66	0.67	Humidity	1.22	1.22	0.0	0.00	Temperature	21.95	6.0	14.0	1.97	Light/temperature	24.39	0.29	21.7	2.4	Humidity/ tempt	2.44	0.0	2.44	0.0	All	18.29	2.4	11.09	4.8	Oviposit time	Afternoon	59.04	13.3	44.6	1.2	34.69	0.00	Early morning	2.41	0.0	0.0	2.4	Mid-morning	38.6	3.6	32.5	2.4	Laying material	Cardboard	12.0	6.0	4.8	1.2	26.93	0.003	Plastic	1.2	0.0	0.0	1.2	Wooden	72.3	10.9	59.0	2.4	None	14.4	1.2	12.0	1.2	Egg hatch duration	3 days	31.3	2.4	27.7	1.2	15.02	0.05	4 days	50.6	10.8	37.3	2.4	5 days	15.6	1.2	12.0	2.4	Above 5 days	2.4
Source of breeding material	Fellow farmer	59.04	10.8	45.8	2.4	2.74	0.841																																																																																																																																		
	Institution	34.94	4.8	26.5	3.6																																																																																																																																				
	Wild	6.02	1.2	4.8	6.0			Cage material affects	Egg laying	20.49	2.4	15.7	2.4	4.21	0.648	BSF mating	65.06	9.6	51.8	3.6	None	14.45	4.8	9.6	0.0	Microenvironment that affect breeding	Light	28.05	3.6	22.0	2.45	32.66	0.67	Humidity	1.22	1.22	0.0	0.00	Temperature	21.95	6.0	14.0	1.97		Light/temperature	24.39	0.29	21.7	2.4			Humidity/ tempt	2.44	0.0	2.44	0.0	All	18.29	2.4	11.09	4.8	Oviposit time	Afternoon	59.04	13.3	44.6	1.2	34.69	0.00	Early morning	2.41	0.0	0.0	2.4	Mid-morning	38.6	3.6	32.5	2.4	Laying material	Cardboard	12.0	6.0	4.8	1.2	26.93	0.003	Plastic	1.2	0.0	0.0	1.2	Wooden	72.3		10.9	59.0	2.4	None	14.4			1.2	12.0	1.2	Egg hatch duration	3 days	31.3	2.4	27.7	1.2	15.02	0.05	4 days	50.6	10.8	37.3		2.4	5 days	15.6	1.2	12.0			2.4	Above 5 days	2.4	2.4	0.0	0.0						
Cage material affects	Egg laying	20.49	2.4	15.7	2.4	4.21	0.648																																																																																																																																		
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	None	14.45	4.8	9.6	0.0			Microenvironment that affect breeding	Light	28.05	3.6	22.0	2.45	32.66	0.67	Humidity	1.22	1.22	0.0	0.00	Temperature	21.95	6.0	14.0	1.97		Light/temperature	24.39	0.29	21.7	2.4			Humidity/ tempt	2.44	0.0	2.44	0.0	All	18.29	2.4	11.09	4.8	Oviposit time	Afternoon	59.04	13.3	44.6	1.2	34.69	0.00	Early morning	2.41	0.0	0.0	2.4	Mid-morning	38.6	3.6	32.5	2.4	Laying material	Cardboard	12.0	6.0	4.8	1.2	26.93	0.003	Plastic	1.2	0.0	0.0	1.2	Wooden	72.3	10.9	59.0	2.4		None	14.4	1.2	12.0	1.2			Egg hatch duration	3 days	31.3	2.4	27.7	1.2	15.02	0.05	4 days	50.6	10.8	37.3	2.4	5 days	15.6	1.2	12.0	2.4		Above 5 days	2.4	2.4	0.0	0.0																										
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	Mid-morning	38.6	3.6	32.5	2.4			Laying material	Cardboard	12.0	6.0	4.8	1.2	26.93	0.003	Plastic	1.2	0.0	0.0	1.2	Wooden	72.3	10.9	59.0	2.4		None	14.4	1.2	12.0	1.2			Egg hatch duration	3 days	31.3	2.4	27.7	1.2	15.02	0.05	4 days	50.6	10.8	37.3	2.4	5 days	15.6		1.2	12.0	2.4	Above 5 days	2.4			2.4	0.0	0.0																																																																														
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	5 days	15.6	1.2	12.0	2.4																																																																																																																																				
	Above 5 days	2.4	2.4	0.0	0.0																																																																																																																																				

4.2.4 Management practices at different stages of the BSF life cycle

Farmers participating in BSF rearing majorly harvested larvae by sieving (50.6%) and by manual picking (36.14%). The major post-harvest practice carried out by farmers was separating larvae from the pupa (87.33%). Other post-harvest handling practices identified included washing and drying harvested larvae before feeding them to the livestock. Most black soldier fly farmers collected eggs after two days (63.86%), whereas inoculation of the substrate was mainly done six days after hatching into larvae. There was no statistical significance in the farmers' management practices across the selected AEZ except for the stage of substrate inoculation, pupa management, and marketing BSF products ($p < 0.05$)

Table 6: Management practices across different BSF stages

Variable	Category (n=83)	Overall (%)	ESG	LVC	WSG	X ²	p-value
Adult fly feeding	Yes	87.33	12.0	66.3	6.0	6.45	0.168
	No	12.66	2.4	9.6	0.66		
BSF egg weighing	Yes	41.03	4.8	34.9	1.2	6.92	0.14
	No	58.97	10.8	42.2	4.8		
	Wild	6.02	1.2	4.8	6.0		
BSF substrate inoculation stage	Eggs	16.90	1.2	15.7	0.0	24.31	0.018
	5 DOL	14.46	3.6	8.4	2.4		
	6 DOL	61.45	9.6	48.2	3.6		
	8 DOL	2.4	0.0	2.4	0.0		
	None	3.6	2.4	1.2	0.0		
Larvae harvesting methods	Sieving	50.6	8.4	38.6	3.6	24.31	0.76
	Manual picking	36.14	8.4	26.5	1.2		
	Self-harvesting	7.23	0.0	6.0	1.2		
Larvae management practices	Separation	31.3	4.8	21.7	4.8	23.27	0.804
	Washing	3.6	0.0	3.6	0.0		
	Drying	4.8	0.0	3.6	1.2		
	All	32.3	7.2	25.2	0.0		
	None	7.2	1.2	6.0	0.0		
Pupa management practices	Watering	1.2	0.0	0.0	1.2	68.34	0.00
	Sorting	50.6	9.6	39.8	1.2		
	Culling	4.8	0.0	4.8	0.0		
	Sorting & culling	14.4	3.6	9.6	1.2		
	Sorting & washing	25.3	3.6	21.7	0.0		
BSF products marketing	Yes	61.4	10.8	50.6	0.0	8.48	0.014
	No	38.6	6.0	26.5	6.0		

4.2.5 Characterization of BSF farmers' substrate use

Farmers generally utilized less animal waste compared to plant waste substrates. Among the different substrates, brewery waste emerged as the most preferred for rearing Black Soldier Fly larvae (BSFL), while water hyacinth was the least favored. Interestingly, farmers reported that market waste yielded the highest production rates. The choice of substrate sources showed significant statistical differences across the three selected agro-ecological zones. However, the type of substrate fed to the larvae and the different substrates used did not show any statistically significant differences.

In the Lake Victoria Crescent (LVC) zone, most farmers purchased their substrates off-farm. Conversely, in the North Eastern Savanna Grassland (ESG) and Western Savanna Grassland (WSG) zones, the primary sources of substrates were on-farm. The study identified two forms of substrates used for feeding the larvae: whole and shredded. More than 50 percent of the farmers opted for shredded substrates.

Within the LVC zone, livestock manure and brewery waste were commonly utilized by farmers. In the ESG zone, the majority of farmers relied on market waste, while in the WSG zone, BSF farmers predominantly used mixed fruit waste for rearing BSFL.

Table 7: Characterization of BSF farmers' substrate use

Variable	Category (n=83)	Overall (%)	ESG	LVC	WSG	X²	p-value
Substrate source	Off-farm free	18.100	35.70	14.10	20.00	12.40	0.015
	Off-farm purchase	56.600	14.30	65.60	60.00		
	On-farm	25.300	50.00	20.30	20.00		
Substrate form	Shredded	75.90	64.30	79.70	60.00	2.95	0.565
	Whole	20.50	28.60	17.20	40.00		
	Both	3.60	7.100	3.10	0.00		
High-yielding substrate used	Bread waste	1.200	0.000	1.600	0.00	10.73	0.953
	Cow dung	1.200	0.00	1.60	0.00		
	Brewery waste	18.10	14.30	18.90	20.00		
	Market waste	38.60	64.30	34.40	20.00		
	Pig manure	2.40	0.00	3.100	0.00		
	Mixed fruit waste	15.70	7.10	15.60	40.00		
	Poultry manure	7.200	0.000	7.800	20.00		
	Restaurant waste	13.30	14.30	14.10	0.00		
	Vegetable waste	1.200	0.000	1.60	0.00		
	Water hyacinth	1.200	0.000	1.60	0.00		
Most preferred substrate	Brewery waste	26.50	35.70	25.00	20.00	14.05	0.725
	Food leftovers	8.40	14.30	7.90	0.00		
	Fruit waste	19.30	21.40	17.90	40.00		
	Maize bran	3.60	7.10	3.10	0.00		
	Market waste	20.50	0.00	25.00	20.00		
	Poultry manure	16.90	21.40	15.60	20.0		
	Pig manure	3.60	0.00	4.70	0.00		
	Water hyacinth	1.20	0.00	1.20	0.00		

4.3 Objective II: Identify preferred traits of black soldier flies in the different agro-ecological zones

4.3.1 Morphometric traits of BSF stages sampled in different agro-ecological zones

Generally, BSF larvae and pre-pupa sampled in LVC weighed the heaviest, whereas pupa in ESG weighed the heaviest compared to those in LVC and WSG (Table 8). Meanwhile, larvae obtained from the WSG were longer than those in the rest of the AEZ. Surprisingly, the width obtained from the BSF stages sampled was relatively similar across all the AEZ (Table 8).

Table 8: Mean and standard deviation of larvae, pre-pupa, and pupa morphometric characteristics in selected AEZs

AE Z	Mean \pm SD (n=83)								
	Larvae			Pre-pupa			Pupa		
	Weigh ht(g)	Length (mm)	Widt h(m m)	Weigh t(g)	Length (mm)	Width(mm)	Weigh t(g)	Length(mm)	Widt h(m m)
LV	0.2 \pm 0	1.7 \pm 0.	0.4 \pm 0	0.5 \pm 0.	1.8 \pm 0.	0.4 \pm 0.	0.14 \pm 0	1.9 \pm 0.3	0.5 \pm 0
C	.09	5	.07	1	3	1	.03		.06
ES	0.1 \pm 0	1.4 \pm 0.	0.4 \pm 0	0.2 \pm 0.	2.0 \pm 0.	0.5 \pm 0.	0.2 \pm 0.	2.0 \pm 0.3	0.5 \pm 0
G	.04	4	.08	05	3	05	07		.06
WS	0.1 \pm 0	1.8 \pm 0.	0.4 \pm 0	0.2 \pm 0.	1.8 \pm 0.	0.4 \pm 0.	0.2 \pm 0.	1.8 \pm 0.4	0.4 \pm 0
G	.04	4	.1	07	4	1	05		.1

4.3.2: Mean average and standard deviation for larvae, prepupa, and pupa with substrate

Generally, BSF larval stages sampled fed poultry manure before pupation weighed lighter and shorter, except at pupal stages; meanwhile, market waste and restaurant waste showed better performance. Strangely, the width obtained from the BSF stages sampled was relatively similar to that of the substrate fed prior to pupation stages (Table 9).

Table 9: Mean average and standard deviation for larvae, prepupa and pupa with substrate

Main substrate	Mean \pm SD(n=83)								
	Larvae			Pre-pupa			Pupa		
	Weight(g)	Length(mm)	Width(mm)	Weight(g)	Length(mm)	Width(mm)	Weight(g)	Length(mm)	Width(mm)
Brewery	0.12 \pm 0.06	1.76 \pm 0.3	0.43 \pm 0.06	0.16 \pm 0.07	1.87 \pm 0.3	0.48 \pm 0.09	0.19 \pm 0.05	2.1 \pm 0.16	0.55 \pm 0.05
Fruit waste	0.07 \pm 0.3	1.3 \pm 0.2	0.4 \pm 0.1	0.2 \pm 0.1	1.8 \pm 0.4	0.4 \pm 0.1	0.1 \pm 0.3	1.7 \pm 0.3	0.5 \pm 0.1
Market waste	0.2 \pm 0.1	1.7 \pm 0.3	0.4 \pm 0.1	0.2 \pm 0.04	1.8 \pm 0.2	0.5 \pm 0.05	0.1 \pm 0.07	1.9 \pm 0.3	0.5 \pm 0.07
Poultry manure	0.1 \pm 0.04	1.2 \pm 0.3	0.3 \pm 0.2	0.1 \pm 0.04	1.6 \pm 0.2	0.5 \pm 0.2	0.2 \pm 0.03	2.0 \pm 0.2	0.6 \pm 0.05
Restaurant waste	0.2 \pm 0.05	1.5 \pm 0.3	0.4 \pm 0.2	0.2 \pm 0.04	2.02 \pm 0.1	0.5 \pm 0.03	0.13 \pm 0.02	1.9 \pm 0.06	0.5 \pm 0.06

4.3.2 BSF farmers' trait preferred across different agro-ecological zones

Overall, big-girth larvae were ranked as the main preferred trait, whereas high protein content larvae were mentioned as the most important trait by the majority of the farmers in the three selected agro-ecological zones. Other important traits preferred were long larval length, short larval growth duration, and high-temperature adaptability. In ESG, other important traits preferred were high protein content and long larval length, whereas in the LVC, big larval size and high protein content were prioritized. Similarly, in the WSG, the most important traits preferred were big larval size, long larval length, light adaptability, and temperature adaptability. Furthermore, preference for high protein content, adaptability to high temperatures, larvae length, and size were statistically significant in all three selected AEZs, whereas adaptability to light, adaptability to humidity, larvae fat content, and time taken for the larvae to grow were not statistically significant.

Table 10: BSFL preferred trait across selected agro-ecological zones

Trait	Response (%) (n=83)	Score of importance					p-value
		ESG	LVC	WSG	Mean	Median	
High protein content	20.30	4.93 ^a	4.32 ^a	3.80 ^b	4.39	5	0.043
High light adaptability	7.50	4.14 ^a	3.78 ^b	4.40 ^a	3.88	4	0.245
High temperature adaptability	14.2	4.93 ^a	4.04 ^b	4.20 ^a	4.20	4	0.0008
High humidity adaptability	4.18	3.28 ^a	3.44 ^b	3.00 ^a	3.39	3	0.607
Long larvae length	15.3	4.86 ^a	4.28 ^b	4.60 ^a	4.40	5	0.035
High-fat content	5.02	3.93 ^a	3.26 ^b	3.20 ^c	3.37	3	0.208
Big larvae girth	18.5	4.93 ^a	4.36 ^b	4.60 ^a	4.47	5	0.037
Time taken for larvae to grow	15.0	4.43 ^a	4.26 ^b	4.60 ^c	4.31	5	0.757

^{a,b,c} Figures on the same row with different superscripts are significantly different

Likert scale: most important -5; important -4; least important -3; indifferent -2; not important -1

4.3.3 Factors influencing farmers' trait preferences

The study assessed different factors that could influence farmers' most important trait choices, including farmers' education level, gender, training in BSF rearing, and production scale. Surprisingly, none of the factors were statistically significant (Table 11).

Table 11: Factors influencing farmers' trait preferences

Dependent variable	Independent variable	Category	Coef	SEM	p-value	CI
Length of the larvae	Education level	Secondary	2.141	0.627	0.359	-1.807- 0.654
		Primary	1			
		Tertiary				
	Gender	Male	-1.177	0.596	0.766	-1.347- 0.992
		Female	1			
	Training in BSF	Yes	0.876	0.307	0.525	1.2736- 2.479
No		1				
Production level	Small	1		0.482	-1.631- 0.770	
	Large	2.121	0.612			
Size of the larvae	Education level	Primary		1		
		Secondary	-0.959	0.572		
		Tertiary		0.551		
	Gender	Male	-1.177	0.329	0.435	0.399-0.917
		Female	1			
	Training in BSF	Yes	1.549	0.244	0.657	1.070- 2.029
No		1				
Production level	Small	1		0.920	-1.003- 1.110	
	Large	0.539	0.539			
Protein content	Education level	Primary	1		0.951	-1.440- 1.534
		Secondary	0.047	0.759		
		Tertiary				
	Gender	Male	-1.77	0.596	0.766	-1.347 -0.992
		Female	1			
	Training in BSF	Yes	-2.418	0.440	0.583	-1.104- 0.620
No						
Production level	Small	1		0.406	-3.769- 0.931	
	Large	0.277	0.333			
Temperature adaptability	Education level	Primary	1		0.951	-1.440 -1.534
		Secondary	0.047	0.759		
		Tertiary	0.250	0.706		

Gender	Male	-1.116	0.321	0.717	-0.745 – 0.513
	Female	1			
Training in BSF	Yes	-1.116	0.321	0.717	-0.745- 0.513
	No	1			
Production level	Small	1			
	Large	0.238	0.321	0.321	-3.391- 0.868

4.4 Objective III. Factors affecting the productivity of black soldier fly in selected AEZ

4.4.1 BSF production challenges

Inadequate supply of substrates emerged as the main production challenge (Figure 9). Most respondents (35.8%) identified low demand for BSF products as the primary marketing limitation, while others pointed to limited infrastructure and poor sale prices as additional concerns. Sourcing substrates remained the main production challenge across all three agro-ecological zones, although it was particularly pronounced in the LVC and ESG areas. Colony collapse was identified as a critical issue leading to production failures in the WSG region. Furthermore, in the ESG zone, the lack of supportive infrastructure, in addition to substrate sourcing issues, significantly hindered production.

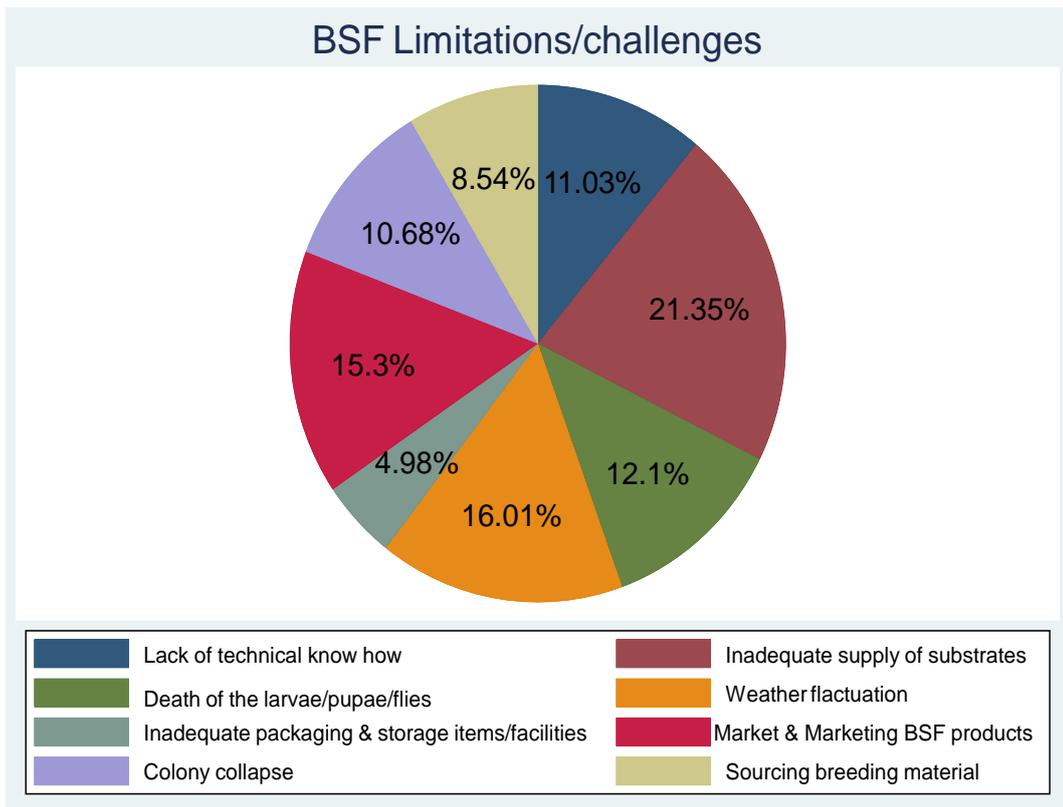


Figure 2: BSF overall production challenges

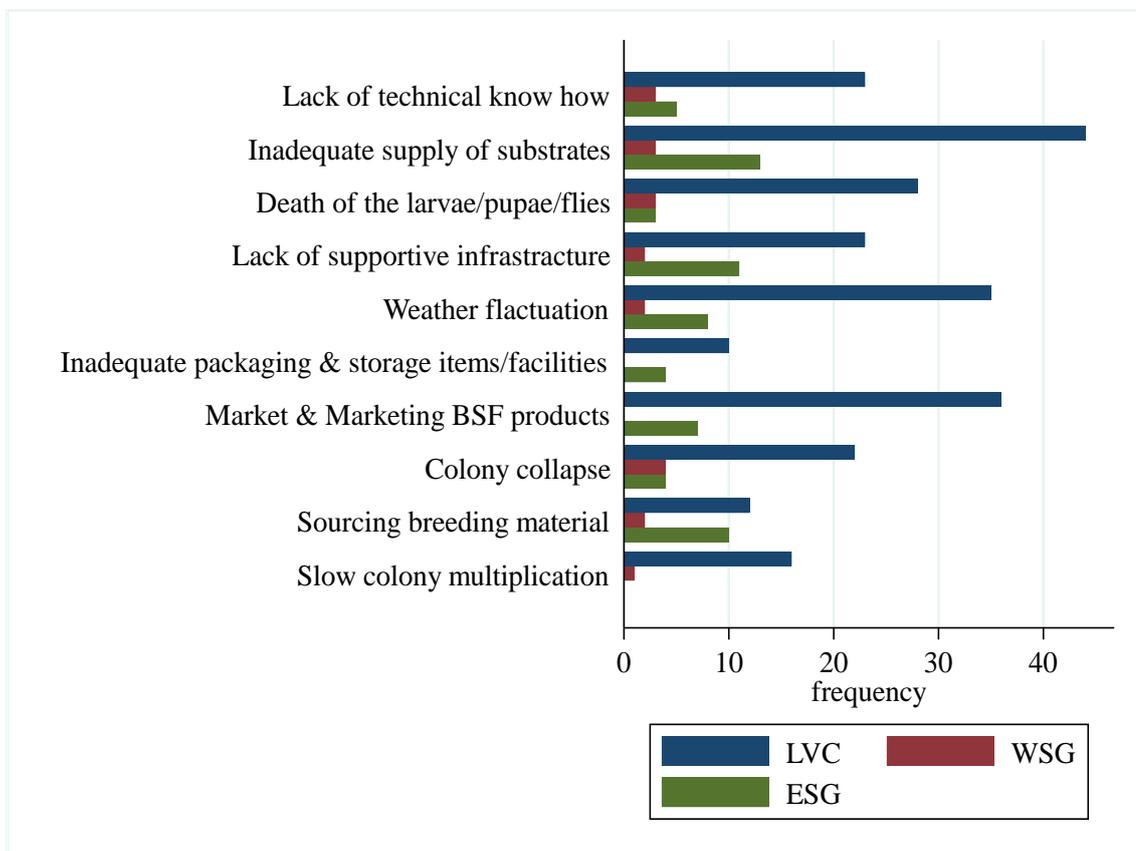


Figure 3: BSF production challenges in different agro-ecological zones

4.4.2 Factors affecting BSFL yield produced

Overall, there was only a statistically significant difference between the yield BSFL and off-farm purchased substrate ($p < 0.012$, coef. 271.49, 95%, SEM, 104.082). Also, a positive relationship was observed between the yield of BSF and the substrate source for producing the larvae. Furthermore, a positive relationship and a statistically significant difference were observed between training in BSF rearing and BSF yield produced ($p < 0.006$, coef. 239.9, SEM, 82.338). Respondent gender had a positive relationship, although it had no statistical significance. On the contrary, a negative relationship and no statistical significance were observed with an increase in respondent age. Similarly, marital status and education level were not statistically significant.

Table 12: Factors affecting BSFL yield produced

Variable	Coef.	T	SEM	p-value	95% CI
Age group (years)					
18-35	R				
36-60	-22.200	-0.260	86.643	0.997	-195.67-150.25
>60	-0.710	-0.000	198.949	7.140	-396.71-395.29
Education level					
Primary	R				
Secondary	-35.710	-1.700	210.496	0.866	-454.69-383.2
Tertiary	56.590	0.290	195.502	0.773	-332.54-445.7
Gender					
Female	R				
Male	113.320	1.240	91.184	0.218	-68.28-294.93
Substrate source					
Off-farm free	R				
Off-farm purchased	271.490	2.5700	104.082	0.012	61.18-481.81
On-farm	23.700	0.2000	113.745	0.845	-216.0-263.45
Training					
No	R				
Yes		2.850	82.338	0.006	72.30-407.50
	239.900				

CHAPTER FIVE

DISCUSSION

This study aimed to characterize the production practices of black soldier flies, identify the preferred traits of black soldier fly larvae, and establish the factors influencing larval productivity across selected agro-ecological zones (AEZs) in Uganda. The goal was to provide foundational information for designing and implementing a breeding program to enhance black soldier fly larvae production.

Key findings revealed that most farmers had one to two years of experience in black soldier fly (BSF) production. They had received training in black soldier fly rearing and primarily focused on production to create livestock feed, mainly for poultry. Most utilized a vertical rearing system within non-permanent structures and predominantly sourced their substrates off-farm, with market waste being the most common substrate used.

Significant variations were observed in larvae traits such as girth, length, and weight across different agro-ecological zones; notably, most farmers preferred larvae with a larger girth as one of the most important desirable traits. Substrate sourcing emerged as the main production challenge faced by producers in all AEZs and positively influenced the yield of black soldier fly larvae produced. The findings of this study can guide future research aimed at developing breeding programs, enhancing understanding of farmers' production practices across various rearing systems, and addressing the production challenges encountered by black soldier fly farmers in different selected agro-ecological zones.

5.1 Black soldier fly production practices

5.1.1 Reasons for black soldier fly larvae production

The findings from this study revealed that “feed for livestock” was the most important production objective of why farmers were engaged in black soldier fly production. Whereas several uses and products can be derived from larvae and substrate by-products, the objective was likely guided by farmers' knowledge, availability of resources, and the market. It was surprising that farmers chose feed as the objective

because black soldier larvae have been profiled for their nutrients and found to be a good replacement for fish or other protein sources in feed for poultry (Edea *et al.* 2022; Nampijja *et al.* 2023; Dorper *et al.*, 2021; Abro *et al.*, 2020); swine (Chia *et al.*, 2021), and fish (Nyakeri *et al.*, 2017). Secondly, the use of BSFL in feed for livestock has been found to provide economic benefits (Abro *et al.*, 2022). Experimental evidence shows, however, that its inclusion in livestock feed should be limited to 540g/kg (Nampijja *et al.*, 2023b). The production objective of the farmer has significant implications for the traits that can be improved. The finding, therefore, suggests that any proposed breeding program should emphasize minimizing the limiting factors for its use and enhancing its good characteristics. The differences observed in the ranking of importance among the different AEZs for the three production objectives, namely, “feed for livestock”, “sale of frass”, and “own manure,” emphasize the different needs of farmers in different locations, which are influenced by local opportunities and challenges throughout the whole value chain. The “income from the sale of larvae” was registered as the second most important production objective; this implies that BSFL can compete with traditional protein sources on the market, such as fish and soya. First, the scale of production might influence both the cost of production and the profits. In this study, the scale of production was still low and based on purchased substrates, which are likely to result in reduced profitability of BSF production (Beesigamukama *et al.*, 2022). A study conducted in Benin by Gougbedji *et al.* (2021), indicated that the cost of BSF production was \$1.84/kg when soybean and pineapple waste were used as substrates. Technical basis for the small-scale production of black soldier fly, *Hermetia illucens* (L., 1758), meal as fish feed in Benin. In Uganda, a cost of \$0.54 was reported but not derived (Nampijja *et al.*, 2023b), and market prices have been reached. Given that the most reported challenge in this study was the inadequate supply of substrate, the objective of earning income from the sale of larvae may not easily be realized.

5.1.2 BSFL rearing system

The study findings revealed that farmers practicing BSFL rearing mainly farmed larvae using a vertical rearing system. Whilst few used horizontal rearing systems. However, there is a lack of clear documentation of the insect-rearing system, particularly for BSF. Many researchers have categorized BSF-rearing systems based on varied parameters. First and foremost, the first system was probably documented in the 1970s, which

involved rearing BSF in the wild and farming domesticated BSF (Sheppard *et al.*, 1995). These studies revealed that BSF rearing in the wild involved exposing the substrate to attract adult female flies so they could lay eggs on the exposed substrate. The system used concrete basins built under either poultry or piggery units. However, it was noted that the system had low production due to uncontrolled conditions, making it unsustainable for BSFL production. On the other hand, the second system involved the domestication of BSF and separating the adult-rearing unit for egg production and the larvae-rearing unit. Farmers practicing BSF rearing have recently adopted this approach, forming the basis for other studies categorizing the BSF rearing system based on separate units to ensure mass larvae production. For instance, a study by Abro *et al.* (2022) categorized the BSF rearing system into three types: a plastic drum system, a modified rearing system using cut jerrican, and a greenhouse using plastic crates, practiced by small-scale, medium-scale, and large-scale farmers, respectively. This finding is in line with the findings from the present study, where most (68%) of the farmers used vertical rearing systems. Farmers rear black soldier fly larvae using this system, which uses rearing materials comprising metallic frames, wooden frames, cut jerricans, basins, cut drums, plastic crates, and other rearing materials used in vertical and horizontal rearing systems. Black soldier fly larvae rearing system influences the ease of the operation, for example, feed management practices involving weighing and turning substrates while regulating substrate depth are slightly easier under the vertical rearing system as compared to the horizontal rearing system. This agrees with a study by Yakti *et al.* (2023), which revealed the effect of substrate properties such as moisture, form, and depth on the performance of the larvae. From the current study, most farmers could have used vertical rearing systems since manipulating these substrate properties could be slightly simpler than horizontal systems, which could be more tedious. On the other hand, a few farmers who used horizontal rearing systems mainly had concrete basins and permanent structures, which could be slightly more expensive than vertical rearing systems. Clear characterization of the BSF-rearing system is still required to understand the production systems in order to inform farmers' production practices under different systems. Farmers' rearing systems, therefore, play a fundamental role in black soldier fly larvae production, as evidenced by the efficiency of production observed in most commercial farmers farming BSFL using vertical rearing systems and permanent structures.

The study findings revealed that small-scale producers dominate BSF production, suggesting that efficient larvae production should use low-cost materials such as wood frame material, wooden eggies, and temporary rearing structures that are affordable to small-scale farmers. However, mass production of BSF will require long-term investments, such as permanent structures, as observed in a few large-scale farms and companies that produce slightly more than 100kg of BSFL per week. According to a study by Tanga *et al.* (2021), the estimated volume of dried BSFL produced by the top nine farms in Uganda and Kenya is 9780 metric tons annually. This figure might have increased, although no empirical data has been documented yet. BSF production in Uganda is slightly lower than in Kenya, which can be attributed to the higher number of large farms in Kenya compared to Uganda.

5.1.3 Black soldier fly breeding practices

The present study's findings revealed that more than 80% of farmers participating in BSF rearing practice breeding obtained their starter colony from fellow farmers. Observations of wooden laying materials in the cage for female flies to lay were made with most of the farmers. These findings are supported by Barrett *et al.* (2023), whose study reported using three egg-laying materials: wooden, plastic, and cardboard. Furthermore, multiple studies reported that environmental parameters affected fly oviposition time and hatching (Boafo *et al.*, 2023; Macavei *et al.*, 2020; Hoc *et al.*, 2019; Zhang *et al.*, 2010). Previous studies reported variations in hatching duration as a result of multiple factors, including nutrition, micro environmental conditions such as temperature and humidity, and egg incubation substrate properties such as moisture and PH (Salam *et al.*, 2022; Ribeiro *et al.*, 2022; Fazli Qomi *et al.*, 2021). The hatched neonates immediately start eating vigorously. However, highly nutritious feed is required. Like in poultry, hatched chicks are fed highly nutritious feeds of about 20-22% crude protein. BSF larvae require a well-balanced ration at this stage. The use of broiler starter feeds in feeding BSF neonates has been reported (Barrett *et al.*, 2023). Feeding BSFL in a well-balanced ration enhanced the nutritional quality of the larvae produced. The present study findings also imply that farmers share breeding material amongst themselves; in scenarios where the undesirable trait is shared, there would be a wide distribution of undesirable characteristics, which could negatively affect black soldier fly breeding. In other words, the few institutions and commercial companies

with well-established nursery facilities should breed and supply seeds with desirable characteristics to farmers instead of sharing amongst themselves, as observed in the present study.

5.1.4 Black soldier fly and larvae feeding management practices

The study findings revealed that most farmers participating in BSF rearing provided water only to the adult flies. Meanwhile, add a few sugars to the water before giving it to adult flies. Feeding BSF with water was reported in previous studies (Barrett *et al.*, 2023; Eawag & Sandec, 2018). Unlike BSFL with well-developed mouthparts, which allow them to feed on various organic substrates, adult BSF mouthparts are characterized by sponging mouthparts, which restrict their feeding to only liquid (Kim *et al.*, 2010). A study by Bertinetti *et al.* (2019) revealed that feeding adult female flies with sugar solution increases egg production and lengthens the oviposition period. The findings coincide with a study conducted by Id *et al.* (2020), which reported that the presence of sugar positively affects egg production (12,93–27,10 mg eggs/female), increases the oviposition period (18,2–31,8 days), and increases adult lifespan (20,79–27,11 days). Furthermore, a similar study revealed that adult life span increases in BSF provided with water, as opposed to BSF not provided with water, in contrast to the present study. The provision of water was achieved by spraying it onto the cotton wool to prevent flies from drowning in it. These findings are in contradiction to adult fly management practices reported in a study carried out by Eawag & Sandec (2018).

Surprisingly, the high-yielding substrate reported by most farmers, "market waste," was not the most preferred substrate used by black soldier fly farmers in all the selected agro-ecological zones; instead, brewery waste was preferred. Farmers' choice for substrate is most likely influenced by not only the yield of larvae produced, but also other factors such as accessibility, affordability, ease of substrate preparation prior to feeding the larvae, desirable end product protein content, and resultant by-product, specifically frass, for use as biofertilizer. For instance, the present study reveals that market waste yielded a higher amount of BSFL; however, its preparation necessitates a rigorous process. This involves sorting unwanted materials commonly found in marketplace waste, such as polythene bags, plastics, and other inorganic substances that may contain heavy metals. Furthermore, market waste might contain fruit waste such as rotten jackfruit, rotten pineapple with large particles, which require breaking down

into smaller particles to increase their surface area for larval utilization. This implies that farmers would not only incur extra costs in substrate preparation but also put end users at risk if larvae consume waste rich in heavy metals. On the other hand, brewery waste requires less preparation, if any, including dewatering or re-watering, but has less risk of inorganic substances. However, market waste could have been more accessible and affordable than brewery waste.

Most farmers use plant-based substrates instead of animal waste. However, farmers' main production objective was to feed their livestock, which could provide on-farm free substrate for feeding the larvae. Although several studies have recommended multiple substrates used in black soldier fly larvae rearing (Barrera *et al.*, 2023; Boafo *et al.*, 2023; Hosseindoust *et al.*, 2023; Hudson *et al.*, 2019). The concept of circular economy has been encouraged to enhance the production efficiency of the black soldier fly larvae (Beesigamukama *et al.*, 2022; Broeckx *et al.*, 2021; Menino & Murta, 2021; Bortolini *et al.*, 2020; Chia *et al.*, 2019). For instance, the study results showed that the most used livestock manure was poultry manure. Encouraging poultry farmers to use poultry manure would significantly relieve them of the burden and costs incurred in managing the manure and obtaining substrates from elsewhere. The study findings are backed by a study by Chia *et al.* (2019), which suggested a BSF production model involving poultry farmers using substrate derived from poultry manure, and a study by Beesigamukama *et al.* (2022) reported that BSFL production is not profitable unless the substrate is sourced on-farm or off-farm for free. This implies that the farmer operates at a loss when obtaining substrate off-farm. A study by Miranda *et al.* (2020) revealed that black soldier flies fed poultry manure perform better than those fed cattle manure, which contains slightly higher fiber content. However, feeding larvae with mixed substrates has been proven to give the best results (Broeckx *et al.*, 2021). The findings from this study imply that most of the black soldier fly farmers are still utilizing substrate off-farm and have yet to adopt the concept of the circular economy in their production process. Therefore, there is still a need to find out why farmers have not yet adopted this approach. However, it can contribute to sustainable BSFL production and ensure a clean environment through the mitigation of greenhouse gases and preventing the deposition of organic waste in landfills and water.

The study found that off-farm purchase was the main substrate source in all three selected AEZs used in feeding BSFL, although it varied across the selected AEZs. Similar findings were reported by Beesigamukama *et al.* (2022), who noted that most black soldier fly farmers sourced substrate for feeding the larvae from elsewhere, whereas a few sourced substrate from their farm. However, there was a slight difference in the source of substrate in the three selected AEZs, where BSF farmers within LVC and WSG agro-ecological zones mainly purchased substrate off-farm, as opposed to BSF farmers in ESG who mainly used substrate on-farm. Farmers in the LVC area who rear BSFL mainly buy their substrate from off-farm sources compared to those in ESG. In this scenario, most farmers producing over 100 basins of larvae weekly are located within LVC.

High production levels are associated with a strong demand for substrates. Intensive livestock farming in LVC, including commercial broiler rearing, pig farming, and fish farming, presents market opportunities for black soldier fly (BSF) larvae, unlike in the Eastern Savannah Grasslands (ESG). In the ESG, farmers primarily raise local chickens in small-scale, free-range systems, which have low feed requirements and face limited market demand due to the purchasing power constraints of rural households. Some BSF farmers in ESG use locally brewed alcohol, known as 'Ajono' in Teso and 'Kongo ting' in Lango, especially during seasons when there is a shortage of fruit wastes (citrus, mangoes, and pineapples). However, during seasons of abundant fruits, ESG farmers mainly obtain their substrates for free from on-farm sources. This implies that substrate sourcing is mainly influenced by the accessibility and affordability of a particular substrate within a given agro-ecological zone.

The profitability of the black soldier fly business is greatly impacted by the location from which the substrates are sourced. According to a study by Beesigamukama *et al.* (2022), farmers who purchase off-farm substrates operate at a loss. This suggests that for black soldier fly farmers to optimize their production efficiently, they should source their substrate either on-farm or obtain it for free off-farm. Alternatively, to reduce production costs by avoiding the transportation of purchased off-farm substrates, a new farming model involving taking black soldier fly larvae to the source of the substrate was recommended in studies by Chia *et al.* (2019) and Beesigamukama *et al.* (2022).

From the present study, the majority of the farmers were sourcing substrate off-farm and were incurring costs in purchasing and transporting substrate to their farms.

In the present study, most farmers reported inoculating shredded substrate with 6-day-old larvae (DOL). Studies by Barrett *et al.*, 2023, Eawag & Sandec, 2018, reported that Substrate preparation significantly influences the larvae's quality and overall performance. Upon receiving the substrate, either dewatering or watering is done to ensure the optimum moisture level. This enhances the larvae's utilization of the substrate. Other substrate preparation practices involve removing unwanted materials, such as plastics and polythene bags, and grinding the substrate before feeding the larvae. Grinding substrate increases surface areas for the larvae to feed, increasing the substrate reduction rate by the larvae.

On the other hand, previous studies reported two feeding phases: phase feeding and continuous feeding. However, phase feeding is highly recommended since it is easier to regulate substrate depth than continuous feeding. Previous research has documented that the black soldier flies larvae' feeding regimen and substrate properties impact larvae performance (Barrett *et al.*, 2023; Eawag & Sandec, 2018). Pupation and emergence of black soldier flies have reportedly been affected by the substrate fed to the larvae during the larval growing period (Holmes & Vanlaerhoven, 2013). Hence, the choice of substrate is one of the most important aspects during larval rearing.

5.1.5 Black soldier fly larvae product harvesting and post-harvest management practices

In the present study, most farmers harvested larvae by sieving and hand-picking, and the most important BSF product preferred for the market was larvae. These findings tally with the BSF larvae harvesting method; sieving, manual picking, and self-harvesting are reported (Barrett *et al.*, 2023; Eawag & Sandec, 2018). Black soldier fly product harvesting is a rigorous, time-consuming practice, especially in large-scale production; it requires more labor than other management practices. To that end, an efficient method of harvesting is fundamental to managing time and lowering production costs. In the present study, farmers observed using plastic baskets and sieves fixed on either metallic stands or mobile wooden stands, which are all shakable, to enhance the separation of the larvae from the frass during harvesting. Furthermore, this

study revealed that farmers participating in BSF rearing were practicing several post-harvest handling measures, including washing the larvae after separating them from frass to enhance further post-harvest practices, such as drying them before storage. However, most farmers prefer fresh larvae. Although several preservation measures have been documented, there is still a gap in information concerning the safety and regulation of insect products, particularly in the context of BSFL for feeding livestock (Nakimbugwe *et al.*, 2021). Previous studies reported separating pupa from larvae when they change dark brown and rearing them separately in dark cages, where they will eventually emerge into adults (Barrett *et al.*, 2023; Eawag & Sandec, 2018). Dark cages provide suitable conditions for the pupa to hatch, whereas most farmers participating in BSF directly put the pupa in the adult fly cage exposed to natural light; more than 80% of the BSF farmers from this study had adult flies, with the majority only using natural light, with a few using artificial light. Pupal management practices carried out after larvae harvest are critical to ensure the production cycle is maintained. Previous studies reported that the size of the hatched flies and the amount of eggs laid are directly proportional to their pupal size (Pastor *et al.*, 2011). Therefore, understanding the requirements and conditions for rearing black soldier flies is critical. 5.2 Trait preference of black soldier larvae

5.2 Morphometric trait measurements for BSF stages sampled

The study findings revealed that the BSF stages sampled had minimal variations across the agro-ecological zones. The variations might probably be a result of the farmer's practices, such as feeding, substrate use, and substrate forms fed to the larvae, rather than variations in the agro-ecological zones. For instance, study findings from this study revealed that BSF stages fed market waste obtained better performance at the pupation stage as compared to other substrates, except restaurant waste, which also recorded good performance. These findings correlate with the findings from this same study, where most farmers reported market waste as a highly yielding substrate. Yet, it was not commonly used compared to brewery waste. The good results obtained from larvae-fed market waste may be attributed to the balanced ratio formed by the mixture of market waste. In contrast, its lesser use could be due to limitations in its accessibility in some of the agro-ecological zones. On the other hand, restaurant waste showed better performance but was the least used substrate. Similarly, just like market waste,

restaurant waste has a mixture of food leftovers and fruit waste, which could also form a balanced ration. However, sustainable BSF production requires farmers to use substrates that are easily accessible and affordable and that yield good results. The study by Cai *et al.* (2022) reported morphometric traits differences in BSF reared domesticated and wild populations. The results showed better performance in the inbred population than in the wild population. This can be attributed to the influence of the environment, such as feeding different substrates

5.3 Farmers trait preferences of BSFL

The findings of the current study underscore that large-girth larvae are the most important trait prioritized by farmers engaged in black soldier fly rearing across all selected agro-ecological zones. Other significant traits mentioned include long-length larvae, high protein content, and strong adaptability to high temperatures. However, only the adaptability to high temperatures was found to be statistically significant across all three agro-ecological zones. Identifying farmers' preferred traits is essential for implementing a selective breeding program (Ouédraogo *et al.*, 2019). The study recommends that prioritizing the most important larval traits is crucial for designing and executing effective selective breeding programs aimed at improving the productivity of black soldier flies. The size of the larvae has been reported to directly correlate with the size of the adult fly at emergence, and the adult size, in turn, correlates with the volume of eggs produced (Pastor *et al.*, 2011).

In the present study, BSF farmers preferred larvae with high protein content over larvae with high fat content. Most farmers' main production objective was feed for livestock; these findings suggest that farmers rearing BSFL could mainly be interested in the protein content of the larvae since protein is a significant component of animal feed, as higher protein is critical in ensuring overall feed efficiency. However, other studies also reported nutritional variation of the larvae resulting from different parameters, including feed resources fed to the larvae (Fuso *et al.*, 2021; Meneguz *et al.*, 2018). This is supported by Leni *et al.* (2024), who observed that BSFL contains high protein and fat content; however, the body composition of the larvae correlates with the quality and quantity of food ingested. The present study findings revealed that the farmers' preferences for larvae's adaptability to high-temperature environmental conditions

significantly differed across the three AEZ and were higher than preferences for larvae's adaptability to light and humidity. Variations in environmental conditions have a huge impact on the overall performance of the larvae. These findings are in agreement with observations from previous studies (Nayak *et al.*, 2024; Ribeiro *et al.*, 2022; Raimondi *et al.*, 2020; Hoc *et al.*, 2019; Shumo *et al.*, 2019), which reported the impact of temperature variations on the performance of different life-cycle stages of the black soldier fly.

5.4 Factors affecting the production and yield of black soldier fly larvae

5.4.1 Black soldier fly farmers' production challenges

The most prominent production challenge was the inadequate supply of substrates, followed by weather fluctuation and the marketing of BSF products (Fig 2). However, variations in production challenges were noted across the three selected agro-ecological zones. The present study's findings are consistent with previous studies on black soldier fly larvae potential and economic feasibility (Abro *et al.*, 2020; Chia *et al.*, 2019), which revealed that substrate sourcing posed a great production challenge. Elsewhere, Dicke *et al.* (2020) reported the same findings in Colombia. The required quantities of organic wastes to rear BSF may be limited on the farm for mass production. Hence, insect farmers incur costs when purchasing and transporting rearing substrates to their farms. These results are consistent with a study by (Beesigamukama *et al.*, 2022), where they reported that acquiring and preparing waste substrates for rearing BSF larvae accounted for 81-90% of the total production cost. The same study stated that it is not economical to produce black soldier flies when purchasing substrate and transporting it from a long distance.

The present study revealed weather fluctuation as one of the production challenges limiting farmers' participation in BSF farming. This is consistent with studies by Holmes *et al.* (2012), which reported that maintaining the recommended temperature is a significant challenge in BSF production. Hence, deriving strategies to mitigate the mentioned production challenge is vital to successful BSF rearing. Elsewhere, black soldier fly (BSF) production faces many hurdles, including high labor costs at various stages, particularly in mass production, where trained and untrained workers are needed (Dicke *et al.*, 2020). A study by Roffies *et al.* (2017) highlighted that in West Africa,

the economic performance of insect-based feed (IBF) production is heavily influenced by labor costs. Therefore, a comprehensive understanding of the labor requirements in BSF operations is crucial for addressing labor shortages and promoting efficient production. In the present study, the use of family labor and temporary hiring of workers, especially during harvest, was suggested as one of the strategies for minimizing labor shortages. In light of the above, efficient black soldier fly-rearing production will require high output with minimal production costs. Therefore, strategies that enable lower production costs while maintaining high output would optimize overall production due to their efficient and practical nature.

5.4.2 Factors affecting the yield of black soldier fly larvae

The present study findings revealed a negative relationship, and no statistical significance was observed for increased respondent age. Studies by Mwangi and Kariuki, (2015) Showed that age correlates with awareness and adoption of new technology. This is consistent with findings from the present study, where the youths represented more significant proportions of the black soldier fly farmers in this study.

A study by Abro *et al.* (2022) revealed that black soldier flies farming has the potential to create jobs for over 563302 people annually, mainly youths currently with a high unemployment rate of 13% of the overall 9% unemployment rate in Uganda, would be able to be absorbed in the diverse BSF value chain where the division of labor which cut across input-making, mobilization of raw materials such as substrates, rearing of the larvae, harvesting of the larvae, product marketing, value addition, amongst others enhanced youths (age 18-35 years) participation in BSF production. The high prevalence of youth participation in BSF rearing as their primary source of income and employment could attract their attention and efforts toward achieving a high yield of BSF production.

In the present study, a positive relationship and a statistically significant difference were observed between the off-farm purchased substrate source and the yield of BSFL. These findings disagree with the report from a previous study by Beesigamukama *et al.* (2022), which reported that the BSF producer does not realize profits when purchasing substrate off-farm. Substrate sourcing is one of the significant production costs in BSF rearing due to additional costs incurred in transportation, loading, and offloading.

However, the production of BSFL at a large scale demands a huge amount of substrate, which might not be available at the farm. According to Beesigmukama *et al.* (2022), approximately 70-80 % of production costs in BSF go into sourcing substrate for feeding the larvae. Indeed, this supports the findings of this study: a producer will put more into buying the substrate to produce more larvae.

In the present study, a positive relationship and a statistically significant difference were observed between the respondent's level of education and BSFL yield. These findings are supported by Bulinda *et al.* (2023), who state that embracing black soldier fly farming technology increases with increased education. This conforms to findings from the present study, where most participants had achieved tertiary education. This implies that most of the black soldier fly farmers had attained at least secondary and above levels of education, signifying their ability to read and write. Thus, training them in production practices and understanding the significance of trait choices in farming BSF could improve their husbandry practices, such as practicing selective breeding of black soldier flies larvae to improve and ensure efficient black soldier fly larvae production. In light of the above, higher formal education is associated with faster adoption of new technologies among farmers since higher knowledge levels enable easy understanding and implementation of new technology, unlike lower education levels, which require more time to comprehend and embrace new technologies. This implies that the high yield of black soldier fly larvae is mainly realized in farms with well-educated and informed workers compared to those with informal training.

The study findings revealed that respondent gender had a positive relationship with the yield of the BSFL produced, although there was no statistical significance. Men dominated participation in BSF farming in this study. However, a study by Bulinda *et al.* (2023) revealed that women were more aware than men that BSF can feed pigs and poultry. From this study, most households were headed by men; in traditional African culture, men have the final say on what should be reared at home. On the other hand, a study by Waithanji *et al.* (2021) reported that women tend to have limited time since many activities, including productive roles, reproductive roles, and other community obligations, occupy them. This finding supports the low participation of women in the present study. Women's time poverty limits their access to new technologies, such as insect rearing. Therefore, interventions promoting women's participation in black

soldier fly-rearing should focus on insinuating gender-responsive projects that would lower the time burden for women and increase their access to black soldier fly-rearing practices. According to Waithanji *et al.* (2021) study findings, women preferred the taste of chicken-fed insects as opposed to men, who were majorly interested in the size of the chicken. This implies that an increase in the number of women adopting black soldier fly production would enhance the production of black soldier fly due to the increased number of those preaching the gospel of tasty chicken-fed BSFL not only to their husbands but also to other potential black soldier fly farmers. In addition to spreading the gospel of tasty chicken-fed BSFL, women could also be involved in a wide range of production value chains, starting from substrate sourcing, breeding practices such as egg collection, sewing textile adult fly cages, harvesting, post-harvesting practices, including washing, blanching, and drying.

The present study findings revealed a positive relationship between farmers' training in BSF and the yield of black soldier fly larvae produced, with the majority being trained by their fellow farmers and a few from training institutions and well-established private companies. This result is consistent with the findings by Tanga *et al.* (2021), who reported that approximately 170,000 households had been trained in BSF rearing by the International Centre of Insect Physiology and Ecology (ICIPE) and its partners, such as research institutions, private companies, Non-governmental organizations (NGOs), Community-Based Organizations (CBOs), and cooperatives. This training has enabled farmers to understand the requirements and conditions necessary for BSFL rearing and key management aspects of black soldier fly larvae production, including waste sourcing, waste processing, breeding technique, larvae rearing, product harvesting frequency, management cycle, and disease and pest control.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The black soldier fly production was characterized by low production in all three agro-ecological zones; most farmers participating in black soldier fly farming are still producing at a small scale, with the majority still obtaining substrate from off-farm sources to rear larvae under a vertical rearing system, while mainly harvesting larvae by sieving. Market waste was the most available and effective substrate used by the farmers, despite it being less preferred than brewery waste in all the selected agro-ecological zones. The preferred traits for black soldier fly larvae included high protein content, large girth, long length, rapid growth, and adaptability to high-temperature conditions. The factors affecting the productivity of black soldier fly larvae were the sourcing of substrate, weather fluctuation, and training in black soldier fly rearing. Lake Victoria crescent produces larger, heavier, and faster-growing larvae.

6.2 Recommendation

1. The study recommends that interventions to promote black soldier fly production should target Lake Victoria Crescent Agro-ecological zones due to tremendous market opportunities provided by a lot of livestock production activities, especially commercial poultry production, and resulting wastes from farms, beer processing factories, and division markets.
2. Farmers should be encouraged to identify and utilize substrates on the farm, including more animal manure, to minimize production costs and promote nutrient recycling.
3. Pragmatically, when designing breeding programs for BSF, consideration should include physical (size), biochemical (protein), and environmental (temperature adaptation) traits.
4. Further research, such as conducting choice experiments on preferred traits, should be done to refine the combinations of traits to be considered when initiating a breeding program.

5. Lastly, to enhance production, farmers should diversify the substrates used and consider participating in additional training in black soldier fly from experts and training institutions to learn developments in new techniques in BSF farming.

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APPENDICES

Appendix I: Research photos

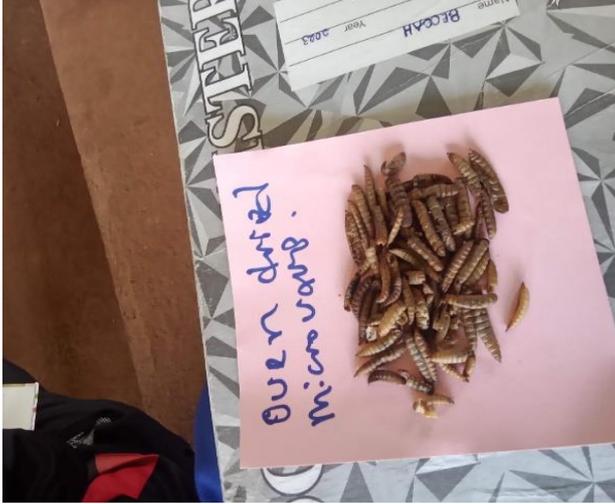


Plate 1: BSFL oven-dried



Plate 2: BSFL sun-dried



Plate 3: BSFL sampling



Plate 4: Adult BSF sampling



Plate 5: Field Survey in BSF small-scale unit in Tororo



Plate 6: Administering questionnaire to Doreen during survey



Plate 7: BSF Horizontal rearing systems



Plate 8: BSF vertical rearing system



Plate 9: BSF waste preparation



Plate 10: Wooden eggies on BSF attractant



Plate 11: BSF stages lab measurement

Appendix II: Survey questionnaire

FLYgene 3

This survey is conducted by a project cooperation between Makerere University (Uganda), Aarhus University (Denmark), University of Copenhagen (Denmark), Jomo Kenyatta University of Agriculture and Technology (Kenya), University of Nairobi (Kenya), International Center for Insect Physiology and Ecology (Kenya), INSECTIPRO Ltd (Kenya), Marula ProTeen Ltd (Uganda). The purpose of this survey is to characterize Black Soldier Fly (BSF) production system and find out traits prioritized by BSF farmers. This will assist in making recommendations on BSF rearing and management that will further boost BSF production. Data collection will follow ethical guidelines and will ensure consent and anonymity of the respondents.

INTERVIEW DETAILS

Questionnaire No:

.....

GPS Location

latitude (x.y °)

.....

longitude (x.y °)

.....

altitude (m)

.....

accuracy (m)

.....



Enumerators name:

.....

Date of survey (DD/MM/YYYY):
<div style="display: flex; justify-content: space-between;"> yyyy-mm-dd hh:mm </div>
Site name
GPS position
Household phone number
Name of the respondent

SECTION 1: SOCIO-ECONOMIC INFORMATION ABOUT BLACK SOLDIER FLY (BSF) FARMERS

<p>1.1 Age category</p> <p><input type="radio"/> Below 18 years</p> <p><input type="radio"/> 18-35 years</p> <p><input type="radio"/> 36-59 years</p> <p><input type="radio"/> over 60 years</p>
<p>1.2 Marital status</p> <p><input type="radio"/> Single</p> <p><input type="radio"/> Married</p> <p><input type="radio"/> Separated</p> <p><input type="radio"/> Divorced</p> <p><input type="radio"/> Widow/Widower</p>

1.3 Highest level of education of the respondent

- None
- Primary school
- Basic Religious Edu.
- Secondary School
- Tertiary Education

1.4 Number of people	Male	Female
Total number of people living in the household		
Number of people below 18 years		
Number of people between 18-35 years		
Number of people above 36 years		

1.5 Indicate the dominant religion of the household

- Christianity
- Islam
- Tradition
- Other specify

1.6 Gender of the respondent

- Male
- Female

1.7 Position of respondent in the household

- Head
- spouse
- Child
- Servant
- Other

Specify

1.8 How long have you been farming BSF?

- Below 1 yr
- 1-2 years
- 3-4 years
- More than 4 years

1.9 Have you ever received any training in BSF farming?

- Yes
- No

1.10 If yes, where did you receive your training?

- Fellow farmer
- Institution (specify)
- Other specify

Institution

Other (specify)

SECTION 2: BSF PRODUCTION AND POST-HARVEST HANDLING

2.1 REASONS FOR REARING BSF	Is this reason important?	If Yes
<hr/>	<hr/>	<hr/>

Income from sale of larvae (protein meal) <hr/>	<input type="radio"/> Yes <input type="radio"/> No	<input type="radio"/> Least important <input type="radio"/> Most important <input type="radio"/> Important <input type="radio"/> Not important <input type="radio"/> Indifferent
Income from sale of frass/fertilizer <hr/>	<input type="radio"/> Yes <input type="radio"/> No	<input type="radio"/> Least important <input type="radio"/> Most important <input type="radio"/> Important <input type="radio"/> Not important <input type="radio"/> Indifferent
Organic fertilizer for the farm <hr/>	<input type="radio"/> Yes <input type="radio"/> No	<input type="radio"/> Least important <input type="radio"/> Most important <input type="radio"/> Important <input type="radio"/> Not important <input type="radio"/> Indifferent
Income from sale of breeding stock (eggs/larvae) <hr/>	<input type="radio"/> Yes <input type="radio"/> No	<input type="radio"/> Least important <input type="radio"/> Most important <input type="radio"/> Important <input type="radio"/> Not important <input type="radio"/> Indifferent
Feed for livestock in the farm <hr/>	<input type="radio"/> Yes <input type="radio"/> No	<input type="radio"/> Least important <input type="radio"/> Most important <input type="radio"/> Important <input type="radio"/> Not important <input type="radio"/> Indifferent

For pharmaceutical use (e.g. Chitin)	<input type="radio"/> Yes <input type="radio"/> No	<input type="radio"/> Least important <input type="radio"/> Most important <input type="radio"/> Important <input type="radio"/> Not important <input type="radio"/> Indifferent
To consume organic waste on the farm	<input type="radio"/> Yes <input type="radio"/> No	<input type="radio"/> Least important <input type="radio"/> Most important <input type="radio"/> Important <input type="radio"/> Not important <input type="radio"/> Indifferent
2.2 BSF BREEDING		
2.2.1 Do you have breeding cages where the parent stock hatch and lay eggs? <input type="radio"/> Yes <input type="radio"/> No		
2.2.2 Where did you source your initial breeding stock from? <input type="radio"/> The wild <input type="radio"/> Fellow farmer <input type="radio"/> Institution (specify) <input type="radio"/> Other (Specify)		
Please specify		
2.2.3 Is your current BSF breeding stock externally sourced? <input type="radio"/> Yes <input type="radio"/> No		

2.2.4 If yes, where did you source your current breeding stock from?

- The wild
- Fellow farmer
- Institution (specify)
- Other Specify

Please specify

2.2.5 Do you periodically bring in new breeding stock to mix with the existing one?

- Yes
- No

2.2.6 How often do you periodically bring in external breeding stock?

- Once a month
- Once every 3 months
- Once every 6 months
- Others specify

Please specify

2.2.7 Do you think that the materials that make up the breeding cage/fly cage/love cage affect breeding?

- Yes
- No

2.2.7a If yes, what aspects of breeding does the materials affect ?

- Mating
- Egg laying
- Other

Other (specify)

2.2.7b What parameters majorly influence the breeding of your colony?

- Light
- Temperature
- Humidity
- Other

Please specify

2.2.8 What is the size of the breeding cage/fly cage/love cage? (Indicate dimensions- L x W x H in cm)

2.2.9 What is the frame material of the cage

- Wooden
- Metallic
- Other, specify

Please specify

2.2.10 What is the netting material of the cage?

- Textile material
- Metallic
- Other, specify

Please specify

2.2.11 Do you put laying material (eggies) in the breeding cage?

- Yes
- No
- Other (specify)

Please specify

2.2.12 If yes, what are they made of?

- Wooden
- Cardboard/paper
- Plastic
- Others specify

Please specify

2.2.13 Do you have laying stimulant in the cage?

- Yes
- No
- Other, specify

Please specify

2.2.14 Do you think it is necessary to have laying stimulants in the cage?

- Yes
- No
- other, specify

Please specify

2.2.15 If yes, what are your three best laying stimulants? (List)

2.2.16 In case you have no breeding cage/stock, where do you obtain eggs/larvae for inoculation?

- Externally
- Other specify

Please specify

2.2.17 What time of the day do the females flies oviposit?

- Before 11am
- 11-noon
- between 12 noon and 1 pm
- After 1 pm
- Other, specify

Please specify

.....

2.2.18 For feeding the adult flies, do you add any substance to their drinking water?

- Yes
- No

2.2.19 If yes, what do you add to their drinking water?

- Water only
- Water and Sugar Solution
- Water and Honey
- Water and Milk powder solution
- Water and Glucose
- Others, specify

2.2.20 COSTS	quantity	Unit price (shs)	Total Amount
Frames			
Netting			
Eggies			

Stimulant			
Watering substrate			
Breeding stock			
2.3 BSF EGG HANDLING			
<p>2.3.1 Do you weigh eggs collected?</p> <p><input type="radio"/> Yes</p> <p><input type="radio"/> No</p>			
<p>2.3.2 If yes, what units do you use to take the measurement?</p> <p><input type="radio"/> Milligrams</p> <p><input type="radio"/> Grams</p> <p><input type="radio"/> Kilograms</p> <p><input type="radio"/> Others, specify</p>			
Please specify			
<p>2.3.3 If no, what reasons do you have for not weighing?</p> <p><input type="radio"/> No measuring device</p> <p><input type="radio"/> No time</p> <p><input type="radio"/> No need</p> <p><input type="radio"/> Not knowledgeable</p> <p><input type="radio"/> Other, specify</p>			
Please specify			

2.3.4 How frequent do you harvest your eggs

- Once daily
- Twice daily
- Thrice daily
- Once every two days
- Other, specify

Please specify

2.3.4 How do you incubate your eggs?

- In a dark room
- In a light room
- Other, specify

Please specify

2.3.5 On average, how long (in days) do the eggs take to hatch?

- 3 days
- 4 days
- 5 days
- Others, specify

Please specify

2.3.6. Cost and quantity of weighing scale(s)

2.4.1 What type of rearing system do you use?

- Horizontal
- Vertical
- Others specify

Please specify

2.4..2 What is the source of your substrate?

- On-farm
- Off-farm free
- Off-farm purchased

2.4.3 What substrate gives you the highest yield of BSF larvae?

2.4.4 Starting with the most preferred, what are your best 3 substrates?	Substrate	Reason	Source	Cost
1				
2				
3				

2.4.5 What is the most preferred form of the substrate?

- Whole (used as is)
- Shredded (reduced in size)
- Other (Specify)

Please specify

2.4.5 What type of larvae rearing containers do you have?

- Plastic basins
- Concrete containers
- Other(specify)

Please specify

2.4.6 How many of these containers do you have?

2.4.7 At any one point in time, what is the maximum number of containers actively holding larvae?

2.4.8 Do you weigh the amount of substrate you place in each of the rearing containers?

- Yes
- No

2.4.9 If yes, what quantity of substrate do you place in each rearing container? (kgs)

Weight(kgs)

First time	
Second time	
Third time	

2.4.10 In case you are feeding more than one time, what determines the frequency of feeding?

Exhausted feed in tray
 Need to enhance growth
 Adulteration
 Other, specify

Please specify

2.4.11 At what stage do you inoculate the substrate?

Eggs
 6-day old larvae
 8-day old larvae
 Other (Specify)

Please specify

2.4.12 What amount of BSF do you harvest from each container? (kgs)

2.4.13 How much do you sell a kilo of larvae?

2.4.14 Do you keep a portion of the larvae and allow it to pupate for breeding purposes?

- Yes
 No

2.4.15 If yes, what proportion is this?

- A third
 A quarter
 Others specify

2.4.16 Where do your rearing operations take place?

- Permanent housing structure
 Temporary structure
 Screenhouse
 Other (specify)

Please specify

COSTS	Quantity	Price
Rearing containers		
Substrate		
Wheel barrow		

Thresher		
Green house/screen house		
Motor vehicle/bike		
Housing structure (permanent or temporary)		

» 2.5 BSF PUPAE HANDLING

<p>2.5.1 Do you have some recently pupated pupae that we can weigh?</p> <p><input type="radio"/> Yes</p> <p><input type="radio"/> No</p>		
<p>2.5.2 If yes, weigh and record the weight of ten pupae (from the dominant size in the container)</p>	<p>Weight (g)</p>	<p>subtrate</p>
<p>Pupae_1</p>		
<p>Pupae_2</p>		

Pupae_3		
Pupae_4		
Pupae_5		
Pupae_6		
Pupae_7		
Pupae_8		
Pupae_9		
Pupae_10		

2.5.3 What management practices do you administer on the pupae during rearing?

- Sorting
- Watering
- Culling
- Other Specify

Please specify

2.5.4 Do you have some pupae just before the transition developmental stage to the fly that we can weigh?

Yes

No

2.5.5 If yes, on average, what is the weight (in grams) of a BSF pupae just before the transition developmental stage to the fly?	Weight (g)	Substrate
Pupae_1		
Pupae_2		
Pupae_3		
Pupae_4		
Pupae_5		
Pupae_6		
Pupae_7		

Pupae_8		
Pupae_9		
Pupae_10		
<p>2.5.6 How do you raise your pupae?</p> <p> <input type="radio"/> Separately <input type="radio"/> Together with the larvae <input type="radio"/> Others specify </p>		
<p>Please specify</p> <hr/>		
<p>2.5.7 How do you prepare your pupae for inoculation in the breeding cages?</p> <p> <input type="radio"/> Keeping them in the dark for several days <input type="radio"/> No further preparation <input type="radio"/> Other, specify </p>		
<p>Please specify</p> <hr/>		
<p>2.5.8 How do you separate the different stages of the larvae/pupae?</p> <p> <input type="radio"/> Self-harvesting <input type="radio"/> Sieving <input type="radio"/> Manual picking <input type="radio"/> No separation <input type="radio"/> Other, specify </p>		
<p>Please specify</p> <hr/>		

» 2.6 BSF LARVAE HARVESTING

2.6.1 When do you harvest your larvae?

- 2 weeks after inoculation
- 3 weeks after inoculation
- 4 weeks after inoculation
- Other, specify

Please specify

2.6.2 Do you have some larvae that we can weight?

- Yes
- No

2.6.3 If yes, weigh and record the weight of ten larvae (from the dominant size in the container)	Weight (g)	Substrate
Larvae_1		
Larvae_2		
Larvae_3		
Larvae_4		

Larvae_5		
Larvae_6		
Larvae_7		
Larvae_8		
Larvae_9		
Larvae_10		

2.6.4 Which equipments do you use during harvesting? (list)

What is the cost of each of the equipment listed above?	Equipment	Quantity	Cost
Basins			
Harvester			

Rearing cages			
Sieves			
Other_1			
Other_6			
Other_2			
Other_3			
Other_4			
Other_5			

» 2.7 POST HARVEST HANDLING

2.7.1 How do you treat your larvae after harvesting? (Tick all that apply)

- Separation from substrate
- Washing until clean
- Draining to remove residual water
- Drying
- Other, specify

Please specify

2.7.2 Do you ever store the larvae on the farm? If not, please specify where else

- Yes
- No
- Others specify

Please specify other non-farm storage area

2.7.3 In which form do you store the larvae (tick all that apply)

- Wet (as is)
- Dry
- Whole
- Milled
- Other specify

Please Specify

2.7.4 Do you package the BSL before storage?

- Yes
- No

2.7.5 If yes, what type of storage container do you use?

- Nylon bags
- Plastic containers
- Other specify

2.7.6 How long do the stored BSFL keep before spoilage occurs?

2.7.7 What is the cost of each of the equipment listed above?	Equipment	Quantity	Cost
.....
Pastuerizer
Dryer
Milling machine
Other_1
Other_2
Other_3

Other_4			
Other_5			
Other_6			
Other_7			
Other Specify			

SECTION 3: BSF PRODUCE MARKETING

3.0 At what level of BSF larvae production are you?

Eggs
 Larvae
 Frass
 Chitin
 BSFL Meal
 Other

3.1 What product from the BSF farm do you sell?

Eggs
 Larvae
 Frass
 Chitin
 BSFL Meal
 Other

Please specify

3.2 Do you market your BSF products?

- Yes
- No

3.3 How often do sell your BSF products?

- Daily
- After every 3 days
- Weekly
- Fortnightly
- Other, specify

Please Specify

3.4 What marketing channel do you use?

- Physical
- Online
- Other, specify

Please specify

3.5 Which BSF product do you find as most appropriate for the market around you?

- Eggs
- Fresh Larvae
- Dry larvae
- Frass
- Chitin
- Other, specify

Please specify

3.6 To whom do you sell the BSF products?

- Neighbour
- Farmer within the village
- Farmer outside the village Other, specify -----
- Other, specify

Please specify

3.7 What constraints do you face when marketing your BSF products?

- Low demand
- Poor sale prices
- Inadequate infrastructure
- Other, specify

Please Specify

3.8 Do you receive any government support towards marketing your BSF products?

- Yes
- No

3.9 What suggestions/changes do you think should be enacted to improve on the BSF marketing channels?

- Improved Sensitization among population
- Enhanced partners collaboration
- Other, specify

Please Specify

SECTION 4: BSF TRAIT PREFERENCES

Rank the following traits by level of importance to your enterprise

4.1 Volume / Number of eggs laid and their hatchability	Level	Ranking
Number or volume of eggs laid	<input type="radio"/> Large amount <input type="radio"/> Medium amount <input type="radio"/> Small amount	<input type="radio"/> Not important <input type="radio"/> Least important <input type="radio"/> Very important <input type="radio"/> Important <input type="radio"/> Indifferent
Proportion of eggs laid that hatch	<input type="radio"/> Large amount <input type="radio"/> Medium amount <input type="radio"/> Small amount	<input type="radio"/> Not important <input type="radio"/> Least important <input type="radio"/> Very important <input type="radio"/> Important <input type="radio"/> Indifferent
4.2.1 Growth and size / length of the larvae	Category	Ranking
Adult larvae length	<input type="radio"/> Long <input type="radio"/> Short	<input type="radio"/> Important <input type="radio"/> Least important <input type="radio"/> Indifferent <input type="radio"/> Most important <input type="radio"/> Not important
Time taken for the larvae to grow to the required size	<input type="radio"/> Long <input type="radio"/> Short	<input type="radio"/> Important <input type="radio"/> Least important <input type="radio"/> Indifferent <input type="radio"/> Most important <input type="radio"/> Not important

Temperature variations <hr/>	<input type="radio"/> Low adaptability <input type="radio"/> High adaptability	* <input type="radio"/> Most important <input type="radio"/> Least important <input type="radio"/> Important <input type="radio"/> Not important <input type="radio"/> Indifferent	
Relative Humidity variations (low, med <hr/>	<input type="radio"/> Low adaptability <input type="radio"/> High adaptability	* <input type="radio"/> Most important <input type="radio"/> Least important <input type="radio"/> Important <input type="radio"/> Not important <input type="radio"/> Indifferent	
Light variations (low, medium or high) <hr/>	<input type="radio"/> Low adaptability <input type="radio"/> High adaptability	* <input type="radio"/> Most important <input type="radio"/> Least important <input type="radio"/> Important <input type="radio"/> Not important <input type="radio"/> Indifferent	
4.5 Lifespan of the larvae <hr/>	Period <hr/>	Ranking <hr/>	
Lifespan of the flies <hr/>	<input type="radio"/> Short <input type="radio"/> Long	<input type="radio"/> Most important <input type="radio"/> Important <input type="radio"/> Indifferent <input type="radio"/> Not important <input type="radio"/> Least important	
Other specify <hr/>	Please specify <hr/>	Level <hr/>	Ranking <hr/>

4.2.2 Growth and size / length of the larvae	Category	Ranking
Adult larvae size	<input type="radio"/> Small <input type="radio"/> Large	<input type="radio"/> Most important <input type="radio"/> Important <input type="radio"/> Indifferent <input type="radio"/> Not important <input type="radio"/> Least important
4.3 Nutrient content of the larvae	Proportion	Ranking
Fat content of the larvae	<input type="checkbox"/> Medium <input type="checkbox"/> Low <input type="checkbox"/> High	<input type="radio"/> Not important <input type="radio"/> Indifferent <input type="radio"/> Important <input type="radio"/> Most important <input type="radio"/> Least important
Protein content of the larvae	<input type="checkbox"/> Medium <input type="checkbox"/> Low <input type="checkbox"/> High	<input type="radio"/> Not important <input type="radio"/> Indifferent <input type="radio"/> Important <input type="radio"/> Most important <input type="radio"/> Least important
4.4 1 Ability of the flies to adapt to micro-cimate conditions	Level	Ranking

Other 		<input type="radio"/> Low/small/short <input type="radio"/> Medium <input type="radio"/> High/large/Long	<input type="radio"/> Indifferent <input type="radio"/> Most important <input type="radio"/> Least important <input type="radio"/> Important <input type="radio"/> Not important
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SECTION 5: BSF FARMING CONSTRAINTS

5.1 What problems/challenges do you face when rearing BSF?

- Lack of technical know how
- Inadequate supply of substrates
- Death of the larvae/pupae/flies
- Lack of supportive infrastructure
- Weather fluctuation
- Inadequate packaging & storage items/facilities
- Market & Marketing BSF products
- Colony collapse
- Sourcing breeding material
- Slow colony multiplication
- Other, Specify

Please Specify

5.2 During production, have you faced problems related to labor?

- Yes
- No

5.3 What coping strategies did you enforce to curb on this labor constraint?

- Utilize household labour
- Use of in-kind payment mode
- Quick hire of casuals to be paid later
- Use of labor meant for other farm enterprise(s)
- Other, Specify

Please specify

5.4 Do you know anyone who has quit BSF rearing?

- Yes
- No

5.5 If yes, please give the details , Name, Contact, Village

SECTION 6: FACTORS AFFECTING ADOPTION OF BSF TECHNOLOGY

Limiting Economic Factors

6.1 How easy/difficult is it to access starting material for BSF larvae production

- Very easy
- Easy
- Indifferent
- Difficult
- Very difficult

6.2 How easy/difficult is it to access training and technical support?

- Very easy
- Easy
- Indifferent
- Difficult
- Very difficult

6.3 How easy/difficult is it to start / construct black soldier fly larvae production unit?

- Very easy
- Easy
- Indifferent
- Difficult
- Very difficult

6.4 How easy/difficult is it to mobilize substrate for black soldier fly larvae production?

- Very easy
- Easy
- Indifferent
- Difficult
- Very difficult

6.5 How easy/difficult is it to store substrate for use in black soldier fly larvae production ?

- Very easy
- Easy
- Indifferent
- Difficult
- Very difficult

6.6 How easy/difficult is it to harvest black soldier fly larvae and other products ?

- Very easy
- Easy
- Indifferent
- Difficult
- Very difficult

6.7 How easy/difficult is it to market black soldier fly larvae products ?

- Very easy
- Easy
- Indifferent
- Difficult
- Very difficult

6.8 How easy/difficult is it to dry black soldier fly larvae ?

- Very easy
- Easy
- Indifferent
- Difficult
- Very difficult

6.9 How easy/difficult is it to store products such as fresh or dry black soldier fly larvae ?

- Very easy
- Easy
- Indifferent
- Difficult
- Very difficult

6.10 How easy/difficult is it to process feed from black soldier fly larvae ?

- Very easy
- Easy
- Indifferent
- Difficult
- Very difficult

Thank you so much for participating
