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Mass Production of Black Soldier Fly Larvae is Feasible in Nigeria: Practical Constraints to Its Adoption

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ABSTRACT

Background: The black soldier fly larvae (*Hermetia illucens* L.) have proven highly beneficial in meeting the growing demand for sustainable protein sources in animal feed production and the pressing need for effective waste management. Interest in insect farming, especially black soldier fly larvae (BSFL), increased with the rising cost and scarcity of conventional feed ingredients such as fishmeal and soybean meal. BSFL now has a reputation as a key player in the circular bioeconomy for its ability to convert organic waste into valuable resources, including protein, lipids, micronutrients, chitin, and nutrient-rich fertilisers. This paper reviews the potential for BSFL production in Nigeria and the constraints hampering the sector's growth.

Methods: An extensive literature search was performed using electronic databases, including Google Scholar, PubMed, and PubMed Central, using relevant keywords such as "Black soldier fly", "Black soldier fly larvae", Hermetia illucens", "Black soldier fly larvae farming", "Black soldier fly larvae production", and combinations of all these phrases with "Nigeria".

Review Findings: Studies from Nigeria and other African countries demonstrate that BSFL can be successfully reared on several locally available organic wastes. However, larval performance varies considerably with substrate composition and environmental conditions. Despite the demonstrated technical and economic viability of BSFL mass production in Nigeria, several challenges across its value chain have limited its widespread adoption. Critical challenges hampering the scaling of BSFL production in Nigeria, including high production costs, the unavailability of affordable, accessible, uncontaminated, and consistently available organic waste for rearing substrates, inefficient waste segregation systems, market development challenges, and other bottlenecks, are discussed in this review. The economic performance of BSFL production is also largely affected by the costs of procuring rearing substrates and labour.

Conclusion: Nigeria possesses considerable potential for BSFL-based circular bioeconomy development, which can be harnessed through interventions targeted at its value chain and economics.

Keywords: Black soldier fly larvae; *Hermetia illucens*; mass production; rearing substrate; Nigeria.

1.0 INTRODUCTION

The ever-growing demand for animal production has necessitated the search for sustainable alternatives to the traditional protein sources of fishmeal and soybean meal used in animal feed. The great potential some insects have shown as sustainable, and even cost-effective, feed ingredients has resulted in the global attention insect farming has received in recent years. Moreover, insect production is more environmentally friendly than fishmeal production, which has been associated with overfishing and environmental degradation, and soybean production, which has been linked to land-use change and deforestation [1-3].

Although insects have proven to be great feed ingredients, their use is often hampered by a lack of understanding of their mass production or rearing viability [4-6]. This does not apply to the black soldier fly (BSF), *Hermetia illucens* (L. 1758), which originated in the tropical, subtropical, and warm-temperate zones of the Americas but is now domesticated in many regions worldwide [7]. The Black soldier fly larvae (BSFL) have gained significant attention due to their high protein content, rapid growth rate, and ability to convert organic waste into valuable biomass [7-9]. The increasing global interest in BSFL farming is driven by its ability to valorise organic waste into valuable resources, including protein, lipids, micronutrients, and nutrient-rich fertilisers [10, 11].

The biology of the BSF and advances in BSFL husbandry enable multiple, continuous mass production. BSFL production systems have proven economically viable, producing high-value by-products while reducing environmental impacts and addressing food security challenges [11, 12]. There are several large commercial production systems in many countries; the French company InnovaFeed and the Dutch company Protix are among the largest insect producers in the world [9, 13]. However, even small-scale operations are profitable, support a circular bioeconomy, and create jobs and livelihoods [10, 14-16]. The potential of BSFL production to provide animal feed ingredients, environmental benefits (reduced greenhouse gas emissions), and socioeconomic benefits (waste management and job creation) has been demonstrated [12, 17]. Nigeria possesses a growing technical and research capacity for BSFL production. Farms across the country are cultivating and reaping the benefits of BSFL, but large-scale adoption, production, and utilisation remain limited. This paper examines constraints associated with BSFL production in Nigeria that are hampering its widespread adoption, production, and utilisation.

2.0 METHODOLOGY

2.1 Literature search strategy

An extensive literature search was performed using electronic databases, including Google Scholar, PubMed, and PubMed Central. Relevant search words were used, such as “Black soldier fly”, “Black soldier fly larvae”, *Hermetia illucens*”, “Black soldier fly larvae farming”, “Black soldier fly larvae production”, “Organic waste”, “Constraints of Black soldier fly larvae production”, and combinations of all these phrases with “Nigeria”. The titles and abstracts of the published articles retrieved from these electronic databases were examined, and only the relevant ones were included in this work.

3.0 BIOLOGY AND LIFE CYCLE OF BLACK SOLDIER FLY

The BSF is an insect belonging to the order Diptera and the family Stratiomyidae. The life cycle of BSF consists of five distinct stages: egg, larvae, pre-pupae, pupae, and adult (Figure 1) and lasts between 30 and 60 days depending on temperature and relative humidity. Female BSF lay eggs in clusters near decomposing organic matter or specialised egg traps, with each female capable of producing over 500 eggs [18]. These eggs hatch into larvae within 3 - 4 days, beginning the larval stage, which is the most critical phase for waste bioconversion [19]. The larval stage lasts between 22 and 24 days, depending on the rearing substrate, but can be prolonged by months under unfavourable conditions [4, 20, 21]. The larval stage is the principal production stage. It is the stage that feeds on organic waste, converting it into nutrient-rich biomass (used in animal feed production) and nutrient-dense frass (a valuable organic fertiliser) [18, 19].

The BSFL are omnivores with complex, voracious feeding habits that enable them to consume a variety of organic materials (substrates), making them strong candidates for organic waste conversion [4, 12, 21]. The growth, production, and maturation of BSFL are highly dependent on the quantity and nutritional quality of the culture substrates, as well as on the environmental conditions [4, 5]. Although they can tolerate a wide range of temperatures (15°C - 47°C) and relative humidity, the optimal culturing temperature is between 27°C and 30°C, whereas the optimal relative humidity is between 50 and 90% [21]. In addition, the moisture content of the rearing substrate influences biomass conversion efficiency [4]. The environmental conditions required for BSF rearing

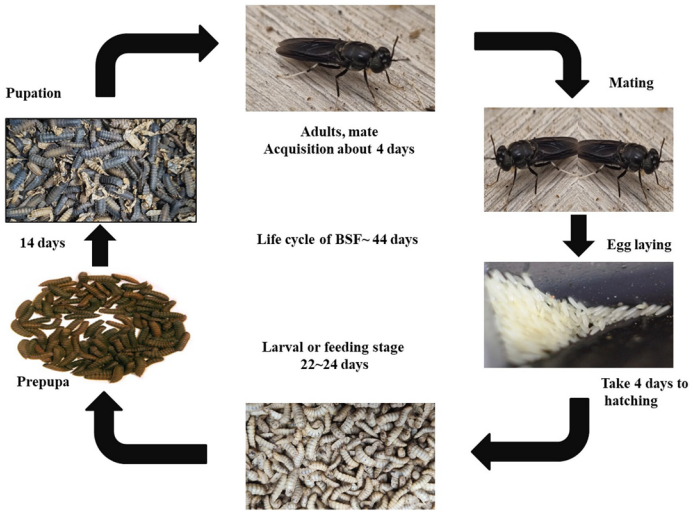


Figure 1. Life Cycle of the Black Soldier Fly (*Hermetia illucens*) [21]

are presented in Table 1. Nigeria's climate, being mostly tropical, is ideal for BSF production. Nigeria has an average annual temperature ranging from 23 °C to 34 °C, and relative humidity can range from below 25% in the north in January to over 80% in the south in July [22].

Table 1: Abiotic Factors for rearing black soldier fly (*Hermetia illucens*) [23]

Abiotic factor	Minimum	Optimal	Maximum
Temperature (°C)	12	26-27	36
Relative humidity (%)	25	60-70	99
Substrate moisture (%)	40	52-70	70
Light intensity (µmol/m^2/s)	60	135-200	-

4.0 THE ROLE OF BLACK SOLDIER FLY IN THE CIRCULAR BIOECONOMY

The insect rearing sector is important to the circular bioeconomy [24], as it can convert organic waste that could otherwise lead to environmental problems into valuable products, including protein, lipids, micronutrients, chitin, and nutrient-rich fertilisers [9]. Amongst the insects farmed, BSF has the greatest potential to convert a wide range of organic waste due to its natural ability to ingest and transform it [5] rapidly. Today, BSFL are used to produce feed ingredients that are as valuable as traditional feed ingredients for animal feed production, such as fish meal and soybean meal. BSFL meal is increasingly used to replace fishmeal and soybean in diets for fish, birds, pigs, and pets [9, 16].

Thus, integrating the farming of BSF in waste management increases protein supply without the need for additional resources while producing waste (nutrient-rich biofertilizer) that can be directly applied to agricultural activity [9, 24]. In addition to being an eco-friendly, cost-effective approach to handling waste, it is a sustainable, resource-efficient food system that can create jobs, generate income, and increase youth engagement. Thus, BSF production brings significant economic benefits while safeguarding the environment from pollution and, with further research and development, can revolutionise waste treatment and animal feed production [9].

5.0 OVERVIEW OF BLACK SOLDIER FLY LARVAE PRODUCTION IN NIGERIA

Black soldier fly larvae (BSFL) production is an emerging and increasingly promising enterprise in Nigeria, driven primarily by the need to convert organic waste into an alternative protein for animal feed. Nigeria generates a substantial volume of organic waste [25], which theoretically provides a strong foundation for BSFL production. There is evidence that BSFL can be successfully reared on a range of locally available organic substrates [26].

Evidence from commercial operations suggests that production in the country has progressed beyond small experimental units and farm-based activities to semi-industrial and emerging industrial-scale systems. Key commercial and emerging BSFL enterprises in Nigeria with substantial production capacities include MagProtein, Bioloop and Unique Biotechnology [13]. Other notable producers include Uptake Farms Ltd (Ekiti State), Fly Colony (Ogun State), and Ent'O'rganics Fly Farm (Ogun State) [13]. Among these, MagProtein Nigeria Limited provides some of the clearest quantitative evidence of commercial BSFL production. The company, which was established in 2017, reported a production capacity of approximately 1-1.5 tonnes of dried BSFL per day with an expansion target of 5 tonnes per day, alongside 6-7 tonnes of organic fertiliser per day as a by-product in 2022 [13, 19, 24].

Despite these developments, the Nigerian BSFL industry remains characterised by limited publicly accessible production statistics [24], inadequate infrastructure and technical training, fragmented waste-supply systems, high production costs, insufficient research, weak policy and regulatory frameworks, among other constraints. The lack of standardised industry statistics is itself an important characteristic of the sector and highlights the need for further research, development and documentation. Similarly, the country has a lot to gain from developing effec-

tive waste collection and supply methods. Nigeria possesses a growing technical and research capacity for the required research. Overall, the future outlook for BSFL farming in Nigeria is promising, given its potential to integrate organic waste management, sustainable animal feed production, and the development of a circular bioeconomy. However, realising this potential will depend on addressing the challenges hindering widespread adoption [27-29].

6.0 CHALLENGES OF MASS PRODUCTION OF BSFL IN NIGERIA

6.1 High Cost of Production: Initial Capital Investment

Black soldier fly larvae (BSFL) have proven to be a great, sustainable, and environmentally safe alternative feed ingredient, albeit not necessarily cheaper than these alternatives, due to their production costs [9]. For alternative feed ingredients to be competitive in animal feed production, they would need to be sourced at lower cost than traditional feed ingredients. They may also need to be locally grown and not compete with demands for human consumption [15]. However, it is still imperative to focus on producing alternatives, even if they are comparatively costlier, to counter the other effects of traditional feed ingredient production, such as uncertainties, scarcity, and environmental impacts.

BSFL production is often promoted as low-cost, but the high initial capital and operational costs involved in establishing production facilities, including rearing structures, substrate processing units, drying equipment, storage facilities, and energy generation, can be prohibitive [28-30]. Large-scale production remains difficult due to limited access to equipment and infrastructure [30]. All these combined costs can make BSF production nearly as expensive as producing conventional feed ingredients.

6.2 High Cost of Production: Rearing Substrates

Substrate costs are the major recurring cost in BSFL production and can strongly influence its economic performance. Rearing substrates, together with labour, account for most of the operating costs in BSFL production [15, 31], sometimes reaching about 90% [10, 32]. A wide range of substrates, from human faecal waste to agricultural and animal by-products to food waste, is used for BSFL production, with varying bioconversion rates [5, 11, 12, 19]. Although this waste may be free (and it often is not), the cost may accrue in the form of payment for labour for collection and sorting, transportation, grinding, and mixing.

The choice of substrates is strongly influenced by availability and proximity. The major materials used for BSFL production in Nigeria, including brewery waste, wheat offal, and palm kernel cake, are not equally abundant or readily available nationwide. These ingredients are also highly sought after, as most of them are already being used, directly or indirectly, in animal feed before the emergence of BSFL farming.

6.3 Availability of Suitable Organic Waste

To be economically profitable, BSF larvae should be reared on substrates that have no alternative value as feed for other animal production. The rearing substrates must be suitable, affordable, accessible, uncontaminated, consistently available, and safe [15, 31]. One of the most critical bottlenecks to the large-scale production and utilisation of BSFL in Nigeria is the difficulty of sourcing wholesome, consistent, and nutritionally adequate organic waste. Umar *et al.* [33] reported that municipal solid waste generation averages between 0.45 and 0.72 kg per person, and organic waste constitutes 50-70% of total municipal waste in Nigeria [34]. Nigeria, therefore, has a significant resource base for BSFL substrate production. Still, the issue is not just about getting waste, but about getting the right kind of waste - consistently, safely, and in adequate volume.

Nigeria is a country with enormous quantities of organic waste but lacks structured, organised systems for waste collection and management [25, 35]. Waste is also not properly segregated, rendering much of it unusable for BSFL production. Studies indicate that waste segregation at the source is minimal to nonexistent in Nigeria, resulting in contamination of organic waste with plastics, glass, stones, metals, hazardous materials, packaging, and synthetic materials [34, 35]. This creates a paradox: there is an abundance of waste necessary for the mass production of BSFL, but this waste is unsuitable or inaccessible for productive use. Even when plans are put in place to collaborate with waste producers to collect waste directly, the time, logistics, and costs of collection can be prohibitive. Still, source segregation could improve substrate consistency and become a central component of Nigeria's BSFL production strategy.

Consequently, the collection, segregation, transportation, and competing uses of organic wastes determine their actual availability for BSFL production. The substrates used by farmers are thus usually influenced by availabil-

ity and proximity to the farm to reduce transportation costs and the overall cost of production [5]. Some BSFL farmers have circumvented this transportation cost by locating their facilities close to their primary substrate supply.

Additionally, the type and quality of waste determine production performance and quality of the final product [14, 36]. Not all organic materials provide the nutrition required for optimal larval growth. Many waste streams used as substrates carry a variety of contaminants, including pathogens, heavy metals, antibiotics, and chemical residues such as pesticides, herbicides, and growth hormones, which can contaminate BSFL products [5]. Contamination can create food and feed safety concerns.

6.4 Seasonality and Environmental Conditions

BSFL production requires controlled environmental conditions, and mismanagement of these conditions can reduce larval growth and productivity [14, 21, 29]. Thus, environmental conditions are another major factor to consider when scaling BSFL production. The dry, hot weather conditions at times of the year in parts of Nigeria can be a considerable constraint in outdoor farming. Outdoor BSFL production was reported to be very poor during hot, dry periods in Burkina Faso, according to Sankara *et al.* [37]. Sankara *et al.* [37] showed that BSFL productivity varied strongly with season, with larval productivity highest during or just after the rainy season, when relative humidity remains high. No larvae were produced in the cool dry season in January - February, and only a few larvae were produced during the hot dry season in April - May. Temperature influences three properties of BSF life: lifespan, fertility, and life-stage transition rates [38].

6.5 Cost of Processing, Labour and Energy

BSFL production in Nigeria is not yet highly automated, and many activities are conducted manually. These may include substrate collection, sorting, weighing, grinding, cleaning, and separation. Harvesting, post-harvest handling, and processing are labour-intensive. Manual separation of BSFL from frass is tedious and time-consuming, even when the harvested larvae are uniform in size, but more so when they are not. Complete separation of BSFL from the frass is almost impossible, especially when the harvested BSFL are not uniform in size. And automating the process can be very technical and expensive [9].

Similarly, separating BSFL from frass is more difficult when the substrates are not uniformly sized. Grinding waste into more uniform, homogeneous bits may make separation easier but, in turn, increase production costs, as grinding machines consume fuel or electricity. More staff may be required to carry out these extra tasks, leading to additional labour costs, which substantially affect profitability [39]. Labour cost, together with the cost of rearing substrates, accounts for the majority of the operating cost in BSFL production [15, 31], sometimes reaching about 90% [10]. Thus, increased labour can reduce profitability.

The process of oven-drying BSFL can substantially increase production costs [29], making it one of the costliest stages in the food and feed production chain [40]. In Nigeria, the problem of unreliable electricity supply necessitates the use of alternative energy sources such as generators, which in turn further increases production costs.

6.6 Limited Access to Finance

BSFL production is a capital-intensive venture that many Nigerian entrepreneurs cannot easily access, especially if they want to operate at commercial scale. A feasibility study in Nigeria highlighted that cost-efficiency and scaling strategies are critical to economic viability and emphasised the need for financial support mechanisms [29]. Nigeria's financial system tends to favour trusted traditional industries over emerging industries like insect farming, making access to loans difficult. The national stakeholders' roundtable, organised by the International Livestock Research Institute (ILRI) in Ibadan, noted the need for additional financing to achieve commercial-scale BSFL production [30]. Insufficient access to finance has been observed to constrain production in other African countries [3].

6.7 Market Development and Profitability

The marketability and profitability of any farming business is as important as the production. There are no ready markets for black soldier fly in many sections of the country yet. The small-scale black soldier fly producer is unable to supply off-takers who may require a reliable supply of specific quantities, and thus cannot break into that market. On the other hand, stakeholders have noted growing interest from feed manufacturers, but the system is still developing, and there are no guaranteed off-takers yet [30]. This highlights a mismatch between potential demand and actual market structures. The absence of guaranteed off-takers has economic implications, such as production uncertainty and investment risk. This uncer-

tainty and the lack of a market discourage both farmers and potential investors.

In a study of farmers' willingness to pay and retailers' willingness to stock BSFL feed in Malawi, Mnthambala *et al.* [41] found that although there was substantial interest, retailers identified limited demand, unfamiliarity, and lack of awareness as barriers. Commercial scaling of the BSFL production will require reliable inputs and markets [10, 31].

6.8 Weak Policy and Regulatory Frameworks

Globally, strong regulatory systems have enabled the safe integration of BSFL into livestock and aquaculture feeds by ensuring product quality and consumer confidence [42]. In contrast, many African countries, including Nigeria, still lack a legal framework regulating the production of edible insects, such as BSFL [43]. Recent stakeholder engagements in Nigeria described Nigeria's insect -based feed regulatory systems as underdeveloped and evolving [30]. An urgent need for policy reforms to support the scaling and commercialisation of BSFL was highlighted. Product certification and licensing will enable access to certain markets. Another challenge is the absence of standardised protocols for substrate use and hygiene in BSFL production. Given that BSFL is reared on waste, concerns about nutrient composition, feed quality, and safety can arise if no strict safety regulations are in place.

6.9 Low Adoption and Inadequate Knowledge

Inadequate understanding of BSF farming and low adoption due to all the constraints outlined above have hampered the benefits the country stands to gain from BSF farming. Adoption remains low due to inadequate awareness and technical capacity among farmers [44]. While scaling production to industrial levels is important, BSF farming can provide an economically viable feed component for small-holder farmers [16].

7.0 CONCLUSION

The potential for mass production of the black soldier fly in Nigeria has been demonstrated. The opportunity is particularly significant because BSFL production can simultaneously address organic waste management, alternative feed production, fertiliser production, job creation, and the development of a circular bioeconomy. However, realising this potential will depend on addressing the challenges that hinder widespread adoption, including inefficient waste-supply systems, high production and processing costs, weak policy and regulatory frameworks, and underdeveloped markets. All these constraints must be addressed for Nigeria to achieve large scale adoption, production, and utilisation of the black soldier fly larvae

8.0 RECOMMENDATIONS

Given the important role BSFL farming can play in creating a circular bioeconomy, there must be ways to overcome these constraints to reap its benefits. Integrating its farming with crop and poultry production is one way for small-holder farmers.

Since BSFL farming has much to gain from the country's abundance of organic waste, waste management needs to be improved. Waste collection should be decentralised, and proper separation of organic waste at the point of generation should be promoted. The industry needs to identify genuinely underutilised waste streams, that is, organic waste not competed for by other animal producers. Research into converting and optimising organic wastes that BSFL cannot ordinarily utilise into forms they can use, for example through fermentation, soaking, etc. Further research into the safety of BSFL end products used in other animal production, especially given reports of potential heavy metal, chemical, and pathogen contamination.

Locally fabricated equipment should be designed for activities such as substrate grinding, mixing, harvesting, larvae-frass separation, and drying to reduce labour and production costs.

Small-scale farmers should be encouraged to form production clusters or cooperatives to improve market access, bargaining power, and even substrate procurement and establish agreements with other stakeholders. Government incentives, including fiscal policies for waste management, soft loans, and grants, could all contribute to the sector's growth.

Conflicts of Interest

The authors declare that there is no conflict of interests.

Authors' Contributions

AO conceived and designed the study, contributed to data collection, and manuscript writing. **AOA** contributed to manuscript writing. All authors approved the final copy of the manuscript.

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