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Systematic Review

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Black Soldier Fly Larva: A Resource Insect Larva Worth Promoting in Achieving Sustainable Development Goals—A Systematic Review

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Abstract
Insect utilisation and its products have gained significant attention. The black soldier fly (*Hermetia illucens*), a common edible insect, plays an important role in various processes. Its applications represent breakthroughs in addressing challenges across sectors such as the food industry, agriculture, and health, areas that are crucial for sustainable development. This systematic review focuses on linking Black Soldier Fly (BSF) applications to sustainable development goals (SDGs). This link can help in making effective policy in the BSF farming sector within the paradigm of the SDGs and their respective targets. In generating this paper, a total of 93 documents were reviewed, comprising 73 articles, 15 reviews, and 5 book chapters from a literature search from some English databases (Web of Science, ResearchGate, Semantic Scholar, and Google Scholar) exploring the potential of BSF rearing in achieving the SDGs. The results showed that BSF can contribute to attaining 11 SDGs (1,2,3,5,6,7,10,12,13,14, and 15) via its products or services.

Keywords:
edible insect; production; valorization; sustainability; black soldier fly; *Hermetia illucens*

1. Introduction

An increase in the animal and human population has brought about an increase in food consumption, the generation of more organic waste, a rise in the price of food proteins, and poor sanitation [1]. In ecosystems, the role of insects in the food chain is crucial and cannot be overemphasised. Insects play several beneficial roles; for example, as human food and animal feed, used in the production of cosmetics, and in bioremediation. Although many insects benefit ecosystems, the black soldier fly (Diptera: Stratiomyidae) stands out in several human-beneficial domains compared to other species. For example, in research done by Beesigamukama et al. [2] on nutrient quality and maturity status of frass fertilizer from nine edible insects, BSF larvae had a high waste degradation efficiency (55–80%), requiring a short bioconversion time, and producing higher amounts of organic fertilizer than the other insect species.

BSF has a lifecycle of about 45 days and is present in four distinct stages in nature: egg, larva, pupa, and adult [3,4]. This fly is a typical insect with numerous benefits to humans. It is commonly called "black gold" and can be used to make changes not only in structures relating to food and animal feed production, but also in areas of agriculture, biotechnology, and pharmaceutics. Though this insect is widespread, it has not been documented as a pest or a carrier of pathogens [5]. It also has no stinging body

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parts. The larva stage of BSF is the most significant of all the stages in the life cycle of BSF. BSF larvae play roles in various sectors, particularly agriculture, biotechnology, animal nutrition, and health.

Even though several works have been carried out on the diverse products obtained using BSF, there is a paucity of evidence regarding their contribution toward achieving the SDGs. This review provides insight into the structure, composition, and applications of BSF, with an emphasis on the role of its larval processes in promoting sustainable development. This review, which focuses specifically on small farming of BSF in tropical areas, is important as it provides contributions to present knowledge on BSF production and its relevance to the United Nations SDGs, Vision 2030. Each of the outlined BSF larva applications is linked to a corresponding SDG summarised in Table 1. It is expected that this review and its dissemination will be beneficial to communities by creating awareness of the importance of the cultivation of BSF.

2. Methods

2.1. Literature Search Strategy, Eligibility, and Inclusion Criteria

Figure 1 depicts a block representation of the review methodology. In exploring the applications of BSF larvae and their contribution to sustainable development, the PRISMA guidelines for systematic review were followed. In establishing this review, articles on the production of BSF larvae, their composition and application, and sustainable development goals from various English databases were sourced. The sourced databases and their websites included: Research Gate (https://www.researchgate.net, accessed on 12 January 2025), Google Scholar (https://scholar.google.co.za, accessed on 12 January 2025), Semantic Scholar (https://www.semanticscholar.org/, accessed 9 February 2025) Scopus (www.scopus.com, accessed 12 January 2025), Science Direct (https://www.sciencedirect.com/science, accessed 12 January 2025), SciELO (https://scielo.org/es, accessed 18 March 2025 and Thomson Reuters' Web of Science databases (https://www.thomsonreuters.com, accessed 18 March 2025).

In sourcing this information, keywords and phrases were used. These included: "Black soldier fly larvae", "Black soldier fly gut microbes and enzymes", "Black soldier fly application", and "Sustainable development goals". Screening of bibliographies from other selected articles was done to identify relevant studies that didn't appear in the search. The search was limited to articles published between 2000 and 2025. The year 2000 was chosen as a starting point because it marked a period of increased research activity on insects, with the first article on edible insects published in 2009, as observed in the global insect research trend and citation metrics [6]. Additionally, online videos containing the production and application of black soldier fly were sorted to enhance understanding.

Inclusion criteria in the generation of this review involved peer-reviewed original articles, published reviews, and perspectives focusing on sustainable development, BSF structure and taxonomy, and its application, published only in English. Non-online notes and textbooks were excluded because of difficulties in citing or verifying by readers.

Articles that met the aforementioned criteria were again sampled and further subjected to additional inclusion criteria with emphasis being;

- Use of standardized, applicable methods without inappropriate sample preparation.
- The articles demonstrate results on BSF larvae production and processing in a manner consistent with a wide literature, having standardised analyses by software packages

At the end of the screening process, a total of 93 documents consisting; 73 articles, 15 reviews, and 5 book chapters were reviewed from the literature search from the above-sampled English databases.

3. Results and Discussion

3.1. Structure of the Black Soldier Fly (BSF)

As mentioned earlier, BSF is present in four distinct stages in nature [3]. The adult form (Figure 2A) is generally found in decomposing organic matter, kitchen waste, waste from abattoirs, animal and human excrements, and even decomposing bodies or carcasses [4]. Just as the name indicates, the adult form is black in colour and subdivided into three segments (head, thorax, and abdomen). The eggs (Figure 2B) of the black soldier fly have an oval form and measure, on average, a millimetre in length. It is pale yellow or creamy white in colour. Female BSF lays 500 to 1000 eggs in packets in the presence of decomposing organic matter. The larvae of BSF (Figure 2C) measure about 1.8 mm when hatched. Upon maturity, each larva is made up of 11 segments, totalling a length of about 25 mm and 6 mm wide. Changes in colour morphology from creamy white to brown are generally observed during the growth to maturity of the larvae [3]. The larval stage is the eating stage of the insect, where it performs

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Table 1: Linking black soldier fly application processes to sustainable development goals.

SDG Number	SDG Theme	Link Between BSF Application Processes to SDG
Goal 1	No poverty	- Sale of BSF larvae or fertilisers by farmers using BSF larvae frass, thus generating income
Goal 2	Zero hunger	- Attaining food security and improving nutrition through BSF larvae farming as a protein source for animal and fish
Goal 3	Good health and wellbeing	- Achieving good health and wellbeing through BSF technology in waste management. - BSF larvae application in the control of pests, vectors, and pathogens - BSF larvae application in therapy through the production of antimicrobial compounds
Goal 5	Gender equality	- BSF farming and management can be done by both men and women, thus empowering women and girls and giving them equal rights
Goal 6	Clean water and sanitation	- Waste management through BSF technology improves sanitation by reducing environmental pollution
Goal 7	Affordable and clean energy	- BSF larvae technology in the production of biodiesel, thus ensuring access to affordable, sustainable, and modern energy
Goal 10	Reduced inequalities	- BSF larvae technology can be done within cities or far from cities, thus supporting the marginalized and disadvantaged
Goal 12	Responsible consumption and production	- Biotechnology involves the efficient recycling and reuse of generated waste.
Goal 13	Climate action	- BSF larvae contribute to the reduction of climate change through the prevention of waste from producing harmful gases or greenhouse gases as byproducts to the atmosphere.
Goal 14	Life below water	- Conserving biodiversity of aquatic species through promoting the use of BSF larvae in animal feeds and reducing reliance on aquatic fish commonly used as fishmeal in fish feeds
Goal 15	Life on land	- Conserving biodiversity of land species through promoting the use of BSF larvae biomass in animal feeds instead of using farmed crops

more of its environmental functions. The pupae of the black soldier fly (Figure 2D) are dark in colour and are usually characterised by total immobility and toughness of the exoskeleton, leading to the development of the future adult [7].

The larva form of BSF is the most significant, with its involvement in numerous processes and domains, typically agriculture, biotechnology, animal nutrition, and health. The larva has an astonishing ability, feeding on virtually any bio-waste, including kitchen waste, human faeces, and animal waste [8].

3.2. Black Soldier Fly Larvae Cultivation or Production

Earlier, many people have focused on BSF rearing with the use of human faecal waste and animal waste (manure) as substrates due to their ease of availability. Unfortunately, human faecal wastes and animal waste can sometimes harbour pathogenic organisms such as pathogenic bacteria, viruses, misfolded prions, and parasites, which pose a health risk [9]. As such, the prohibition by the European Union (EU) involving the use of animal and human waste for BSF larvae rearing was put in place to curb the risk of pathogen and other contaminants recycling when recirculating such materials within the food chain [10].

For small-scale production in communities by local farmers or producers, rearing of this fly can be done in cages typically with dimensions such as length (70.0 cm), width (70.0 cm), and height (140.0 cm) (Figure 3). This cage of chosen dimensions in length, width, and height is made of mosquito nets fixed on wooden frames. A circular opening is made on the net for ease of manipulation

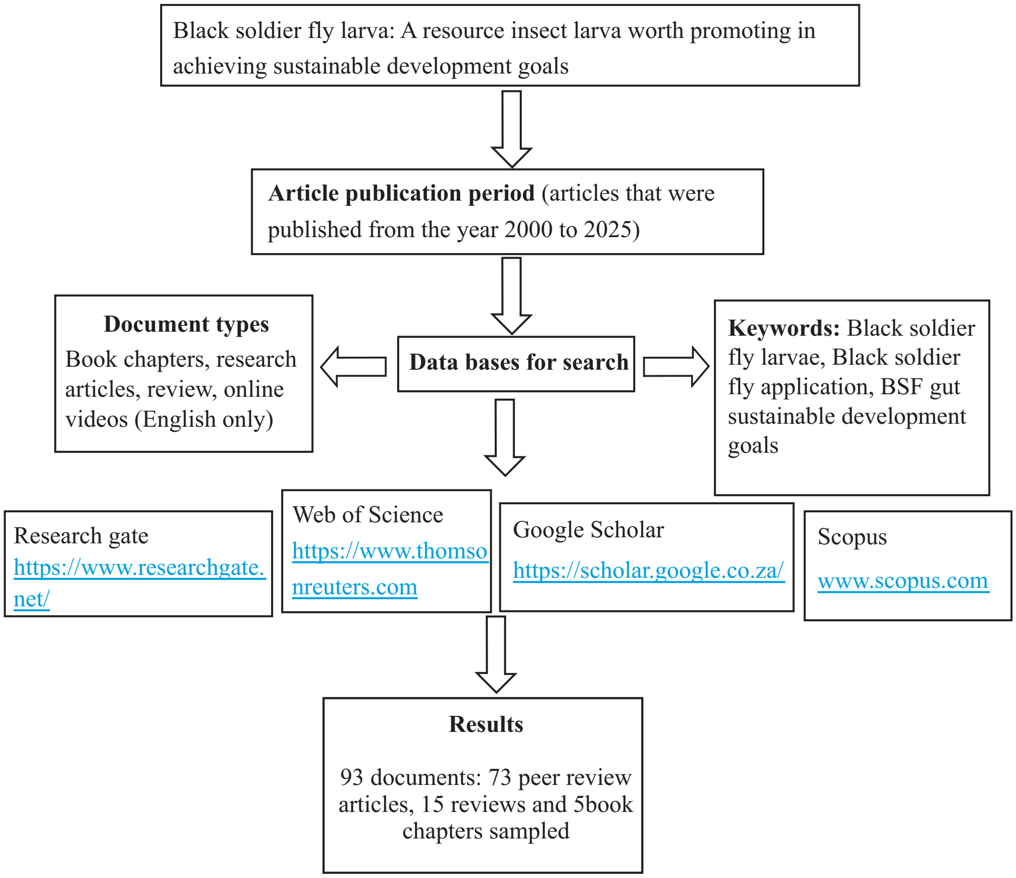

Figure 1: Schematic diagram showing the PRISMA methodology followed during the review process.

within. Egg-collecting structure composed of four or five pieces of wood of short dimensions stacked together using rubber bands is placed in the cage.

Though chicken feed is commonly used as substrate for BSF larvae growth, these larvae can still grow well on various organic waste, having a suitable water content. Dortmans et al. [11] document 70–80% as a suitable range for BSF larvae growth and organic waste processing. Based on literature with the use of food waste as substrates, Lalander and Guidini [12] recommended that, in meeting the nutritional requirements of BSF larvae, different substrates should be blended. The substrates should be chopped into small quantities to increase the surface area for BSF larvae to assimilate.

3.3. Black Soldier Fly Gut Microbes and Enzymes

Most of the processes performed by BSF are carried out due to the presence of microbes in their guts that secrete enzymes of multiple functions. The most dominant genera of bacteria present in BSF gut include *Bacteroides*, *Dysgonomonas*, and *Phascolactobacterium* [13], while *Pichia*, *Trichosporon*, *Rhodotorula,* and *Geotrichum* are the dominant fungal genera [14]. As the fly feeds on diets, gut microbes metabolise the diets due to their enzymes they secrete. For example, Jeon et al. [15] and Lee et al. [16] documented that bacteria in BSF Larvae' gut possessed enzymes that could hydrolyse starch, cellulose, proteins, and fats, which contributed to the decomposition of biowaste. BSF larvae secrete pepsin and lysozyme in their gut, which decompose substrates [17]. Proteins containing antimicrobial properties, typically antimicrobial peptides and reactive oxygen generating enzymes, have been shown to also be secreted by these larvae [18].

3.4. Black Soldier Fly Larvae Contribution Towards Sustainable Development Goals

Sustainable development goals (SDGs), also referred to as global goals, are a set of 17 interconnected goals formulated by the United Nations (UN) with the mission to foster peace and prosperity for people and the planet, now

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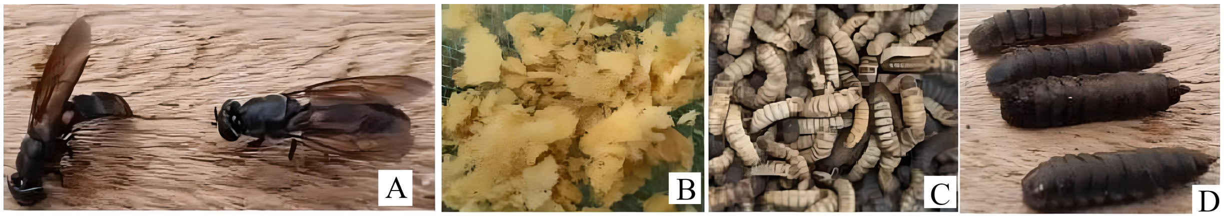

Figure 2: Structure of black soldier larvae showing its different stages (courtesy of photos taken by the author during BSF rearing). (**A**) Adult black soldier fly. (**B**) Eggs in batches. (**C**) Larvae. (**D**) Pupae.

and into the future. These goals were developed to be achieved by the year 2030. It is possible that with the massive exploitation of BSF in various sectors such as biotechnology, animal nutrition, agriculture, bioremediation and waste management, pest control, and therapy, most of these goals will be achieved. Understanding the application of BSF in these sectors and the nature of their contribution to achieving sustainable development goals is therefore important. Table 1 presents a link between black soldier fly application and the Sustainable Development Goals.

3.4.1. Black Soldier Fly Larvae in Biotechnology for Waste Recycling and Energy Production

Biotechnological processes using BSF in biowaste recycling into useful products have been studied widely [19]. Interest in BSF in biotechnology resides in its potential in the conversion of waste organic matter into biomass rich in proteins and lipids. The oil extracted from BSF larvae can be transformed and used as biodiesel [20], thus enabling access to affordable, sustainable, and modern energy (SDG-7, Affordable and clean energy). Producing biodiesel from BSF larvae also reduces the reliance on some unsustainable sources for biodiesel production, for example utilisation of jatropha plants [4,20]. The high reproductive ability of BSF and its shorter life cycle place them in a better position relative to energy plants, which require long life cycles and large land mass, thereby competing with humans [20]. The larvae of this fly have also been used in the production of grease used in cosmetic industry.

The application of BSF larvae in biotechnology is also a direct contribution to SDG-12, involving efficient recycling and reuse of generated waste and sustainable management of natural resources.

3.4.2. Black Soldier Fly Larvae in Attaining Food Security and Improving Nutrition

There is a massive need for innovative solutions to deal with the food insecurity challenges as a result of the growing population. Attaining food security is one of the goals of sustainable development (SDG-2). Adoption of BSF larvae farming as a protein source for animal and fish feeds, to make fish cheaper and affordable to a greater population, contributes directly to food security. BSF larvae are full of protein, fat, essential vitamins, minerals, and other important nutrients. These larvae primarily consist of proteins and lipids, although the proportion of these components varies depending on their rearing substrates. Studies by Barragan-Fonseca et al. [21] and Scala et al. [22] document that BSF larvae contain protein and lipids as their major nutritional contents; protein (40%), lipid (30%) on a dry matter basis. As a result of their high protein and lipid levels, the larvae can be used for feed production in various animal production sectors, including poultry and aquaculture industries, thus offering higher nutritional value compared to conventional animal feed [23]. This provides a better solution to food security problems documented by FAO [24] in search of alternative protein sources for use in animal diets.

3.4.3. Black Soldier Fly Larvae in Biodiversity Conservation

BSF farming uses a small amount of land, which is often done in close environments using horizontal and vertical farming spaces [25,26]. The use of small land in BSF farming contributes to mitigating biodiversity losses. Promoting the use of BSF larvae biomass in animal feeds instead of using farmed crops will lead to a reduction of reliance on plants for feed, thus contributing to increasing biodiversity. Also, promoting the use of BSF larvae in animal feeds will reduce the utilisation of aquatic fish commonly used as fishmeal in fish feeds. This will lead to biodiversity conservation of aquatic species. Hence, thereby contributing to conserving aquatic biodiversity, which is a sustainable development goal (SDG-14).

Figure 3: Experimental cage for black soldier fly rearing of dimensions: length (70.0 cm), width (70.0 cm), and height (140.0 cm), showing emerging flies and BSF egg trapping devices made of short planks stacked together by rubber bands (courtesy of a photo taken by the author during BSF rearing).

3.4.4. Black Soldier Fly Larvae in Agriculture (Farming)

Insect production for food and feed generates insect residual streams such as insect exuviae and frass. BSF larvae have been proven to be important in the field of farming in improving soil health through the action of their frass. When organic waste is introduced into the BSF larvae, the larvae process the waste. The waste residue (frass) is a quality input for soil amendment (used as fertiliser).

Frass is a combination of insect faeces, fragments of shed exoskeletons, and non-digested feed. Through its frass, soil fertility is enhanced, rich in nitrogen, phosphorus, and potassium content. Studies have demonstrated that crops grown using BSF larvae frass have higher yields than those grown on conventional fertilisers. For example, Beesigamukama et al. [26] demonstrated that maize grown in plots treated with BSF frass had 14% higher grain yields, produced taller plants (11% taller) and higher chlorophyll concentrations (18% higher) than plots treated with a commercial organic fertiliser. Frass application in soils also induces plant resistance to abiotic stress. Frass reduces the demand for synthetic fertilisers, which are often imported, playing a part in the national economy. Frass also offers more reliance on organic fertilisers. The implementation of BSF rearing technology for soil amendments and fertiliser production for farmland contributes to sustainable agriculture, healthy crops, and income generation for farmers. This contributes to the economic development of smallholder farmers, bringing about poverty reduction, which is one of the Sustainable Development Goals (SDG1)

3.4.5. Black Soldier Fly Larvae in Bioremediation and Waste Management

The natural and rapid biodegradability of food and animal waste makes their management more difficult [27]. The huge generation of food and animal waste poses a danger to the environment due to the bad odour, breeding grounds of harmful insects, and carbon dioxide production [28]. In most sub-Saharan countries, managing waste is considered a major environmental issue, with the organic fraction representing 90% of all the waste [29]. A greater proportion of this organic waste, though recoverable, is managed by burying, composting, or incinerating, which brings about environmental issues, typically soil and air pollution by releasing greenhouse gases and contaminating groundwater with toxic compounds and nutrients from leachate [30]. Faced with these global phenomena, it is essential to look for alternative ways to manage the organic waste produced, while generating fewer greenhouse gases and an alternative biofertilizer to replace chemical fertilizers.

BSF larvae utilisation is an evolving technology in managing or treating biowaste [31]. These larvae are more effective than traditional composting in the reduction of bulk proportion of waste organic matter within a short duration since they can consume enormous amounts of organic waste, decompose waste matter from animals and humans, decompose food waste, and other trash during their feeding until they attain the prepupae or non-feeding stage. This can be supported in work done by Amrul et al. [32] who documented a reduction of the initial weight of organic waste by about 50% in a shorter period than conventional composting. BSF larvae also develop on decomposing organic matter and generate less odour than other processes [33]. Application of BSF technology in waste management also fosters the attainment of two major sustainable development goals, which include: healthy living and promotion of well-being (SDG-3) and Sanitation for all (SDG-6).

3.4.6. Black Soldier Fly Larvae in Reducing Climate Change

BSF larvae convert waste to protein before decomposition occurs, preventing waste from producing harmful gases or

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greenhouse gases as byproducts in the atmosphere. Production of smaller amounts of greenhouse and harmful gases contributes to Sustainable Development Goal-13 (SDG-13), which focuses on the reduction of climate change and its impacts [34]. BSF presents an outstanding reproductive ability and fast development even when feeding on materials of low grade, like organic waste or garbage. Using BSF larvae for waste management provides an eco-friendly and low-cost approach to significant waste reduction and limiting disease transmission [35].

3.4.7. Black Soldier Fly Larvae in Control of Pest, Vectors, and Pathogens

BSF is non-pathogenic to humans. They colonise matter rich in pathogens, suggesting that their immune system can resist and defeat pathogens located in their environment [2]. Through competition, the larval stage controls the population of houseflies on materials they have colonized, by preventing oviposition of houseflies on the same material [36]. The BSF larvae accomplish this by the secretion of a distinct odour (info-chemical), sending away the houseflies, including all other pest flies. Involvement of BSF technology in pest and vector control thus contributes to attaining SDG-3 (healthy living and promotion of well-being) and SDG-6 (Sanitation for all).

3.4.8. Black Soldier Fly Larvae in Therapy

Natural products of organisms are better therapeutic agents than standard drugs due to the lower acquisition of resistance by parasites. Studies carried out have documented the gut microbiota of BSF larvae harbouring fungi that secrete bioactive components protecting them against attack from pathogens. Some fungal species identified in the gut microbiota of BSF larvae have been recognized as producers of various bioactive compounds and metabolites, which hold significant importance for the pharmaceutical industry [37]. Furthermore, some of these identified gut species, for example *Trichoderma* sp., have been identified to be laccase producers [38]. Laccase has also been recognized to be an enzyme of great importance in both pharmaceutical industries. Studies documented by Jaya et al. [39] documented laccase, possessing the ability to break down and destroy cancerous cells. Clinical trial with the use of edible mushroom showed laccase screened from it, induced apoptosis in cancer cell lines [40]. Other studies on laccase activity documented it as an inhibitor to HIV-1 reverse transcriptase [41].

Additional studies by Kinney et al. [42] reported the activity components of BSF larvae against *Staphylococcus aureus*. Various compounds isolated from the BSF have also yielded success in animals. For example, chitin isolated from BSF was demonstrated to prevent Leishmania infection in mice [43]. Furthermore, research carried out by Erickson et al. [36] showed a significant reduction of *E. coli* 0157:H7 and *Salmonella enterica* measured in hen manure following its incorporation with BSF larvae. Erickson et al. [36] and Zheng et al. [13] have documented antibacterial and fungicidal compounds being produced by BSF guts through the action of lysobacter bacteria present in their guts. For example, lauric acid obtained from BSF larvae fats has been proven to possess anti-microbial activity against lipid-coated viruses (HIV and measles viruses), some pathogenic bacteria (*E. coliform*, *Clostridium*), and pathogenic protozoans like Coccidiosis [44,45]. Chitin, making up the exoskeleton of the pupa and adult form of the BSF, is believed to possess immunity-enhancing effects [46]. Liu et al. [46] reported a reduced population of intestinal *E. coli* and *Salmonella* in chickens fed on chitin. Based on these findings, chitin and its products have the potential to replace antibiotics incorporated in animal feeds.

The widespread nature of the black soldier fly, its possession of various antimicrobial compounds, and its implementation in feed and food make it an interesting alternative to currently used therapeutic agents. Involvement of BSF technology in the field of therapy thus contributes to attaining SDG-3 (healthy living and promotion of well-being) and SDG- 6 (Sanitation for all).

3.4.9. Black Soldier Fly Farming in Reducing Inequality Within or Among Countries and Gender

BSF larvae farming can be done in any setting, be it on a small scale or large scale, thus can end poverty in all its forms everywhere, by ensuring an income to populations far from cities, thus supporting marginalized and disadvantaged (SDG-10, reduced inequalities). Also, within households, the production and management of BSF can be done by both men and women, thus empowering women and girls and ensuring their equal rights in the work process (SDG-5, gender equality). Black soldier fly farming is also not resource-demanding or capital-intensive, making it more accessible for women compared to certain farming practices that are culturally regarded as male-dominated.

There were challenges in bringing about significant or sufficient information on the literature on the importance of BSF in various processes. This was as a result of the fact that only literature and data published in English were taken into consideration. This means that relevant information on the subject, which could be useful but was published in languages other than English, was excluded.

4. Conclusions

This review covered BSF larvae rearing, its application in various processes, and its contribution to sustainable development. It could be seen from this review that no SDG is independent of the other; thus, acceptance of BSF rearing indirectly also contributes to the attainment of other SDGs. The review showed the potential of BSF to confer several benefits to humans and the environment, making them valuable for the future. Although our review highlights the link between BSF production and the SDGs, achieving these goals within communities largely depends on policymakers and stakeholders, who serve as the driving force behind any production system. In developing countries or low-income settings, BSF technology is still in its infancy. Therefore, policymakers should engage the public through training programs on the production and transformation processes, emphasizing the potential benefits of this technology.

Also, in most communities, especially in developing countries, the use of BSF products remains unregulated, which poses a risk to consumers of food from BSF products. In this regard, policies need to be formulated guiding quality BSF production and use of its products, typically in food systems. Production of quality BSF will create premium markets both locally and internationally, thus enhancing income to farmers.

List of Abbreviations

BSF	Black Soldier Fly
EU	European Union
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
SDG	Sustainable Development Goal
UN	United Nations

Author Contributions

T.E.A.: Conceptualization, Data curation, Investigation, Writing—original draft, Writing—review & editing, H.N.T.: Conceptualization, Data curation, Investigation, Writing—original draft, Writing—review & editing, L.T.A.: Conceptualization, Data curation, Investigation, Writing—original draft, Writing—review & editing, L.G.: Writing—review & editing. All authors have read and agreed to the publication of the paper.

Availability of Data and Materials

The data that support the findings of this study are available on request from the corresponding author.

Ethics Committee Approval

This study was conducted following the ethical principles for research. Administrative authorizations were obtained from the Dschang School of Science and Technology in the University of Dschang, Cameroon [N°0330/2024/UDS/FS/DBA], following a seminar presentation done on the 7th of May 2024 by the corresponding author. All experimental procedures were carried out in accordance with the recommendations of the laboratory ethics committee and the Ministry of Scientific Research and Innovation of Cameroon.

Consent for Publication

No consent for publication is required, as the manuscript does not involve any individual personal data, images, videos, or other materials that would necessitate consent.

Conflicts of Interest

Authors declare no conflicts of interest

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Standards of Reporting

This systematic review was conducted and reported in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.

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