BLACK SOLDIER FLY (HERMETIA ILLUCENS) LARVAE OIL: A SYSTEMATIC LITERATURE REVIEW OF CHARACTERISTICS, APPLICATIONS, AND FUTURE RESEARCH DIRECTIONS

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Abstract

Black Soldier Fly (BSF) (Hermetia illucens) larvae oil has attracted increasing attention as a sustainable alternative lipid source due to its high fatty acid content, particularly lauric acid, and its potential applications across various sectors. This study aims to systematically review the current state of research on BSF larvae oil. A systematic literature review (SLR) was conducted following the PRISMA 2020 guidelines. Relevant articles were retrieved from Scopus and ScienceDirect databases.Results showed that research on BSF larvae oil has grown substantially in recent years, with the majority of studies focusing on animal nutrition, aquaculture, growth performance, lipid metabolism, and feed efficiency. Bibliometric analysis revealed five major research clusters covering feed applications, fatty acid composition, growth performance, physiological responses, and alternative applications such as biodiesel. Overlay visualization showed a recent shift from basic feed utilization studies toward investigations of gut microbiota, lipid metabolism, and health-related effects. Research on industrial applications, cosmetic products, household cleaning products, and commercialization aspects remains limited.

Keywords: *Black Soldier Fly oil, Hermetia illucens, insect oil, lipid source, systematic literature review*

1. Background

Increasing global population and economic activities have intensified the demand for natural resources. Global material extraction increased from 27 billion tons in 1970 to 92 billion tons in 2017, contributing to biodiversity loss, water resource depletion, and environmental degradation. More than 90% of global biodiversity loss and water stress have been associated with resource extraction and processing activities, with agriculture being one of the major drivers of these impacts (IRP, 2019). In parallel, the production of vegetable oils has expanded rapidly over the past two decades, reaching 208 million tons in 2020. Palm oil, soybean oil, rapeseed oil, and sunflower oil account for approximately 87% of global vegetable oil production, with palm oil experiencing the highest growth rate (FAO, 2022).

The increasing demand for vegetable oils is closely linked to land-use change and biodiversity loss. Agricultural expansion for commodity production has been identified as one of the primary causes of habitat conversion and species extinction worldwide (Cabernard et al., 2024). Furthermore, vegetable oil production contributes significantly to global land-use change, resulting in substantial environmental impacts throughout supply chains . Consequently, the development of alternative and more sustainable lipid sources has become an important research priority.

At the same time, global waste generation is projected to reach 3.40 billion tons by 2050, with organic waste representing a major fraction of municipal solid waste, particularly in low- and middle-income countries (Kaza et al., 2018; United Nations Environment Programme, 2024). In Indonesia, food waste accounts for the largest proportion of municipal waste, representing approximately 38% of total waste generation (SIPSN, 2024). These challenges have increased interest in waste valorization technologies capable of converting organic residues into high-value products.

Among the available approaches, insect-based bioconversion has emerged as a promising strategy for transforming organic waste into valuable resources. Black Soldier Fly (BSF) (*Hermetia illucens*) larvae are capable of converting a wide range of organic substrates, including food waste, agricultural residues, and animal manure, into nutrient-rich biomass (Siddiqui et al., 2025). Previous studies reported that BSF larvae can reduce organic waste by 24–73% while recovering carbon and nitrogen from waste streams and generating lower greenhouse gas emissions than conventional composting systems (Pang et al., 2020). Consequently, BSF-based bioconversion is increasingly recognized as an important component of circular bioeconomy and sustainable waste management systems.

BSF larvae contain considerable amounts of lipids and proteins, making them attractive as alternative biological resources. On a dry matter basis, BSF larvae contain approximately 38% lipids and 40% protein (Bogevik et al., 2022). The extracted oil is characterized by a favorable fatty acid profile dominated by lauric acid, followed by palmitic, oleic, and linoleic acids (Bogevik et al., 2022; Suryati et al., 2023). Due to its composition, BSF oil has attracted increasing attention as a potential substitute for conventional vegetable oils and animal-derived lipid sources.

In addition to its functional properties, BSF oil offers significant environmental advantages. A recent life cycle assessment reported that BSF oil production generates substantially lower greenhouse gas emissions than conventional vegetable oils. While palm kernel oil, coconut oil, rapeseed oil, and soybean oil generate between 1.30 and 3.75 kg CO_2-eq per kilogram of product, BSF oil generates only 0.47 kg CO_2-eq per kilogram of product (Francis et al., 2025). These findings highlight the potential of BSF oil as a sustainable alternative lipid source within circular production systems.

Although research on BSF-derived products has expanded considerably, most waste valorization studies continue to focus on energy recovery rather than the development of high-value bio-based products (Arias et al., 2025). Moreover, studies investigating BSF oil remain fragmented across different application sectors, including animal feed, aquaculture, biofuel production, pharmaceutical formulations, and industrial products. A comprehensive synthesis of existing knowledge is therefore needed to identify research trends, major application areas, and future development opportunities.

This study aims to systematically review the current state of research on Black Soldier Fly larvae oil and identify emerging research opportunities through descriptive and bibliometric analyses.

2. Methods

2.1 Eligibility Criteria, Article Search Strategy, and Dataset Development

This study employed a systematic literature review (SLR) approach to evaluate the current state of research on Black Soldier Fly (*Hermetia illucens*) larvae oil. The review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (Page et al., 2021) guidelines to ensure a transparent and reproducible article selection process.

The eligibility criteria were established using the Population, Intervention, Comparators, Outcomes, and Study Design (PICOS) framework. The population consisted of Black Soldier Fly larvae oil (BSF oil). The intervention focused on the utilization and application of BSF oil in various sectors, including animal feed, aquaculture, biofuel production, pharmaceutical formulations, and industrial products. The outcomes included the identification of application areas, characteristics, benefits, limitations, and future research opportunities related to BSF oil. Only peer-reviewed journal articles written in English were considered in this review.

After careful evaluation, a dataset containing studies related to the characteristics, applications, and potential utilization of BSF oil was constructed and extracted. The articles were carefully selected following the PRISMA framework and managed using Mendeley Reference Manager (https://www.mendeley.com/). For each selected article, the following information was extracted: (1) author(s); (2) publication year; (3) journal source; (4) application category of BSF oil; and (5) major findings.

The literature search was conducted using the Scopus and ScienceDirect databases. The search period covered publications published between January 2021 and June 2026. The search was performed using the following terms:

("Black Soldier Fly oil" OR "BSF oil" OR "Hermetia illucens oil" OR "BSF larvae oil" OR "Black Soldier Fly larvae oil" OR "BSF lipid") AND (utilization OR application OR valorization OR potential)

Initially, 227 records were identified from the selected databases, consisting of 120 records from Scopus and 107 records from ScienceDirect. Duplicate records were subsequently removed, followed by title and abstract screening. Articles were excluded if they were unrelated to BSF oil, focused exclusively on Black Soldier Fly larvae meal, published as conference proceedings, book chapters, editorials, or notes, or if full-text access was unavailable. Following the screening and eligibility assessment process, 47 articles met the inclusion criteria and were included in the final review dataset (Figure 1).

The selected studies were analyzed using descriptive and bibliometric approaches. Descriptive analysis was conducted to identify publication trends, major application areas, and research developments related to BSF oil. Furthermore, bibliometric analysis was performed using VOSviewer (version 1.6.20) to visualize keyword co-occurrence networks, thematic clusters, and emerging research trends. Network visualization and overlay visualization were generated to examine thematic relationships and the evolution of BSF oil research over time. The findings were subsequently synthesized to identify current research focuses, challenges, and future opportunities for the development of BSF oil as a value-added product derived from organic waste valorization.

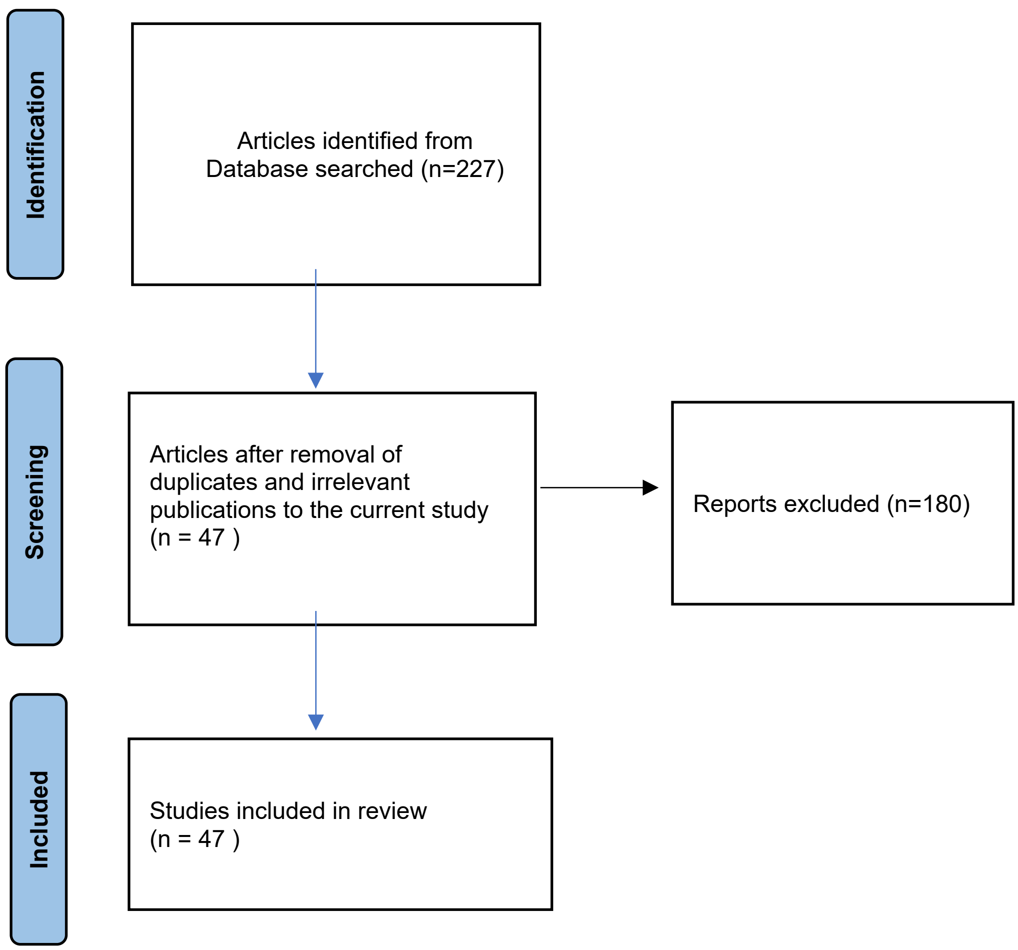

Figure 1 presents the PRISMA flow diagram illustrating the article selection process.

Table 1. Research Protocol

Item	Description
Databases	Scopus and ScienceDirect
Search Terms	**Group 1 (Scopus):** TITLE-ABS-KEY ("Black Soldier Fly oil" OR "BSF oil" OR "Hermetia illucens oil" OR "BSF larvae oil" OR "Black Soldier Fly larvae oil" OR "BSF lipid") AND (utilization OR application OR valorization OR potential)
	Group 2 (ScienceDirect): TITLE, ABSTRACT, OR KEYWORDS ("Black Soldier Fly oil" OR "BSF oil" OR "Hermetia illucens oil" OR "BSF larvae oil" OR "Black Soldier Fly larvae oil" OR "BSF lipid") AND (utilization OR application OR valorization OR potential)
Search Strategy	Boolean operators (AND, OR)
Inclusion Criteria	Articles discussing the utilization, application, potential, or valorization of Black Soldier Fly (BSF) oil; published in peer-reviewed journals; full-text available; written in English.
Exclusion Criteria	Conference papers, book chapters, editorials, notes, non-English publications, duplicate records, and articles unrelated to BSF oil applications.
Language	English
Document Type	Article
Timeframe	January 2021 – June 2026
Software	Microsoft Excel and VOSviewer (version 1.6.20)
Method	Systematic Literature Review (SLR) based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020)
Analysis	Descriptive analysis, publication trend analysis, journal distribution analysis, and keyword co-occurrence mapping using VOSviewer

3. Results and Discussion

3.1 Literature Selection

The literature search identified a total of 47 publications from Scopus and ScienceDirect databases. The selection process was conducted following the PRISMA guidelines. After removing duplicate records and applying the inclusion and exclusion criteria, the remaining studies were assessed through title, abstract, and full-text screening. The final selected articles were used for descriptive and bibliometric analyses.

3.2 Publication Trends of BSF Oil Research

Research on Black Soldier Fly larvae oil has shown a growing trend in recent years. The increasing number of publications reflects the growing interest in sustainable bio-based products derived from insect biomass and waste valorization systems.The reviewed studies were published across various journals related to animal science, aquaculture, biotechnology, sustainability, and environmental management. Most publications originated from countries with established insect farming and circular economy initiatives, particularly in Europe and Asia. The increasing publication trend demonstrates the expanding recognition of BSF oil as a potential alternative lipid source capable of supporting sustainable production systems.

Table 2. Number of Publication by Year

Publication Year	**Number of Publications**
2021	3
2022	8
2023	7
2024	17
2025	6
2026	6
Total	**47**

In terms of journal distribution, the reviewed publications appeared across 26 different journals, *Poultry Science* was the most productive outlet with 7 publications, followed by *Aquaculture* with 6 publications. *Animal Feed Science and Technology*, *Heliyon*, and *Animals* each contributed 3 publications.

Table 3. Most Productive Journals Publishing BSF Oil Research (2021–2026)

Journal	**Number of Publications**
Poultry Science	7
Aquaculture	6
Heliyon	3
Animals	3
Animal Feed Science and Technology	3
Journal of Agriculture and Food Research	2
Frontiers in Microbiology	2
Animal Nutrition	2
Animal	2
Tropical Journal of Natural Product Research	1
Applied Food Research	1
Food Chemistry	1
Advances in Animal and Veterinary Sciences	1
Journal of Dairy Science	1
Separation and Purification Technology	1
Journal of Animal Science and Biotechnology	1
Journal of Applied Pharmaceutical Science	1
Aquaculture Reports	1
Journal of Insects as Food and Feed	1
Asian Journal of Agriculture	1
Results in Engineering	1
Carbohydrate Polymer Technologies and Applications	1
The Journal of Nutrition	1
Comparative Immunology Reports	1
AACL Bioflux	1
Fish and Shellfish Immunology Reports	1
Total	**47**

3.3 Bibliometric Analysis

3.3.1 Network Visualization

The co-occurrence analysis generated by VOSviewer identified 44 keywords grouped into five major clusters. The most prominent keywords included *Hermetia illucens*, *black soldier fly oil*, *growth performance*, *fatty acid*, and *lipid metabolism*. The first cluster mainly focused on poultry nutrition and animal feed applications. The second cluster represented studies investigating the chemical composition and fatty acid profile of BSF oil. The third cluster was associated with growth performance and feed efficiency. The fourth cluster emphasized physiological responses, including lipid metabolism and gut microbiota. The fifth cluster contained studies related to biodiesel and alternative applications. These findings indicate that current BSF oil research is strongly concentrated on animal nutrition and biological performance.

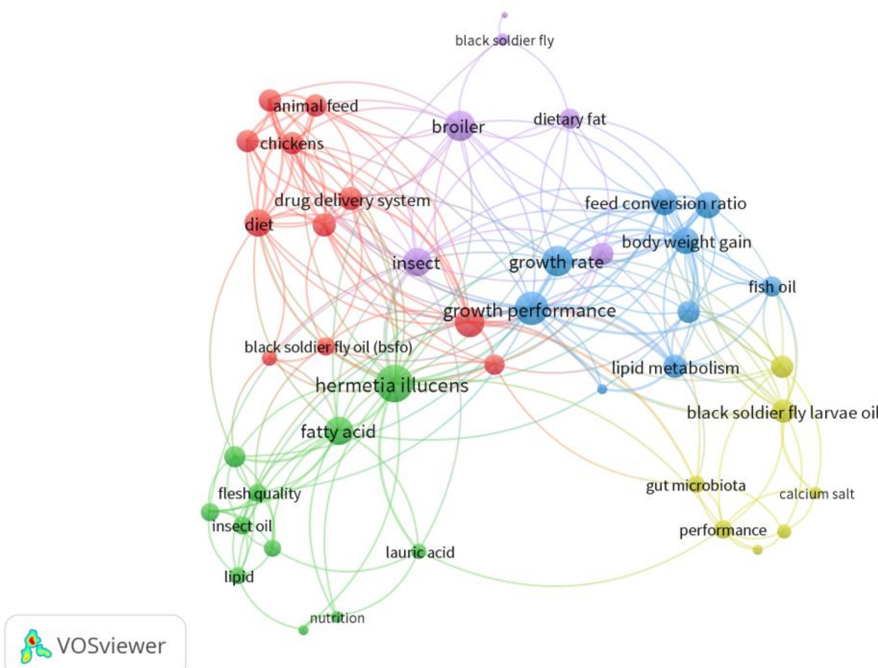

Figure 2. Network Visualization

3.3.2 Overlay Visualization

Overlay visualization revealed a shift in research focus over time. Earlier studies primarily investigated the suitability of BSF oil as a feed ingredient and substitute for conventional lipid sources. More recent studies have increasingly examined lipid metabolism, gut microbiota, inflammatory responses, and nutritional functionality. The emergence of keywords such as *gut* *microbiota*, *lipid metabolism*, and *nutrition* suggests that BSF oil research is moving beyond basic feed replacement toward understanding its physiological and functional impacts.

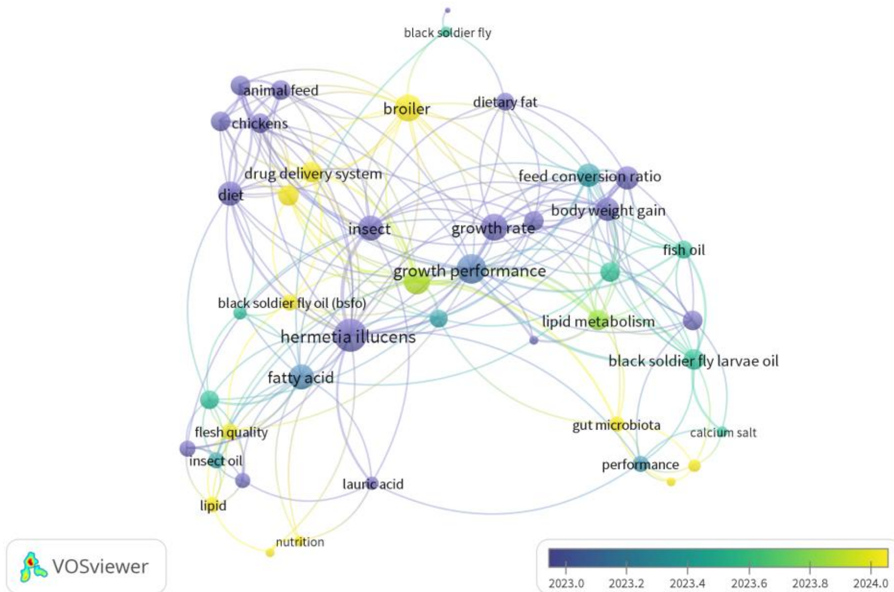

Figure 3. Overlay Visualization

3.4 Potential Applications of BSF Oil

3.4.1 Poultry and Livestock Feed Applications

Animal feed represents the most extensively investigated application of BSF oil. The increasing global demand for meat, eggs, and dairy products has intensified the search for sustainable feed ingredients capable of reducing dependence on conventional lipid sources such as soybean oil, palm oil, and fish oil. In addition, increasing concerns regarding feed costs and environmental sustainability have encouraged the development of alternative ingredients derived from circular production systems.

BSF oil is characterized by a high concentration of medium-chain fatty acids, particularly lauric acid, which contributes to both nutritional value and antimicrobial activity. These characteristics make BSF oil a promising ingredient for poultry and livestock diets. Several studies demonstrated that BSF oil can partially or completely replace conventional dietary oils without negatively affecting animal performance. Kierończyk et al. (2022) reported that BSF larval fat provided adequate metabolizable energy for broiler chickens and could successfully replace conventional dietary oils while maintaining growth performance. In a subsequent study, Kierończyk, Rawski, et al. (2022) also observed that dietary inclusion of BSF fat improved breast meat quality in broiler chickens. Similar findings were reported by Hartinger et al. (2022), who demonstrated the suitability of *Hermetia illucens* larvae meal and fat in broiler diets.

Azizah et al. (2024) reported improvements in growth performance and intestinal histomorphology of broiler chickens fed diets supplemented with BSF oil. Likewise, Dewanti et al. (2024) found that nano-emulsified BSF oil improved growth performance, immune responses, and health status in broilers. Anas et al. (2025) further demonstrated that BSF oil influenced the expression of genes associated with lipid metabolism in broilers fed low-protein diets, while Anas et al. (2024) reported improvements in intestinal morphology and barrier function in laying hens.

Kierończy (2022) successfully replaced soybean oil with cold-extracted BSF fat in turkey diets without adverse effects on performance. In laying hens, Khan et al. (2024), Patterson et al. (2021), and Tajudeen et al. (2026) reported that BSF oil supplementation maintained productive performance while improving several nutritional and physiological parameters.Nekrasov et al. (2022) reported positive effects of BSF fat supplementation on the health and productivity of dairy cows, while Baila et al. (2026) successfully replaced palm fatty acid distillate with BSF oil in dairy ewe diets. Similar observations were reported by Hervás et al. (2022), highlighting the potential of insect-derived oils as sustainable lipid sources for sheep production systems.

3.4.2 Aquaculture Applications

Aquaculture is one of the fastest-growing food production sectors globally and is expected to play an increasingly important role in meeting future protein demand. However, the industry remains highly dependent on fish oil and fish meal as major sources of dietary lipids and proteins. The increasing demand for aquafeed ingredients, combined with concerns regarding overfishing and marine resource depletion, has intensified the search for sustainable alternatives to conventional fish oil.

BSF oil has emerged as a promising alternative lipid source due to its favorable fatty acid profile, availability from waste valorization systems, and lower environmental footprint compared with marine-derived oils. Consequently, numerous studies have evaluated the suitability of BSF oil as a replacement for fish oil in aquaculture diets. Xia et al. (2024) reported that BSF larvae oil served as a suitable lipid source for largemouth bass, supporting normal growth and feed utilization. Similarly, Yuan et al. (2024) found that dietary BSF oil enhanced growth performance and improved several physiological parameters in largemouth bass. Positive results were also reported in juvenile mirror carp by Xu et al. (tahun perlu dilengkapi) and in black seabream (*Acanthopagrus schlegelii*) by Gu et al. (2025).

Moutinho et al. (2024) demonstrated that BSF oil could be used as an alternative lipid source in diets for gilthead seabream (*Sparus aurata*) juveniles while maintaining growth performance and fillet quality.

In salmonid species, Borland et al. (2024) investigated the effects of BSF oil on rainbow trout and reported favorable growth performance and hepatic gene expression responses. However, Liao et al. (2026) observed that complete substitution of fish oil with BSF oil may influence the gut–liver axis and lipid metabolism, suggesting that replacement levels should be carefully optimized according to species-specific nutritional requirements. Additional studies by Fawole et al. (2021) and Riesenbach et al. (2026) further demonstrated the feasibility of incorporating BSF-derived products into rainbow trout diets. Beyond growth performance, several studies highlighted the functional benefits of BSF oil in aquaculture nutrition. Improvements in immune responses, intestinal health, metabolic regulation, and disease resistance have been reported in various fish species. Farias et al. (2025) identified BSF oil as a potential nutraceutical ingredient for hybrid catfish diets, while Goda et al. (2024) reported enhanced growth performance in Nile tilapia fry fed diets enriched with BSF oil.

Overall, the reviewed literature indicates that BSF oil represents a viable and sustainable alternative to fish oil in aquaculture feeds. Although optimal inclusion levels vary among species, current evidence suggests that BSF oil can contribute to reducing dependence on marine resources while maintaining fish growth, health, and production performance**.**

3.4.3 Animal Health and Functional Feed Applications

Beyond its role as an alternative lipid source, BSF oil has attracted increasing attention due to its potential functional and health-promoting properties. This interest is largely associated with its high concentration of lauric acid, a medium-chain fatty acid known for its antimicrobial, immunomodulatory, and metabolic functions. Consequently, recent studies have expanded beyond evaluating growth performance to investigate the effects of BSF oil on gut health, immune responses, microbiota composition, and metabolic regulation.

Anas et al. (2025) reported that BSF oil supplementation affected the expression of genes associated with lipid metabolism in broiler chickens, suggesting its potential role in regulating nutrient utilization and energy metabolism. In another study, Anas et al. (2024) observed improvements in intestinal morphology and barrier function in laying hens fed diets containing BSF oil calcium salts. Similarly, Azizah et al. (2024) reported beneficial effects on intestinal histomorphology in broilers, while Dewanti et al. (2024) found improvements in immune responses and overall health status following supplementation with nano-emulsified BSF oil.

The influence of BSF oil on gut microbial communities has also become an important area of investigation. Atallah et al. (2023) reported that dietary inclusion of *Hermetia illucens* oil altered the caecal microbiota composition of Japanese quails. Likewise, Liu et al. (2022) demonstrated that BSF oil supplementation modified gut microbial communities in pigeons, suggesting potential benefits for digestive health and nutrient utilization. These findings are particularly important because gut microbiota play a crucial role in animal growth, immune competence, and disease resistance.

In aquaculture species, BSF oil has also been associated with physiological and metabolic benefits beyond growth performance. Several studies reported positive effects on hepatic metabolism, immune regulation, and intestinal function. Borland et al. observed changes in hepatic gene expression in rainbow trout fed diets containing BSF oil, while (Liao et al., 2026) investigated the effects of complete fish oil replacement on the gut–liver axis and lipid metabolism. Such findings indicate that BSF oil may influence multiple physiological pathways in addition to serving as a dietary energy source.The antimicrobial properties of BSF-derived lipids have also attracted research interest. Mohamed et al. (2022) demonstrated the bactericidal activity of fatty acids extracted from *Hermetia illucens* larvae fat against *Klebsiella pneumoniae*, highlighting the potential of BSF oil-derived compounds as natural antimicrobial agents. This finding suggests possible applications not only in animal nutrition but also in health-related and pharmaceutical sectors.

3.4.4 Pharmaceutical and Cosmetic Applications

In recent years, increasing attention has been directed toward the utilization of BSF oil in pharmaceutical and cosmetic products. This growing interest is primarily associated with its unique fatty acid composition, particularly its high lauric acid content, as well as its antimicrobial, antioxidant, and emollient properties. Compared with conventional plant-derived oils, BSF oil offers the additional advantage of being produced through the valorization of organic waste, thereby supporting circular economy principles and sustainable resource utilization. Several studies have explored the potential of BSF oil as an ingredient in topical pharmaceutical formulations. (Rahayu et al., 2024) demonstrated the effectiveness of BSF prepupa oil emulgel in promoting burn wound recovery, suggesting its potential application in wound-healing products. The beneficial effects were attributed to the bioactive compounds and fatty acid composition of the oil, which may support tissue regeneration and reduce inflammation.

Advances in drug delivery technologies have also expanded the potential applications of BSF oil. Dewanti (2024) developed a self-nanoemulsifying drug delivery system (SNEDDS) based on BSF oil and reported favorable physicochemical characteristics that could improve the delivery and bioavailability of active pharmaceutical compounds. These findings indicate that BSF oil may function not only as an active ingredient but also as a carrier material in pharmaceutical formulations.

The cosmetic industry has similarly shown growing interest in insect-derived oils. Almeida et al. characterized lipid extracts from *Hermetia illucens* larvae and highlighted their suitability as ingredients for pharmaceutical and cosmetic applications. Likewise, Santos Filipe et al.(2024) investigated the potential of BSF larvae extracts in dermocosmetic formulations and reported promising functional properties relevant to skin-care products. The presence of fatty acids with moisturizing and antimicrobial characteristics further supports the development of BSF oil-based cosmetic formulations.

Additional evidence was provided by Muangrat & Pannasai (2024) who reported favorable physicochemical characteristics and antioxidant properties of BSF oil. These properties may contribute to product stability and functionality in cosmetic and personal care applications. The combination of antioxidant activity, lipid composition, and sustainability advantages positions BSF oil as a promising alternative to conventional cosmetic oils.

Research on pharmaceutical and cosmetic applications remains limited compared with feed and aquaculture studies. Most existing investigations are still conducted at laboratory scale, and further studies are required to evaluate product efficacy, safety, formulation stability, regulatory compliance, and consumer acceptance. Nevertheless, the available evidence suggests that pharmaceutical and cosmetic products represent promising high-value applications capable of enhancing the economic value of BSF-derived oils.

3.4.5 Biofuel and Industrial Applications

The increasing demand for renewable energy and sustainable industrial materials has encouraged the exploration of alternative feedstocks derived from biological resources. Conventional fossil-based fuels and industrial chemicals are associated with greenhouse gas emissions, resource depletion, and environmental degradation. Consequently, the utilization of waste-derived resources such as BSF oil has emerged as a promising strategy to support sustainable production systems and circular bioeconomy development.

Due to its high lipid content and favorable fatty acid composition, BSF oil has attracted considerable interest as a feedstock for biodiesel production. Unlike conventional biodiesel feedstocks such as palm oil and soybean oil, BSF oil can be produced from organic waste through bioconversion processes, thereby reducing competition with food crops and minimizing land-use requirements.

Several studies have investigated the feasibility of converting BSF oil into biodiesel. Ningrum et al. demonstrated the production of biodiesel from Black Soldier Fly larvae through direct transesterification processes and reported promising fuel characteristics. Similarly, Sitepu et al. developed an intensified biodiesel production process using a controlled crushing device and reported improvements in biodiesel yield and process efficiency. These findings indicate that BSF oil possesses suitable physicochemical properties for biofuel applications and may serve as an alternative renewable energy source. Beyond biodiesel production, BSF oil has also shown potential for the development of industrial bioproducts. Silitonga et al. investigated the production of biolubricants derived from BSF oil and demonstrated its potential as a sustainable substitute for petroleum-based lubricants. The growing demand for environmentally friendly lubricants further supports the industrial relevance of insect-derived oils.

Recent studies have also explored the incorporation of BSF oil into advanced biomaterials. Istiqomah et al. developed cellulose nanofiber/chitosan/BSF oil composite bioplastic films and reported favorable mechanical and functional properties. Such developments highlight the potential of BSF oil as a component in biodegradable packaging materials and other sustainable industrial products. The efficient extraction and recovery of BSF-derived lipids also play a critical role in industrial utilization. Chen et al. (2025) emphasized the importance of integrated extraction and recovery technologies to maximize the value obtained from BSF biomass. Advances in processing technologies are expected to further improve the economic feasibility and commercial viability of BSF oil-based products.

Idustrial applications of BSF oil is less studied than feed-related applications. Most available studies focus on laboratory-scale evaluations, while large-scale production, techno-economic assessments, and life cycle sustainability analyses remain limited. Nevertheless, the current evidence suggests that biodiesel, biolubricants, bioplastics, and other bio-based materials represent important future opportunities for expanding the utilization of BSF oil beyond the feed sector. Such developments could substantially increase the value generated from organic waste bioconversion while supporting sustainable industrial transitions.

4. Challenges and Research Opportunities

4.1 Challenges in the Utilization of BSF Oil

Although BSF oil has demonstrated significant potential as a sustainable lipid source, several challenges remain that may hinder its large-scale adoption. One of the primary challenges is the variability in oil composition. The fatty acid profile of BSF oil is strongly influenced by the type of organic substrate used for larval rearing. Different feedstocks may result in variations in lipid content, lauric acid concentration, and overall oil quality, creating difficulties in standardization for commercial applications.

Another challenge relates to extraction technologies and production costs. Various extraction methods, including mechanical pressing and solvent extraction, can affect oil yield, quality, and economic feasibility. The selection of appropriate extraction technologies is therefore essential to ensure efficient and sustainable production. Regulatory issues also represent an important barrier. While BSF-derived products have gained increasing acceptance in several countries, regulations governing insect-based products differ considerably among regions. Regulatory uncertainty may limit market expansion and commercial investment in BSF oil-based products.

Furthermore, most existing studies have been conducted under laboratory or pilot-scale conditions. Research evaluating industrial-scale production, long-term economic feasibility, and commercial implementation remains limited. Consequently, further studies are needed to bridge the gap between experimental findings and industrial application.

4.2 Research Opportunities

The growing interest in circular economy and waste valorization presents substantial opportunities for the future development of BSF oil. Since BSF larvae can convert organic waste into valuable biomass, the resulting oil can be considered a high-value product derived from low-value waste resources. This characteristic supports sustainable resource management and contributes to reducing environmental burdens associated with organic waste disposal.

Future research should continue exploring the use of BSF oil as a substitute for conventional lipid sources in animal feed and aquaculture. In addition, investigations into its effects on animal health, immune responses, gut microbiota, and metabolic regulation are expected to remain important research areas. Beyond feed applications, industrial utilization of BSF oil remains largely unexplored. The high content of medium-chain fatty acids, particularly lauric acid, suggests considerable potential for the development of oleochemicals, surfactants, soaps, detergents, lubricants, and household cleaning products. Research focusing on product formulation, performance evaluation, and consumer acceptance could significantly expand the commercial value of BSF oil. The biodiesel sector also offers promising opportunities. As concerns regarding fossil fuel depletion and carbon emissions continue to increase, BSF oil may serve as an alternative renewable feedstock for biofuel production. Additional studies are needed to evaluate fuel quality, process optimization, and economic viability at commercial scales.

5. Conclusion

Black Soldier Fly (*Hermetia illucens*) larvae oil has emerged as a promising value-added product derived from organic waste bioconversion. The increasing number of publications indicates growing scientific interest in its utilization as a sustainable alternative lipid source. Bibliometric analysis revealed that current research is primarily concentrated on animal feed, aquaculture, growth performance, fatty acid composition, and lipid metabolism. The reviewed studies demonstrate that BSF oil possesses favorable nutritional and functional properties, particularly due to its high content of medium-chain fatty acids such as lauric acid. These characteristics support its application in animal nutrition and suggest broader potential in biodiesel production, pharmaceutical formulations, and industrial products.

Despite the growing body of research, studies focusing on industrial applications, commercialization, sustainability assessment, and large-scale implementation remain limited. Future research should therefore emphasize the development of value-added products, techno-economic feasibility, life cycle assessment, and circular economy approaches to maximize the utilization of BSF oil.

Overall, BSF oil represents a promising waste-derived resource with significant potential to contribute to sustainable production systems, resource recovery, and circular bioeconomy development.

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