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Global Research Trends on Black Soldier Fly Larvae for Organic Waste Bioconversion and Sustainable Animal Feed: A Bibliometric Analysis

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Abstract: The increasing organic waste generation in line with population growth requires sustainable management solutions. Black Soldier Fly (*Hermetia illucens*) larvae are a promising innovation as they can convert organic waste into animal feed and fertilizer with economic value. This study aims to analyze global research trends in bioconversion by considering feed ratio using Systematic Literature Review (SLR) and Bibliometric Analysis (BA) approaches. Data obtained from Scopus for the period 2020-May 2026 May 3, 2026 were analyzed using VOSviewer for 281 publications. The results show a significant increase in the number of publications. The subject area dominated by Agricultural and Biological Sciences. Relevant journals include Animal, Poultry Science and Journal of Insect as Food and Feed. The most productive authors there is Biasato,I., (12 publication with 203 total citation). Meanwhile, Italy is the country with the highest output. The most prominent keywords are Larva. The research focuses on the efficiency of converting waste materials into environmentally friendly protein sources.

Keywords: Bibliometric; Black soldier fly; Feed ratio; Waste bioconversion

Introduction

The increase in organic waste, in line with population growth, has become one of the major environmental challenges of today. According to data from the World Bank, more than 50% of the world's municipal solid waste consists of biodegradable organic materials. One of the technologies that can be applied to address this issue is bioconversion using Black Soldier Fly (*Hermetia illucens*) larvae. The Black Soldier Fly is an insect with great potential in the bioconversion of organic waste into economically valuable products such as animal feed and organic fertilizer (Surendra et al., 2020). The use of Black Soldier Fly (BSF) larvae also supports the principles of a circular economy, as the products generated from the bioconversion process can be reused as new and sustainable resources (Kim et al., 2020).

One of the critical factors determining the success of the bioconversion process is the feed ratio between the substrate and the larvae. The feed ratio refers to the proportion of substrate provided relative to the number of larvae used. An appropriate feed ratio significantly influences larval growth, the rate of waste conversion, and the nutrient composition of the resulting biomass (Franco et al., 2025; Silvaraju et al., 2024).

One important research direction focuses on optimizing the composition and characteristics of the substrate. The protein and fat contents of the substrate directly influence larval growth efficiency and waste reduction rates. Substrates with a protein content of approximately 20–25% have been shown to produce optimal larval growth and biomass conversion (Broeckx et al., 2025; Hutabarat & Mangindaan, 2024). Other studies have also confirmed that food waste. Key environmental factors such as temperature, humidity, and larval density have been found to significantly

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influence larval growth and substrate conversion rates (Oddon et al., 2024; Chen et al., 2023). For example, the optimal temperature for BSF larval growth ranges from 27°C to 30 °C, with a relative humidity of 60–70%. Meanwhile, the ideal larval density is below 5 g of substrate per larva to minimize population stress (Lin & Shelomi, 2024; Siddiqui et al., 2024).

The studies mentioned above demonstrate the diverse research focus within BSF bioconversion, which often varies depending on the feed ratio applied. However, only a limited number of studies have mapped publication trends related to the use of Black Soldier Fly larvae in waste bioconversion, specifically focusing on the feed ratio as a key variable. Such research is essential to guide future innovations and identify emerging directions in global BSF studies. With the increasing interest in organic waste bioconversion technologies, research on BSF and the factors influencing its efficiency has expanded significantly over the past decade (Nielsen et al., 2025; Satori et al., 2021). Therefore, this study was conducted using bibliometric analysis techniques to analyze trends, collaborations, and publication recommendations related to the topic of BSF in waste bioconversion and feed use ratio (Camperio et al., 2025; Kullan et al., 2024; Mangindaan et al., 2022).

Bibliometric analysis is a well-established and effective approach for quantitatively assessing research patterns and trends by mapping publications, keywords, and relationships among authors. With the aid of software such as VOSviewer, bibliometric analysis can identify scientific networks, international collaborations, and dominant research themes within a particular field (Donthu et al., 2021). In addition to providing an overview of global research trends, this study also aims to address the following research questions: How the distribution of Black Soldier Fly (BSF) research publications on organic waste bioconversion with feed utilization ratios during the period 2020–2025?; Which journals and authors are the most relevant in BSF research related to waste bioconversion and feed utilization ratios?; Which countries contribute most significantly to the field of BSF research and organic waste bioconversion involving feed utilization ratios ?; What are the main keywords that appear most frequently in publications concerning BSF, bioconversion, and feed utilization ratios?; What are the primary subject areas most actively involved in BSF and organic waste bioconversion research focusing on feed utilization ratios?. Although research on bioconversion using Black Soldier Fly (BSF) has increased rapidly in recent years, most studies still focus primarily on experimental aspects such as larval growth performance, waste conversion efficiency, and the utilization of larvae as an alternative protein source. To date, studies specifically mapping the development of BSF research through a bibliometric approach remain relatively limited, particularly those integrating analyses of publication trends, international collaboration networks, keyword co-occurrence, publication sources, and the comprehensive evolution of research themes. Therefore, this bibliometric study is important to provide a comprehensive overview of the structure, dynamics, and global development of BSF research.

Method

This study employs a combination of the Systematic Literature Review (SLR) and Bibliometric Analysis (BA) methods, collectively known as the Systematic Literature Network Analysis (SLNA) approach, to assess current research trends, identify gaps, and provide an in-depth understanding of the factors influencing the effectiveness of organic waste bioconversion using Black Soldier Fly (BSF) larvae (Passas, 2024; Ullah et al., 2022). This methodology follows previous research that suggests bibliometric analysis (BA) is used to map reviews and identify current research patterns through citation analysis, keyword analysis, and title-abstract networks. As a method for conducting network analysis, BA is a fast, practical tool that provides in-depth insights into identifying research trends and gaps (Apriliyah & Arifianto, 2022; Colicchia et al., 2019). However, since Bibliometric Analysis (BA) has limitations in conducting in-depth content analysis, the Systematic Literature Review (SLR) approach is employed to complement these shortcomings and provide a more comprehensive and time-efficient review of the literature (Lendra et al., 2023).

This study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The use of the PRISMA framework ensures a transparent and comprehensive reporting process, allowing readers to evaluate the methodological application, analytical results, and the validity of the study's conclusions (Page et al., 2021; Sarkis-Onofre et al., 2021). To apply the PRISMA template, there are four main stages, namely: identification, screening, eligibility, and determining the studies included in the final analysis (Rethlefsen et al., 2021). Figure 1 provides a detailed illustration of the implementation procedures for these four stages. The topic of this study focuses on the application of the Black Soldier Fly (BSF) in the bioconversion of organic waste and its associated feeding ratio. The reviewed publications were obtained from the Scopus database, which provides comprehensive and credible coverage of scientific literature. The SLR procedure was conducted in accordance with the PRISMA guidelines, involving several stages: initial article identification, screening based on keywords and publication years, evaluation of

content relevance, and the final selection of articles that met the established criteria for further analysis (Hoang, 2025). Figure 1 illustrates the systematic flow of the SLR process, which follows the PRISMA statement framework as the basis for data selection and processing in this study.

The filtering process was conducted by entering specific keywords into the Scopus database relevant to this study's topic. The keywords used were "Larvae Black Soldier Fly," "Bioconversion," and "Feed Ratio." The initial search results retrieved 499 journal documents. Subsequently, a series of filtering steps were applied based on publication year, selecting studies published between 2020 – May 2026 to identify research trends from the past five years. The document type was limited to journal articles, and only publications written in English and categorized under "Journal" as the source type were included. Furthermore, only open-access journals were selected for analysis. After completing the filtering process, the Scopus data were exported in CSV format and mapped using VOSviewer software. The data export for this study was performed on 3 May, 2026 resulting in a total of 281 documents that met the inclusion criteria**.** After the CSV export, manually screened the 281 documents to ensure they truly addressed the feed ratio before further analysis.

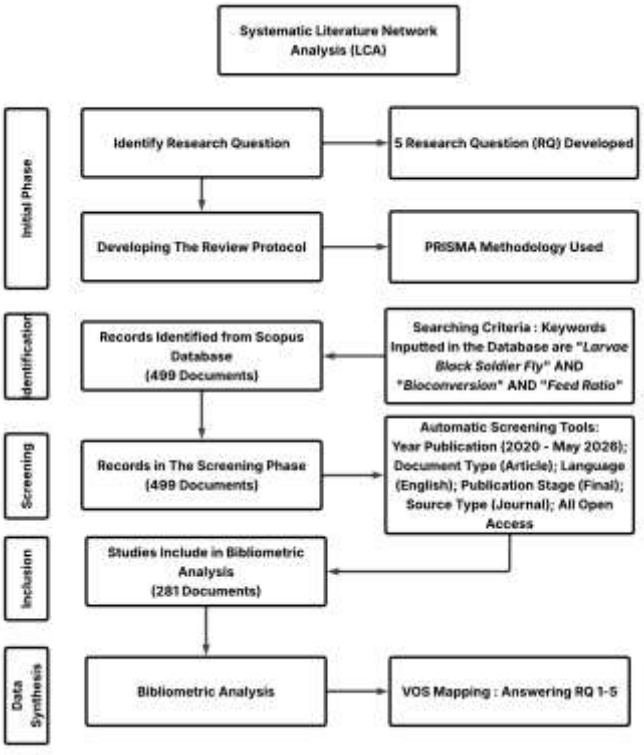

Figure 1. Systematic literature review process using the PRISMA statement template

Data analysis of the Scopus documents was carried out using bibliometric methods with the aid of VOSviewer software. After the manual filtering of the initial Scopus data, a total of 281 documents were selected for analysis. VOSviewer is commonly used to construct mappings of authors or journals based on co-citation data. In addition, keyword mapping can be performed through co-occurrence analysis to identify relationships and trends among research topics (Soegoto et al., 2021). The search result data files obtained in CSV format were imported into VOSviewer software for comprehensive bibliometric analysis. The analysis consisted of several stages: keyword co-occurrence analysis, which aimed to identify major research themes, map current research trends, and illustrate the relationships among concepts that frequently appear together in scientific publications; co-authorship analysis, which was used to examine collaborative relationships among researchers within the same field of study; and citation analysis, which served to identify influential documents or authors based on the number of citations received. In analyzing collaboration networks between countries, a minimum threshold of one document per country was applied, indicating that each country included in the analysis had at least one publication relevant to this research topic.Meanwhile, the parameter for the number of countries selected was adjusted to ensure that the resulting network map visualization remained clear, legible, and informative. Furthermore, for the keyword co-occurrence analysis, a minimum occurrence threshold of two was applied, meaning that a keyword had to appear at least twice to be included in the network mapping. By applying these parameters, the VOSviewer software was able to generate a comprehensive network visualization of relationships among authors, countries, and keywords, thereby providing a clear representation of the structure and direction of research development within the studied field.

Result and Discussion

Publication Dynamics

This study aims to examine publication trends related to the use of Black Soldier Fly (BSF) in waste bioconversion and feed ratio studies during the 2020 – May 2026 period. The number of publications on the topic of bioconversion using Black Soldier Fly (BSF) has shown a significant increasing trend during the publication period from 2020 to May 2026. In 2020, the number of publications on this topic indexed in Scopus was 13 documents, which was relatively low compared to the following years that experienced an increase, such as 29 documents in 2021 and 32 documents in 2022. This increase continued gradually in 2023 with 45 documents

and in 2024 with 58 documents. The highest number of publications occurred in 2025, with a total of 83 documents. This significant increase reflects the high interest in scientific studies discussing the utilization of BSF in organic waste bioconversion.

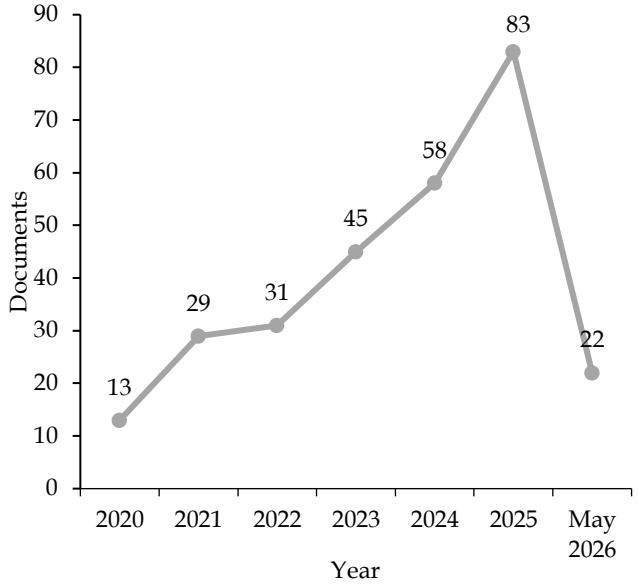

Figure 2. Graph showing the number of publications on Black Soldier Fly (BSF) bioconversion research from 2020 to May 2026. The y-axis represents the number of documents published, while the x-axis represents the year of publication. This visualization highlights trends in research output over the six-year period

The number of publications in 2026 shown in the graph indicates a decrease, with only 22 documents. However, this decline is not necessarily due to a decrease in research interest in this field, but rather because of data limitations that do not yet cover a full year or an incomplete year. The data were collected from January to May 2026. The increase in the number of publications from 2020 to May 2026 indicates that organic waste bioconversion using Black Soldier Fly larvae as a biological agent is a rapidly developing scientific field. This significant increase in publications also demonstrates the emergence of innovative and sustainable solutions for organic waste management using BSF larvae.

Relevant Sources

The subsequent research question focuses on identifying the most relevant journals and authors who have contributed to studies on bioconversion using Black Soldier Fly (BSF) larvae, particularly concerning the feed ratio during the 2020– May 2026 period. Identifying the most relevant journals is essential for understanding how the research topic has evolved and which publication outlets serve as key platforms for disseminating scientific advancements in this field. The results of the journal relevance analysis are illustrated in Figure 3.

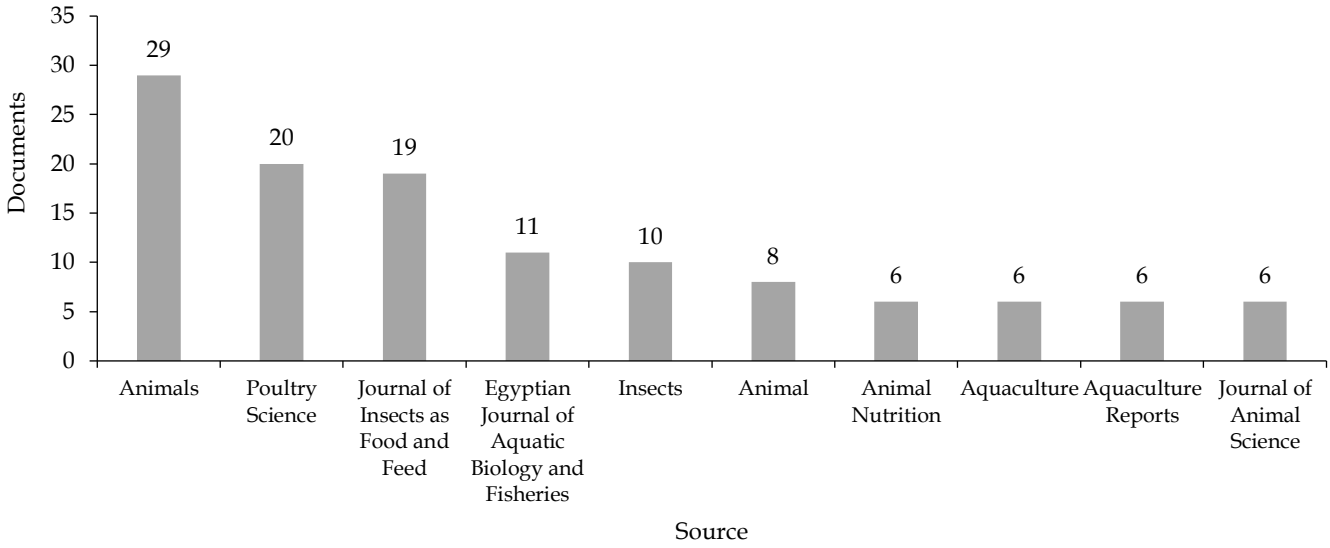

Figure 3. Chart depicting the most relevant journals publishing research on Black Soldier Fly (BSF) bioconversion from 2020 to 3 May, 2026. The x-axis represents the number of publications in each journal, while the y-axis lists the top 10 most relevant journals in this research field

Figure 3 illustrates the distribution of publications across relevant journals, showing that research focusing on organic waste processing using Black Soldier Fly (BSF) larvae with feed formulation is dominated by several key journals. The analysis based on source titles was conducted to identify the distribution of

publications regarding organic waste bioconversion using Black Soldier Fly while considering the feed ratio provided across various journals. The journal fields dominating publications on this topic include animal science, entomology, and aquaculture. The journal with the highest number of publications on this topic during the period from 2020 to May 2026 is "*Animals*" with a total of 29 publications, followed by "*Poultry Science*" which has 20 publications on this topic. In addition, the "*Journal of Insects as Food and Feed*" ranks third with a total of 19 publications. Other journals such as "*Egyptian Journal of Aquatic Biology and Fisheries*" (11 publications), "*Insects*" (10 publications), and "*Animal*" (8 publications) have also made significant contributions to the development of BSF research. The variety of journals above indicates that the main focus of BSF research in organic waste bioconversion while considering the feed ratio provided is still closely related to the utilization of larvae as an alternative protein source for feed. The contribution of publications in journals such as "*Poultry Science*" and "*Animal Nutrition*" indicates that many studies are directed toward evaluating the nutritional content of larvae, livestock growth performance, and the potential substitution of conventional feed ingredients. Furthermore, the presence of the "Journal of Insects as Food and Feed" as one of the main publication sources indicates significant attention toward the utilization of BSF larvae as a bioconversion agent in sustainable food and feed systems.

The most relevant journals were further examined by analyzing their Total Publications (TP), Total Citations (TC), Citation Scores, and Publishers. This evaluation provides a comprehensive overview of the journals' influence and contribution to the development of research on Black Soldier Fly (BSF) bioconversion and feed ratio studies. The distribution and performance of these journal sources within the publication trends are presented in Table 1.

In addition to the number of publications across various journals, the analysis was also conducted based on Total Citation (TC), Citation Score (CS), and Publisher. Total citations were calculated based on the accumulation of all citation counts related to research on bioconversion using BSF larvae while considering the feed ratio provided in each journal. The citation data were obtained from the Scopus database and were used to describe the level of influence of the published studies. The higher the number of citations obtained by a publication source, the greater its contribution and scientific impact on the development of the related research field. In addition, total citations indicate that articles published in these journals are frequently used as references by other researchers, thereby reflecting the relevance, quality, and influence of the research within the global scientific community. Citation Score was obtained from the Scopus database of each journal and was used to describe the level of influence and scientific quality of a journal based on the average number of citations received from the journal's overall publications across various topics. The publisher column was analyzed to identify the institutions or publishers responsible for publishing journals related to organic waste bioconversion research using BSF larvae with feed ratio considerations. Publisher analysis aims to determine the distribution reach and scientific influence of a journal within the academic community.

Table 1. The most relevant journals in research on feed ratios in bioconversion using Black Soldier Fly (BSF) larvae. This table summarizes publication counts, citation metrics, and publisher information to identify key sources contributing to this field

Source	TP	TC	CS	Publisher
Animals	29	839	5.2	Multidisciplinary Digital Publishing Institute (MDPI)
Poultry Science	20	485	7	Elsevier
Journal of Insects as Food and Feed	19	39	7.8	Brill
Egyptian Journal of Aquatic Biology and Fisheries	11	5	1.3	Egyptian Society for the Development of Fisheries and Human Health
Insects	10	101	5.6	Multidisciplinary Digital Publishing Institute (MDPI)
Animal	8	75	7.8	Elsevier
Animal Nutrition	6	227	12.4	KeAi Communications Co.
Aquaculture	6	212	8.9	Elsevier
Aquaculture Reports	6	112	5.9	Elsevier
Journal of Animal Science	6	120	4.3	Oxford University Press

The journal "*Animals*" published by the Multidisciplinary Digital Publishing Institute (MDPI), has the highest total citations, with 839 citations from 29 publications. The higher the number of citations obtained by a publication source, the greater its contribution and scientific impact on the development of the related research field. Furthermore, total citations indicate that articles in the journal are frequently used as references by other researchers, reflecting the relevance, quality, and influence of the studies within the global scientific community. The journal "*Poultry Science*" published by Elsevier, ranks second with 485 citations from a total of 20 publications and has a Citation Score of 7 based on its overall publications across various topics. This indicates that studies published in this journal have a strong influence, particularly regarding the utilization of BSF larvae as an alternative poultry

feed ingredient. Meanwhile, the "*Journal of Insects as Food and Feed*" published by Brill, has accumulated 39 citations from 19 publications. This journal has a Citation Score of 7.8, indicating that research on the utilization of BSF larvae in food and feed systems has become one of the central areas in the global development of BSF research.

Interestingly, some journals with relatively fewer publications actually have higher total citation counts. For example, the journal "*Animal Nutrition*" published by KeAi Communications Co, only has 6 publications, but these publications have accumulated a total of 227 citations. This indicates that although the number of published articles is smaller, the studies in this journal have a strong scientific impact and are frequently cited by other researchers. On the other hand, some journals show relatively low citation counts compared to their number of publications, such as the "*Egyptian Journal of Aquatic Biology and Fisheries*" published by the Egyptian Society for the Development of Fisheries and Human Health, which has 11 publications on this topic but only 5 total citations. This may be influenced by several factors, such as journal scope, international visibility, publication age, and the level of specialization of the published topics. Differences in citation levels among journals indicate variations in the scientific impact and research reach of organic waste bioconversion using BSF larvae with feed ratio considerations. In addition to illustrating publication development, this analysis also reveals a research gap in the distribution of research focus. Most of the dominant journals still originate from the fields of animal science, animal nutrition, and aquaculture, while publications in journals oriented toward environmental engineering, process engineering, and waste management remain relatively limited.

Leading Authors

In addition to identifying the most relevant journals, this study also examined the authors who have made the most significant contributions to publications on the topic of organic waste bioconversion using Black Soldier Fly (BSF) larvae, with particular consideration of the feeding ratio variable. The analysis was conducted based on data obtained from the Scopus database. The ten most productive authors were identified and further analyzed using VOSviewer software to visualize their research networks and collaborations. Figure 4 presents a list of the top 10 authors who have contributed most extensively to research in this field.

The leading author analysis was conducted based on the list of authors who have the highest number of publications and provide a strong influence on this topic. In addition to the list of authors and their number of publications, the analysis was also carried out based on the Total Citation (TC) of each author's publications and the H-index obtained from the authors' Scopus database profiles. The analysis of the most productive authors was conducted by selecting the top 10 most productive authors. The authors with the highest number of publications occupy the top two positions, namely "*Biasato, I.*" and "*Rawski, M.,*" each with a total of 12 publications. "*Biasato, I.*" ranks first because, compared to the author in the second position, this author has a higher H-index value. The authors in the third and fourth positions also have the same number of publications, with 11 publications each, namely "*Schiavone, A.*" and "*Tanga, C.M.*" The author ranked tenth among the most productive authors is "*Bellezza Oddon, S.,*" with a total of 9 publications on this topic. "*Biasato, I.*" and "*Rawski, M.*" are the authors with the highest number of publications, each with a total of 12 documents. However, "*Rawski, M.*" has a higher number of citations, with 505 citations compared to "*Biasato, I.*" with 203 citations. This demonstrates that the publications produced by "*Rawski, M.*" have a greater scientific impact and are more frequently used as references by other researchers. "Bellezza Oddon, S." is the author with the lowest number of citations among the 10 most productive authors, with a total of 138 citations.

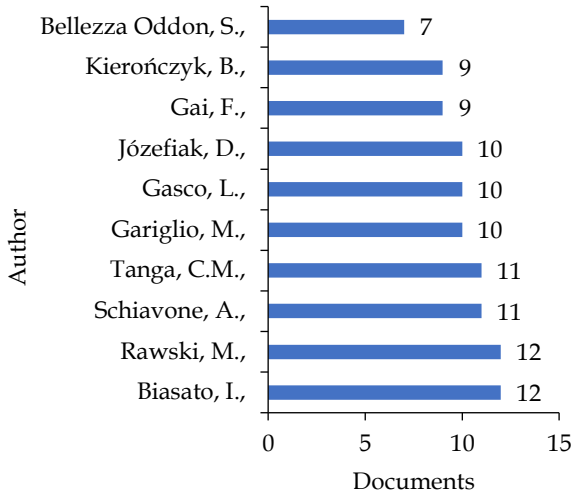

Figure 4. Bar chart illustrating the most productive authors in research on Black Soldier Fly (BSF) bioconversion between 2020 until 3 May 2026. The x-axis represents the author names, while the y-axis indicates the total number of publications for each author during the observed period

In addition to the number of publications and citations, the authors' H-index values were also analyzed to indicate the consistency and scientific influence of each author. In this analysis, "*Gasco, L.*" has the highest H-index compared to the other 10 authors, with a value of 67, even though the number of

publications on this topic is only 10 documents. This value indicates that the author has a very strong academic track record and is highly productive in producing high-quality research that is widely cited. Other authors such as "*Gai, F.*" and "*Schiavone, A.*" also have high H-index values, namely 48 and 43, respectively, indicating significant contributions to the development of BSF research and other related fields. Based on institutional affiliations, most of the authors originate from institutions in Italy and Poland, such as Università degli Studi di Torino and Uniwersytet Przyrodniczy w Poznaniu. This indicates that Europe has become one of the major centers for the global development of BSF research. In addition, the presence of "*Tanga, C.M.*" from the International Centre of Insect Physiology and Ecology (icipe) in Kenya shows that BSF research is also developing in developing countries, particularly in the context of organic waste management and food security in Africa. Therefore, the leading author analysis not only illustrates the productivity and scientific influence of the major researchers in the field of BSF with feed ratio considerations, but also highlights the dominant direction of current research development. Furthermore, the distribution of authors and institutions opens opportunities for the development of international and multidisciplinary collaborations to expand the scope of BSF research into more applicable and sustainable fields.

Table 2. Data of the most productive authors in research on Black Soldier Fly (BSF) bioconversion, including Total Publications (TP), Total Citations (TC), and Institutional affiliations. This table highlights the leading contributors, their research output, and institutional background in the 2020- 3 May 2026 period

Author	TP	TC	H-Index	Institution History
Biasato, I.	12	203	32	Università degli Studi di Torino, Turin, Italy
Rawski, M.	12	505	29	Uniwersytet Przyrodniczy w Poznaniu, Poznan, Poland
Schiavone, A.	11	206	43	Università degli Studi di Torino, Turin, Italy
Tanga, C.M.	11	342	42	International Centre of Insect Physiology and Ecology Nairobi, Nairobi, Kenya
Gariglio, M.	10	198	16	Università degli Studi di Torino, Turin, Italy
Gasco, L.	10	234	67	Università degli Studi di Torino, Turin, Italy
Józefiak, D.	10	346	38	Uniwersytet Przyrodniczy w Poznaniu, Poznan, Poland
Gai, F.	9	181	48	Consiglio Nazionale delle Ricerche, Rome, Italy
Kierończyk, B.	9	323	27	Uniwersytet Przyrodniczy w Poznaniu, Poznan, Poland
Bellezza Oddon, S.	7	138	15	Università degli Studi di Torino, Turin, Italy

Productive Countries

The third research question focuses on identifying the countries that have made the most significant contributions to research on organic waste bioconversion using Black Soldier Fly (BSF) larvae. This bibliometric analysis aims to provide insights into the global distribution of research, identify key centers of scientific activity, and explore the role of international collaboration in advancing BSF technology. Figure 5 presents a chart ranking country from the highest to the lowest number of publications, along with their respective publication counts.

The purpose of this country-based bibliometric analysis is to identify global research trends, determine which countries serve as hubs of development and innovation, and evaluate the potential for international collaboration to enhance both research and the practical application of BSF-based organic waste bioconversion across diverse environmental and economic contexts. The distribution of publications by country shows that research focusing on organic waste bioconversion using BSF larvae while considering the feed ratio provided is dominated by several countries with different levels of contribution. The country with the highest number of publications is Italy, with 38 documents. The next position is occupied by China with 28 documents, making it the country with the second-highest number of publications. Indonesia ranks fourth with a total of 25 publications. This indicates that developing countries also make a significant contribution to publications on this topic. Meanwhile, Germany contributed 23 publications. Kenya, Poland, and Thailand have the same number of publications, with 16 documents each. The country with the lowest number of publications on this topic is Egypt, with 11 publications. Indonesia's position among the top five countries with the highest number of publications on this topic indicates a strong interest in research on the utilization of BSF as an organic waste bioconversion agent with special attention to the feeding rate provided. This is relevant to the condition of Indonesia, which generates high amounts of organic waste from diverse sources and compositions, particularly from the household, market, and agricultural sectors. Nevertheless, the distribution of publications on this topic also indicates the existence of a geographical research gap. Research is still concentrated in certain countries, while contributions from many other developing countries remain relatively low. This condition suggests that the implementation and development of BSF technology have not yet been evenly distributed globally.

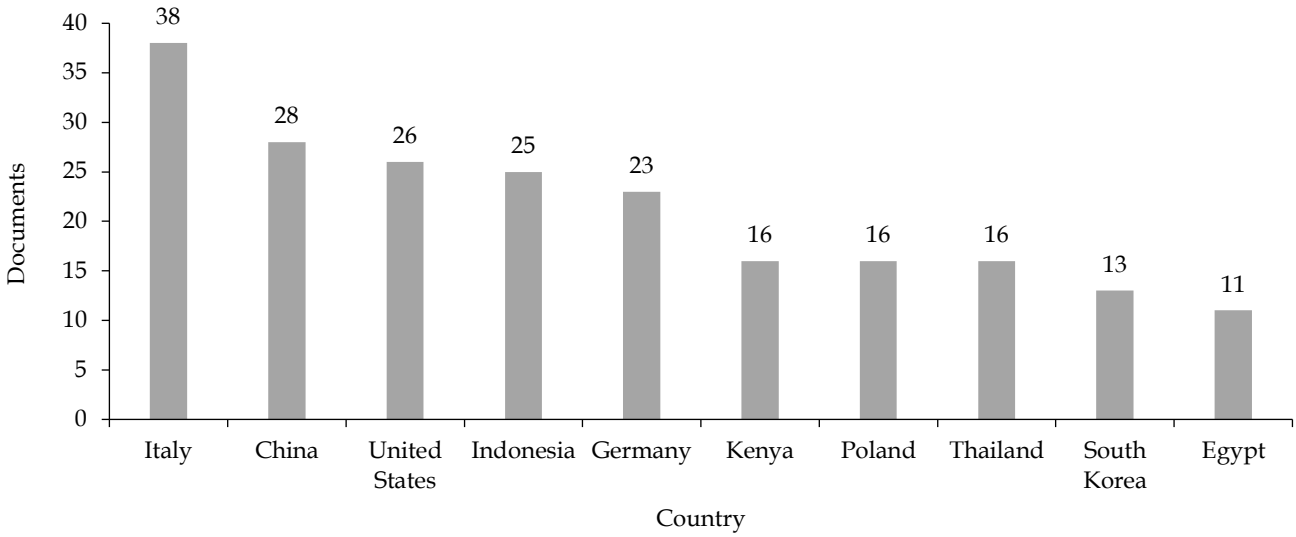

Figure 5. Bar graph showing the number of publications produced by the top 10 contributing countries in research on Black Soldier Fly (BSF) bioconversion from 2020 to 3 May 2026. The x-axis represents the number of publications, while the y-axis lists the countries with the highest research output

Further research has shown that bacterial communities present in food waste play a crucial role in supporting larval growth and development (Chen et al., 2023). When native bacteria are removed, larval performance declines significantly. Over a 12-day period, bacteria originating from the larval gut are carried into the waste residue, indicating a symbiotic relationship that enhances the efficiency of the bioconversion process.In addition, this study also examines co-authorship relationships between countries involved in BSF-based bioconversion research, with particular attention to feed ratio considerations. Using the VOSviewer tool, the resulting co-authorship map visualizes international research collaborations, highlighting the interconnectedness of global scientific efforts in advancing BSF waste bioconversion technology. This network visualization is presented in the following Figure 6.

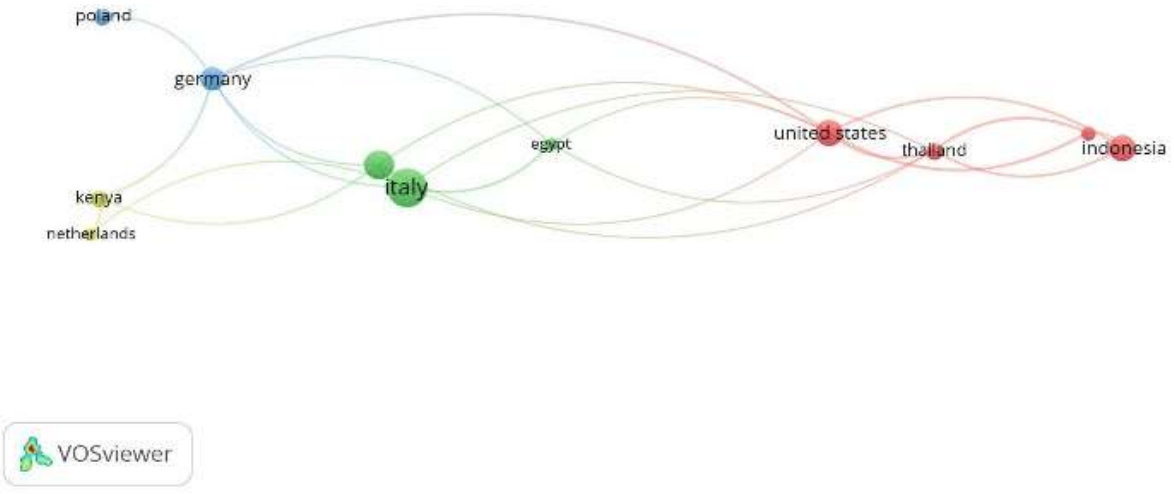

Figure 6. Map illustrating international co-authorship relationships in Black Soldier Fly (BSF) bioconversion research. Connecting lines represent collaborative links between authors from different countries, while the size of each circle corresponds to the number of publications contributed by that country, highlighting global research networks and partnerships

Keyword Mapping

The fourth research question focuses on identifying the main keywords used in studies related to bioconversion with Black Soldier Fly (BSF) larvae, particularly those that consider the effect of feeding ratios during the 2020– May 2026 period. This analysis examines the correlation and frequency of keywords appearing across various relevant publications to reveal emerging research themes and conceptual linkages. The visualization presented in Figure 7 illustrates the co-

occurrence network of all keywords retrieved from the Scopus database, providing an overview of the thematic structure and interconnections among topics within this research field.

The analysis results reveal that the keyword with the highest frequency of occurrence is "larva", appearing 69 times with a link strength of 952, indicating that this topic serves as a central focus in research related to the bioconversion and cultivation of Black Soldier Fly (BSF). The second most frequent keyword is "animal food" (60 occurrences; link strength 915), reflecting a strong research emphasis on the utilization of BSF-derived bioconversion products as animal feed. Additionally, keywords such as "nonhuman" (58; 887), "animal" (61; 884), and "Diptera" (61; 882) highlight close associations with studies exploring the biological and taxonomic characteristics of BSF insects. Meanwhile, the keywords "animals" (61; 874) and "animal feed" (49; 743) further reinforce that the dominant research direction focuses on the potential of BSF as a sustainable alternative feed source for livestock.

Overall, the observed keyword co-occurrence pattern reflects a strong concentration of research on the application of insect larvae as a sustainable solution for organic waste management and the production of environmentally friendly animal feed.

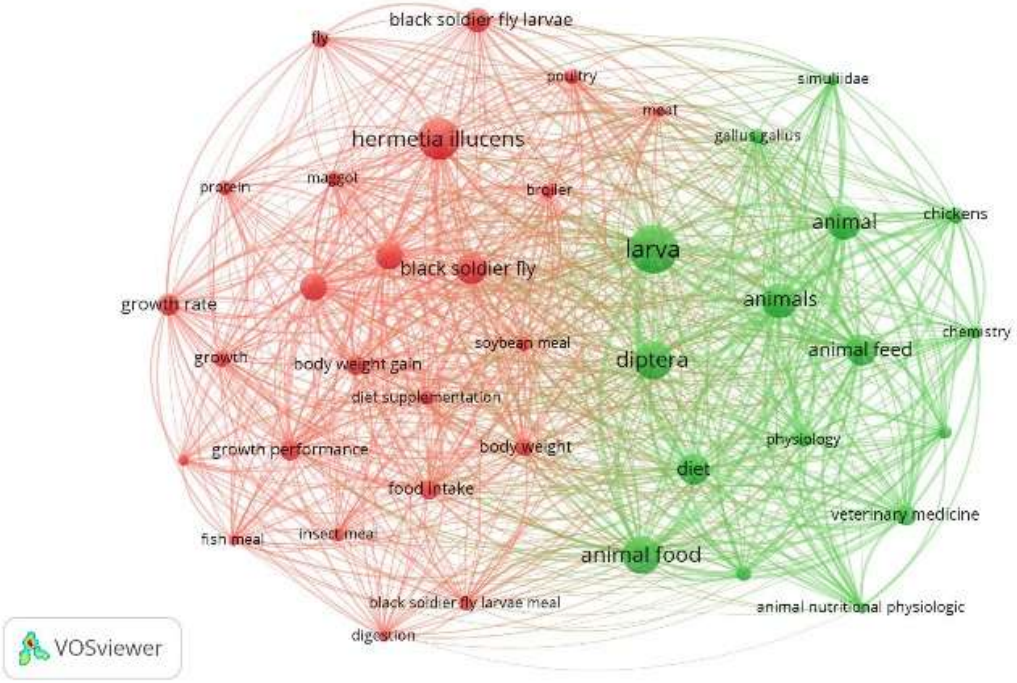

Figure 7. Map illustrating the co-occurrence relationships among all keywords in Black Soldier Fly (BSF) bioconversion research. Connecting lines represent the co-occurrence links between keywords, while the size of each circle reflects the frequency of keyword occurrences, providing an overview of research themes and their interconnections

The analysis of author keywords provides a clear overview of the primary research focus in studies on organic waste processing using Black Soldier Fly (BSF) larvae. Based on the data presented in the table, the most frequently used keyword is "*Hermetia illucens*", appearing 35 times with a link strength of 274, followed by "Black Soldier Fly", which appears 30 times with a link strength of 271. The dominance of these two keywords confirms that the BSF species serves as the central focus of numerous studies in the areas of waste bioconversion and alternative protein feed production, underscoring its importance in advancing sustainable waste management and circular bioeconomy practices. Furthermore, the keywords "bioconversion" (12 occurrences; link strength 146) and "growth performance" (14; 143) indicate that current research also emphasizes the efficiency of converting organic matter into biomass and its impact on livestock growth performance. Keywords such as "poultry" (6; 131) and "alternative protein" (5; 115) highlight the strong relevance of this research to the livestock sector and its contribution to the development of sustainable protein sources. In addition, the presence of keywords such as "black soldier fly larvae" (17; 111), "insects" (6; 111), and "circular economy" (8; 107) reflects the growing orientation of research toward integrating insect-based systems within circular economy frameworks. Overall, the observed keyword pattern demonstrates that research on BSF extends beyond biological studies of the larvae to encompass their application in sustainable development, waste management, and the substitution of conventional protein sources.

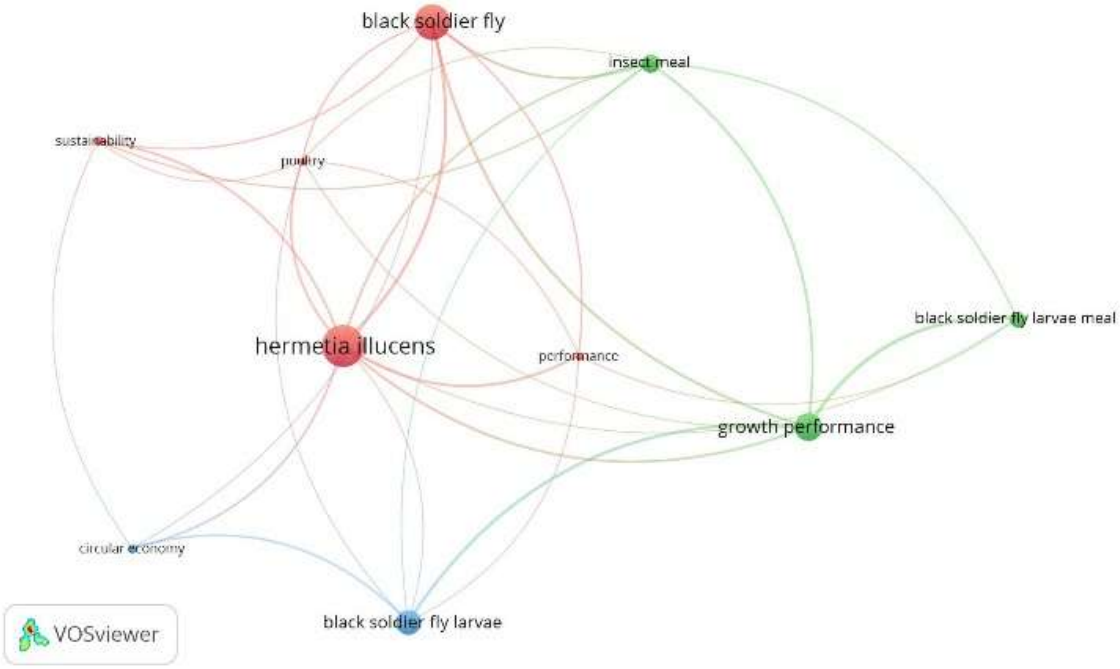

Figure 8. Map showing the co-occurrence relationships of author keywords in Black Soldier Fly (BSF) bioconversion research. Connecting lines indicate relationships between keyword occurrences, while the size of each circle represents the frequency of each keyword, highlighting the main research focuses and thematic connections identified by the authors

Scientific Disciplines

To address the fifth research question, which aims to identify the most influential fields of study in Bioconversion with Black Soldier Fly Larvae, an analysis was carried out by categorizing publications based on their disciplinary domains. The results of this analysis are presented in Figure 9.

The analysis based on subject areas shows that research publications on bioconversion using Black Soldier Fly larvae are dominated by the field of "*Agricultural and Biological Sciences*", with a total of 211 publications. This number is significantly higher compared to publications in other fields, indicating that BSF research is still highly focused on biological aspects, agriculture, and the utilization of organisms in organic waste management while considering the feed ratio used. The second position is occupied by the field of "*Veterinary*" with 70 publications, followed by "*Environmental Science*" with 35 publications. The fourth position is held by "*Biochemistry, Genetics and Molecular Biology*" with a total of 29 publications. Other fields contributing to the top 10 publications on this topic with relatively lower numbers include "*Multidisciplinary*" with 14 publications, "*Immunology and Microbiology*" with 11 publications, "*Medicine*" with 10 publications, "*Social Sciences*" with 10 publications, and "*Energy*" with 8 publications. The field with the fewest publications among the top 10 is "*Computer Science*" with only 6 publications.

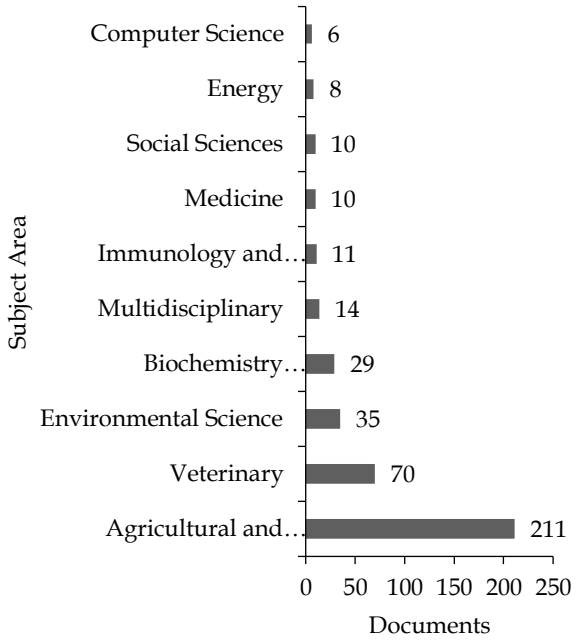

Figure 9. showing the number of publications across the top 10 most relevant subject areas in Black Soldier Fly (BSF) bioconversion research. The chart highlights the disciplines contributing most to the field, illustrating the interdisciplinary nature of research in agriculture, veterinary science, environmental science, and related areas

The dominance of the "*Agricultural and Biological Sciences*" field indicates that most studies are still

focused on the biological performance of BSF larvae, such as waste degradation efficiency, larval growth, nutrient conversion, and their potential utilization as an alternative protein source. The high number of publications in the "*Veterinary*" field also indicates considerable attention toward the use of BSF larval meal as a raw material for livestock and aquaculture feed. This shows that the development of BSF is not only viewed as a waste management solution, but also as an innovation in the food security sector. The distribution of publications across subject areas also indicates the existence of a research gap in multidisciplinary approaches. Fields such as Energy, Computer Science, and Social Sciences still have very low publication numbers. This suggests that the integration of BSF technology with digital systems, artificial intelligence-based optimization, system modeling, and socio-economic analysis has not yet attracted significant attention. These fields are necessary for the future development of BSF technology, which requires interdisciplinary approaches to ensure that the implementation process becomes more effective, efficient, and widely applicable at both industrial and community scales. The low contribution of publications in the "*Multidisciplinary*" field indicates that BSF research still tends to be conducted sectorally and has not widely integrated various scientific perspectives comprehensively. Therefore, further research is needed to connect biological, environmental, technological, economic, and social aspects. This is important for the development of sustainable waste management using BSF larvae in supporting sustainable development.

The results of this bibliometric analysis demonstrate that research on Black Soldier Fly (BSF) larvae in organic waste management, specifically using bioconversion methods with varying feed ratios, has shown a steady increase in publications during the 2020–May 2026 period (Deen et al., 2023). The rising number of publications reflects a growing scientific interest in the use of Black Soldier Fly (BSF) larvae as an innovative approach to organic waste management, as well as an environmentally sustainable solution, given that the larvae can serve as a high-protein alternative feed source (Amrul et al., 2022; Hopkins et al., 2021). Research in this area also aligns with the global bio-circular economy paradigm, in which organic waste is regarded as a valuable resource that can be reused and transformed through the bioconversion process (Safitri et al., 2025).

The distribution of publications demonstrates contributions from international journals such as Animals (MDPI), Insects, and Poultry Science, indicating that BSF larvae bioconversion research with optimized feed ratios is closely linked to the fields of Agricultural and Biological Sciences as well as Veterinary Science. Studies in this area reveal that BSF larvae can effectively convert various types of organic waste including fruit, vegetable, and food waste into nutrient-rich biomass. This biomass can be repurposed as high-protein animal feed, highlighting the dual benefits of waste reduction and sustainable feed production (Nayak et al., 2024; Yu et al., 2023). The analysis also demonstrated that both the feed ratio and substrate type significantly affect the efficiency of the waste bioconversion process using BSF larvae. These factors, in turn, influence the larval growth rate and the nutrient composition of the resulting biomass (Pertiwi et al., 2023).

Research trends also indicate widespread international interest in this topic. Geographically, Italy ranks first in publication output, followed by Poland and China. These countries host active research groups and institutions focused on BSF larvae bioconversion, such as the Università degli Studi di Torino and the University of Przyrodniczy w Poznaniu, which emphasize the utilization of BSF in sustainable animal feed systems. Keyword analysis or keyword mapping reveals that terms such as "*Hermetia illucens*," "Bioconversion," "Animal Feed," and "Growth Performance" are frequently used in research on this topic. This pattern indicates a research focus on the utilization of BSF larvae for organic waste processing. BSF larvae are recognized for their ability to accelerate the decomposition of organic waste, enhance waste reduction efficiency, and convert waste into nutrient-rich biomass suitable for use as high-protein animal feed (Kutty et al., 2015). The bioconversion of organic waste using Black Soldier Fly (*Hermetia illucens*) larvae is increasingly recognized as an environmentally friendly technology for the management of organic solid waste (Mulyatna et al., 2022; Silvaraju et al., 2024). This process leverages the enzymatic capabilities of BSF larvae to break down complex organic materials into high-value biomass and nutrient-rich organic fertilizer residues (Silvaraju et al., 2024). One of the most important parameters influencing the success of bioconversion is the feed ratio, defined as the ratio between the amount of substrate and the number of larvae used (Addeo et al., 2021; Wang et al., 2025).

With the growing emphasis on bioconversion efficiency, recent research trends have highlighted the integration of fermentation technologies to enhance the nutrient availability of substrates. Pre-fermentation using microorganisms such as Lactobacillus sp. or Saccharomyces cerevisiae has been shown to reduce lignocellulose content and accelerate the breakdown of complex organic materials, thereby enabling larvae to more efficiently assimilate the substrate (Khasanah et al., 2024).

A potential driver of emerging publication trends in this field is research on the bioconversion of organic waste with the addition of fermentation agents.

According to the journal Sustainability, Black Soldier Fly larvae have the potential to convert organic waste into highly nutritious feed enriched with natural bioactive compounds. This evidence further underscores the relevance of BSF as an effective bioconversion agent within a sustainable circular economy system (Camperio et al., 2025). The condition of the substrate used in the bioconversion process particularly substrates that have undergone biological treatments such as anaerobic digestion has been shown to affect both the efficiency of bioconversion and the safety of BSF larvae (Rossi et al., 2025; Waithaka et al., 2022). This highlights the importance of further research on substrate modification through fermentation to enhance larval performance and bioconversion efficiency.

The addition of biochar in the bioconversion of soybean waste by BSF larvae has been shown to enhance decomposition efficiency, reduce greenhouse gas emissions, and increase nitrogen retention in the resulting residue (Qin et al., 2022). his research provides a solid foundation for studies exploring the use of additional agents such as biochar, EM4, or fermentative enzymes in BSF-based bioconversion systems. Other studies have demonstrated that the application of EM4 in the bioconversion of various types of organic waste can improve the quality of the resulting compost, particularly by enhancing nitrogen content and the C/N ratio, while also accelerating the decomposition process (Pratama et al., 2022; Zampiga et al., 2025).

The findings from the aforementioned studies indicate a new research direction in the field of organic waste bioconversion: the integration of BSF larvae activity with microbial fermentation processes to enhance overall system performance. This combined approach aims to increase bioconversion efficiency, accelerate the degradation rate, and produce higher-quality residual products that can be utilized as organic fertilizers or soil conditioners. Furthermore, this integration opens opportunities for future research focusing on the optimization of fermentation agents such as Effective Microorganisms 4 (EM4). in conjunction with varying feed ratios and different waste compositions. Such studies would contribute significantly to developing environmentally friendly organic waste management systems, aligned with the principles of the circular economy and sustainable resource utilization.

Conclusion

Based on the results of the bibliometric analysis, it can be concluded that research on the bioconversion of organic waste using Black Soldier Fly (BSF) larvae, particularly with attention to feed ratio variations, has shown a significant upward trend in publications during the 2020 – 3 May 2026 (incomplete year). This growth reflects the increasing recognition of BSF as a sustainable and efficient solution for organic waste management and the production of environmentally friendly alternative feed, supporting the broader framework of the bio-circular economy. The most productive author identified in this study is Biasato, I., with a total of twelve publications between 2020 until 3 May 2026. Furthermore, the analysis highlights that leading journals such as Animals, Poultry Science, and Journal of Insects as Food and Feed have become key publication platforms in this field. The dominant subject areas contributing to this topic include Agricultural and Biological Sciences and Veterinary, underscoring the strong interdisciplinary connection between insect-based bioconversion, livestock nutrition, and environmental sustainability. Additionally, countries such as Italy, China, and United States have emerged as the main research hubs in this field, supported by the active contributions of institutions such as the Università degli Studi di Torino and the University of Przyrodniczy w Poznaniu. The keyword mapping analysis further reveals that the core research themes center around "Larva," "Animal feed," "Feed conversation ratio," and "*Hermetia illucens*." These findings highlight a consistent research direction focused on improving the efficiency of organic waste conversion into high-value protein sources.

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Author Contributions
Conceptualization, A.Y.A. and S.S.; methodology, software, formal analysis, investigation, resources, data curation, writing-original draft preparation, writing—review and editing, supervision, project administration, A.Y.A.; validation, A.Y.A., S.S., and B.Z.; visualization, funding acquisition, S.S. All authors have read and agreed to the published version of the manuscript.

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The authors declare no conflict of interest.

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