

RESEARCH ARTICLE



Insect's Bioconversion of Organic Waste: A Systematic Literature Review and Bibliometric Analysis

Nur Riana Rochimawati^{a,b}, Arief Sabdo Yuwono^c, Anuraga Jayanegara^d, Neni Sintawardani^e

^a Doctoral Program in Natural Resources and Environmental Management Science, Graduate School IPB University, IPB Baranangsiang Campus, Bogor, 16143, Indonesia

^b Environmental Research Center, International Research Institute Environment and Climate Change, IPB University, IPB Dramaga Campus, Bogor, 16680, Indonesia

^c Department of Civil and Environmental Engineering, Faculty of Agricultural Technology, IPB University, IPB Dramaga Campus, Bogor, 16680, Indonesia

^d Department of Nutrition and Feed Technology, Faculty of Animal Science, IPB University, IPB Dramaga Campus, Bogor, 16680, Indonesia

^e Research Center for Environmental and Clean Technology, National Research and Innovation Agency, Bogor, 16911, Indonesia

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ABSTRACT

Food waste, a type of solid waste is a significant environmental concern, particularly in developing nations. The utilization of insects as bioconversion agents is becoming more significant due to rapid population expansion and the rise in organic waste on a global scale. The research on waste bioconversion utilizing insects is now limited to a few bug species and lacks long-term strategy and sustainability considerations. This study conducted bibliometric analysis and a comprehensive literature evaluation on studies related to waste bioconversion processes utilizing insect bioconversion agents in publications from 2013 to 2023. A bibliometric analysis will offer an overview of research and collaboration trends in this sector, while a systematic literature review (SLR) will provide summaries on selected issues from relevant works. Studies on waste bioconversion using insects have primarily focused on key factors such as the type of organic waste, the rate of waste reduction achieved, the formulation of substrates tailored to insect nutritional needs, and the downstream utilization of insect biomass as feed or for energy production (biogas, biodiesel, and biomass fuel). Most of the existing research centers on the Black Soldier Fly (169 publications), which has demonstrated high efficiency in reducing organic waste. This concentration on BSF highlights a research gap and potential opportunities for investigating other insect species like crickets, mealworms that may offer different advantages in specific waste types or environmental conditions.

Introduction

Waste is the residual byproduct of natural processes or human activity, and typically exists in a solid state. Food waste, among other solid wastes, is a significant environmental concern, particularly in developing nations [1,2]. Managing municipal solid waste (MSW) is of significant concern because of its impact on both environmental and health aspects [3,4]. Organic waste bioconversion systems involve using microbes, enzymes, or insects to transform organic waste into beneficial and eco-friendly products, such as bioenergy, fertilizers, animal feed, or chemicals. As a major component of MSW, food waste contributes significantly to landfill overflows and greenhouse gas emissions. In response, organic waste bioconversion technologies using microbes, enzymes, or insects are gaining attention for their ability to transform food and other organic waste into valuable products such as bioenergy, fertilizers, animal feed, and bio-based chemicals. These approaches offer sustainable alternatives to conventional waste disposal, aligning with circular economy

Corresponding Author: Nur Riana Rochimawati  nur.riana@apps.ipb.ac.id  Doctoral Program in Natural Resources and Environmental Management Science, Graduate School IPB University, IPB Baranangsiang Campus, Bogor, Indonesia.

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goals. Research on organic waste bioconversion systems has significantly increased in recent years because of the growing recognition of the harmful effects of organic waste on the environment and human health and the economic and social opportunities presented by bioconversion products.

Research on the bioconversion of organic waste by insect agents has been increasingly explored, particularly for its potential in sustainable waste management and resource recovery. Current research progress can be determined by examining publications in international journals and conference proceedings. Research on waste bioconversion using insects is currently limited to a few bug species (black soldier fly and house fly), and long-term strategies and sustainability considerations are lacking. This research employed a bibliometric analysis and systematic literature review to investigate organic waste bioconversion processes utilizing insect bioconversion agents in publications from 2013 to 2023. The purpose of this study was to analyze research on organic waste bioconversion utilizing insects and to determine the mapping of sustainability relationships in the studies that have been carried out, while also identifying any research gaps. The findings of this study can serve as valuable data and guidance for future research and policymaking regarding waste management and by-product utilization.

Materials and Methods

This study employed two methodologies. One method involved conducting a bibliographic analysis using the Publish or Perish (PoP) program and VOSviewer. Both these software solutions allow for the creation of relationship networks and the display of keywords in each cluster. The initial method focuses on examining bibliometric patterns, including citation counts, author productivity, and research collaboration, using PoP. VOSviewer helps visualize correlations among keywords in the published literature. The second methodology involved a systematic literature review to perform additional analysis of the chosen journals by pinpointing research subjects concerning the bioconversion of organic waste carried out in the past decade. A systematic literature review provides a thorough overview of the methods used, the main discoveries, and the research development in a specific field. This study seeks to offer a thorough understanding of the advancements and research patterns in the bioconversion of organic waste by insects by integrating these two methodologies.

Analysis of Bibliometric Data

The process of searching for publications involved the use of two software programs: PoP and VOSviewer. The software "Publish or Perish" aids in efficient and responsible retrieval and analysis of quotes [5]. This program assists academics and individuals in locating and analyzing the required sources of information from different publication databases. Database sources compatible with PoP include Crossref, Google Scholar, PubMed, OpenAlex, Scopus, Semantic Scholar, and Web of Science. The chosen publication databases were Scopus, Google Scholar, and Crossref. The publication's search criteria include the terms "waste bioconversion" and "insects" during the period frame of 2013 to 2023. Search results from the three databases were saved in files using the Research Information System (RIS) extension.

Visualizing Scientific Landscapes (VOSviewer) is a software created by Nees Jan van Eck and Ludo Waltman from Leiden University in the Netherlands. This software is utilized for bibliometric mapping, which involves analyzing and visualizing bibliographic data [6]. It assists people in comprehending the connections between aspects, including authors, keywords, and publications, through the utilization of data analysis and visualization tools. The software may categorize bibliographic elements into groups or clusters by analyzing the similarity of specific properties, such as keywords or study themes. VOSviewer stands out for its focus on similarity-based clustering, integration of temporal trends, and emphasis on creating accessible and visually rich representations of bibliographic data. This combination makes it highly effective in exploring and understanding research landscapes.

Systematic Literature Review

A literature review plays a crucial role in research by serving as a foundation, guiding knowledge creation, informing policies and practices, providing evidence, and potentially generating new ideas, future study areas, and theories when conducted well. Literature reviews can assess the quality of existing research gaps [7]. A systematic literature review adheres to specific guidelines for locating and combining pertinent papers to evaluate the knowledge of a particular issue [8]. A systematic review offers a detailed and critical analysis of the research findings on a certain issue. The steps are as follows:

Choosing a Database

This study utilized database sources from international journals and conference proceedings indexed by Scopus. A systematic search was conducted on the Scopus, Science Direct, and Google Scholar platforms using the keywords "waste bioconversion and insects" and "waste bioconversion by insects". The selection criteria focused on peer-reviewed articles published within the last ten years, with relevance to the use of insects in organic waste management, nutrient recovery, and by product utilization.

Criteria for Determining What is Included and Excluded

Inclusion criteria were established to regulate the publications that need to be located and assessed in this systematic literature review. Exclusion criteria are employed to remove papers and publications that are not relevant to addressing the author's research issue. The authors establish inclusion and exclusion criteria to make the decision more objective, as outlined in Table 1.

Table 1. Inclusion and exclusion criteria of the systematic literature review.

Criteria	Inclusion	Exclusion
Theme	All research related to waste bioconversion by insects on all its topics	Research not related to the topic of waste bioconversion by insects
Publication type	Open-access international journals and proceedings	Limited access to international journals and proceedings
Year of publication	2013–2023	Before 2013
Language	English	Not in English

Methodical Search Approach

The systematic search technique involved several key steps to ensure the selection of relevant and high-quality publications. These steps included keyword-based searching, filtering publications based on relevance and recency, and applying advanced search criteria such as publication type, subject area, and time range. This method enabled the identification of studies specifically focused on insect-based bioconversion of organic waste. By following this structured approach, the study ensured that the final selection of papers was both comprehensive and aligned with the research objectives. A total of 2,798 publications were initially identified through a keyword search using "waste bioconversion and insect" and "waste bioconversion by insect" in three major databases: Scopus (211 results), ScienceDirect (1,593 results), and Google Scholar (994 results). During the first screening phase, studies were excluded if they were published before 2013, not written in English, or were not published in international journals or conference proceedings. This filtering reduced the number of eligible publications to 794. In the next stage, duplicate entries and studies that were not directly related to the theme of insect-based waste bioconversion were removed. As a result, 208 relevant publications were selected for further analysis based on specific themes and topics. Figure 1 shows a flow diagram of the publication search and filtering system.

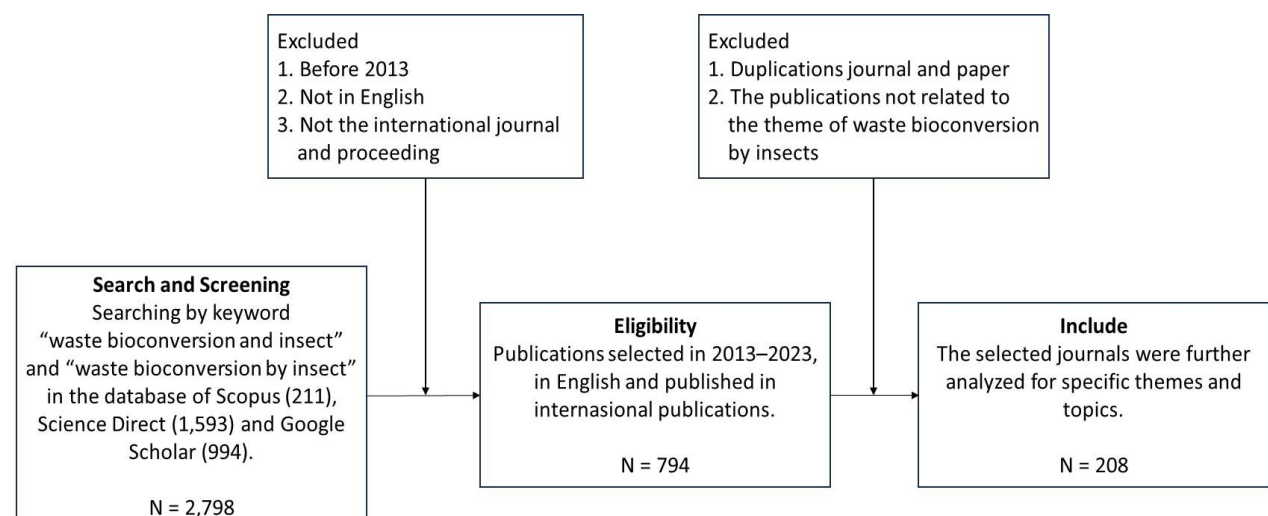


Figure 1. Flowchart of the systematic literature search technique.

Results

Mapping Research on Cluster Visualization and Waste Bioconversion by Insects

Visualization was generated using *VOSviewer* Software, which analyzes keywords and concepts extracted from the titles and abstracts of the publications. These publications were sourced from renowned databases including Scopus, Google Scholar, and Crossref. Figure 2 presents the results of the network analysis, highlighting the interconnections between keywords associated with garbage and insect bioconversion studies. This analysis provides a comprehensive overview of the research trends and focuses on this field over the past decade.

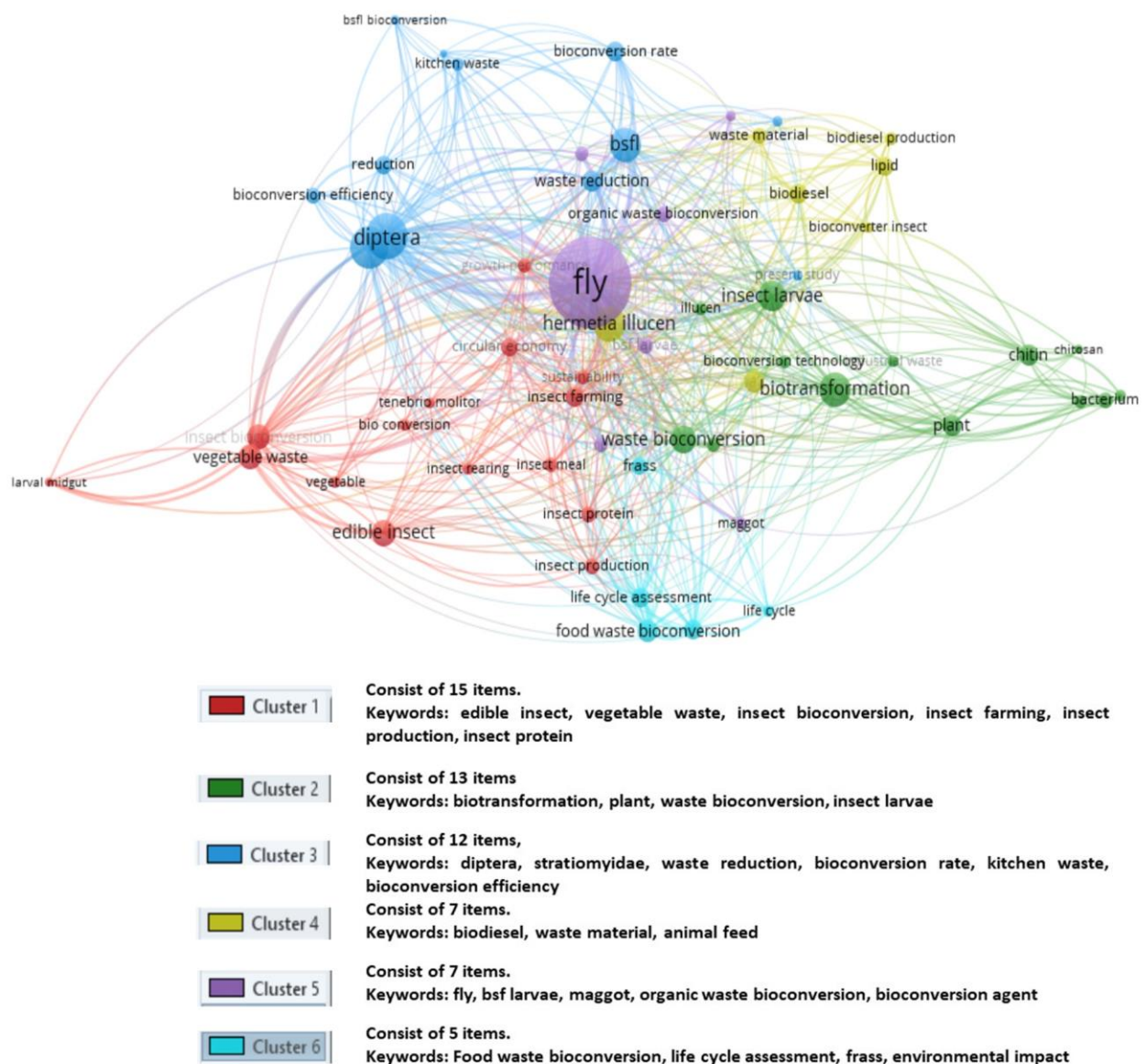


Figure 2. Visualizing and mapping waste bioconversion using insect research networks.

Figure 2 illustrates the division of the study into six clusters based on distinct color types. The size of a cluster ball (node) indicates its significance based on factors such as frequency of occurrence, number of connections, or overall impact. Larger nodes highlight influential elements such as widely cited publications, frequently used keywords, or highly collaborative authors. The largest cluster, identified by size and color, represents the most prominent research theme or area, providing insights into dominant trends and key contributors. Cluster 1 is focused on researching topics relating to insects, as shown by the phrases edible insect, insect farming, and insect protein. Cluster 2 is primarily focused on research related to waste

bioconversion and biotransformation. Cluster 3 is focused on Diptera, namely Stratiomyidae, and bioconversion efficiency. Cluster 4 represents research that typically discards materials that can be utilized as animal feed or for biodiesel production. Cluster 5 was the largest cluster focused on research related to keywords such as fly, Black Soldier Fly (BSF) larvae, maggot, organic waste bioconversion, and bioconversion agent. Many studies have used flies or BSF larvae as bioconversion agents for organic waste. Cluster 6 shares similarities with cluster 2 regarding the phrase food waste bioconversion, but focuses more precisely on life cycle evaluation and environmental effects.

Superimposed Visualization

Overlay visualization refers to the capability of a software to incorporate more information into the depiction of bibliometric maps or scientific networks. Users can enhance their comprehension of structures and relationships in bibliographic datasets by highlighting or displaying extra attributes for particular items. In addition to showing color differences across clusters, data can be enhanced by overlaying time-dimension explanations. The temporal layer graphic illustrates the evolution of linkages and structures over time. Figure 3 displays the research history organized by publication year. Where information is provided for the year and midyear.

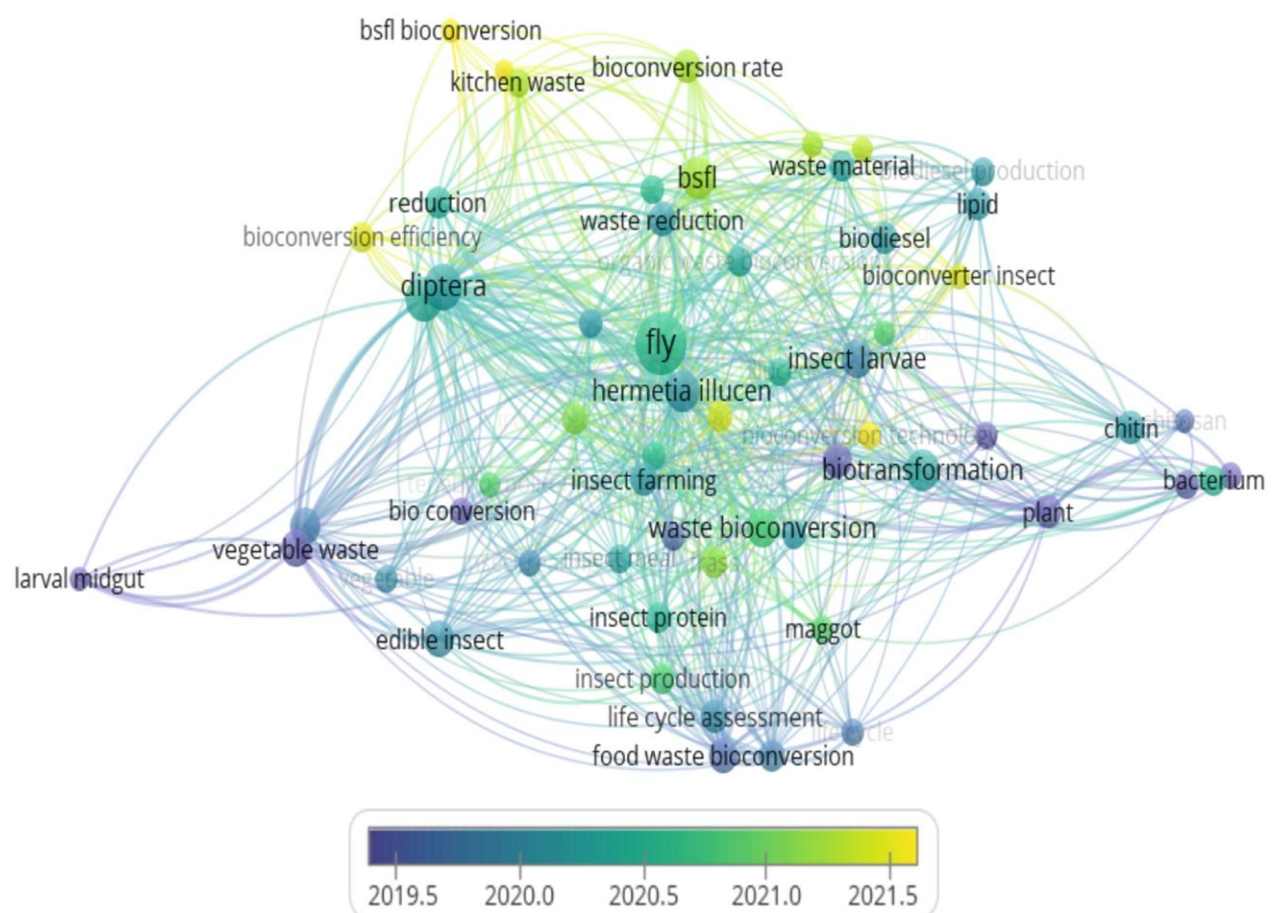


Figure 3. Overlay visualization of the year of publication's research.

VOSviewer is utilized to analyze patterns within a specific study sector. The vivid yellow hue in Figure 3 signifies new research. Darker or dark blue colors signify the types of studies conducted in earlier years. If we look again at Figure 2, it can be seen that Cluster 2 is focused on bioconversion technology, whereas Cluster 3 is centered on black soldier fly larvae (BSFL) bioconversion, bioconversion efficiency, and fruit waste. Cluster 4 focuses on insect bioconverters, whereas Cluster 5 centers on black soldier larvae. This image indicates that recent research on waste bioconversion utilizing insects has not made much progress, as evidenced by the limited presence of yellow tissue. This study also indicates the potential for innovative research on waste bioconversion using insects.

Visualization of Density for High-res Images

VOSviewer is a density visualization tool that allows users to generate and display bibliometric networks, illustrating the distribution of items in the network according to their proximity. These objects may include authors, publications, keywords, journals, and other entities linked to a particular similarity metric. Figure 4 displays a representation of the study density concerning waste bioconversion utilizing insects, categorized by type of research (a) and cluster (b).

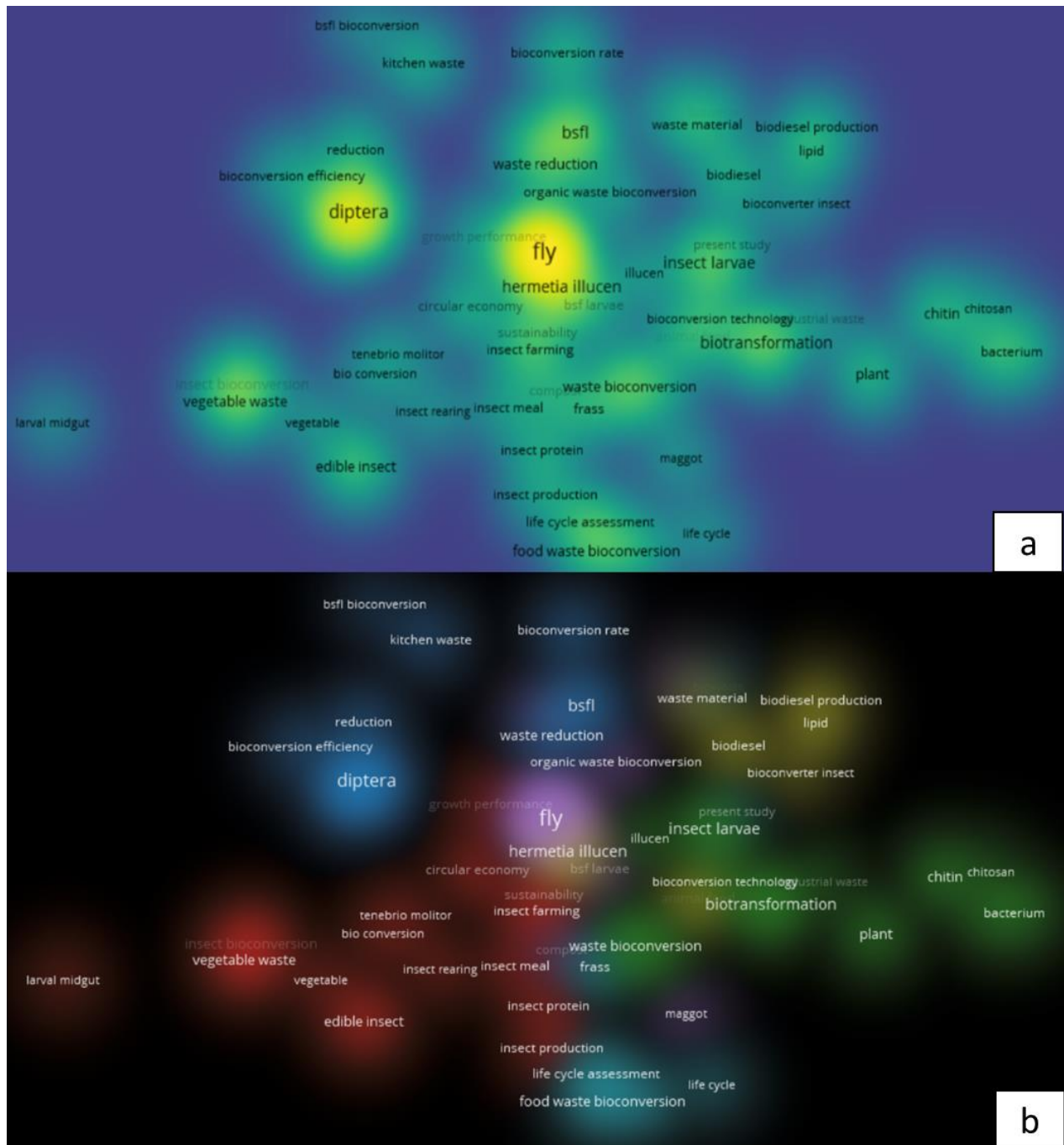


Figure 4. Visualization of waste bioconversion by insects' study density can be categorized by (a) type or (b) cluster.

The clustering-based visualization (Figure 4a) categorizes research themes into distinct groups, highlighting major focus areas such as insect biology, waste utilization, industrial applications, and BSF studies, with larger nodes like "fly" and "*Hermetia illucens*" indicating key topics. Figure 4a highlights that flies (Diptera), especially black soldier flies (*Hermetia illucens*), dominate bioconversion research due to their efficiency and versatility. While other insect orders, such as Coleoptera (*Tenebrio molitor*), have also been studied, they are

less prominent and focus on niche applications, such as food waste utilization. This dominance reflects the adaptability and established role of flies in waste-management systems. Density visualization (Figure 4b) emphasizes areas with high research activity, with brighter regions showing dominant themes. Each cluster in figure 4b represents a different area of research: cluster 1 (red) is about edible insects, cluster 2 (green) is about insect larvae, cluster 3 (dark blue) is about diptera, cluster 4 (yellow) is about animal feed, cluster 5 (purple) is about flies, and cluster 6 (light blue) is about the bioconversion of food waste.

Research on Sustainability Considerations in Waste Bioconversion by Insects

The subject of sustainability is prominently featured in the bibliometric analysis conducted using VOSviewer software. As shown in figure 5, sustainability appears as part of cluster 1, but it is also connected to all other clusters through strong network linkages, indicating its cross-cutting relevance. This suggests that while sustainability is a central theme, it is not confined to a single area of research. However, despite its presence across clusters, not all sustainability-related research themes have been fully explored, highlighting opportunities for further investigation. The network emphasizes strong connections between "sustainability" and concepts like "edible insects", "waste bioconversion", and "life cycle assessment (LCA)". These links highlight the role of flies, particularly in sustainable food production and organic waste management, in reducing environmental impacts and resource use. This reinforces the idea that utilizing flies supports a circular economy and promotes environment-friendly practices.

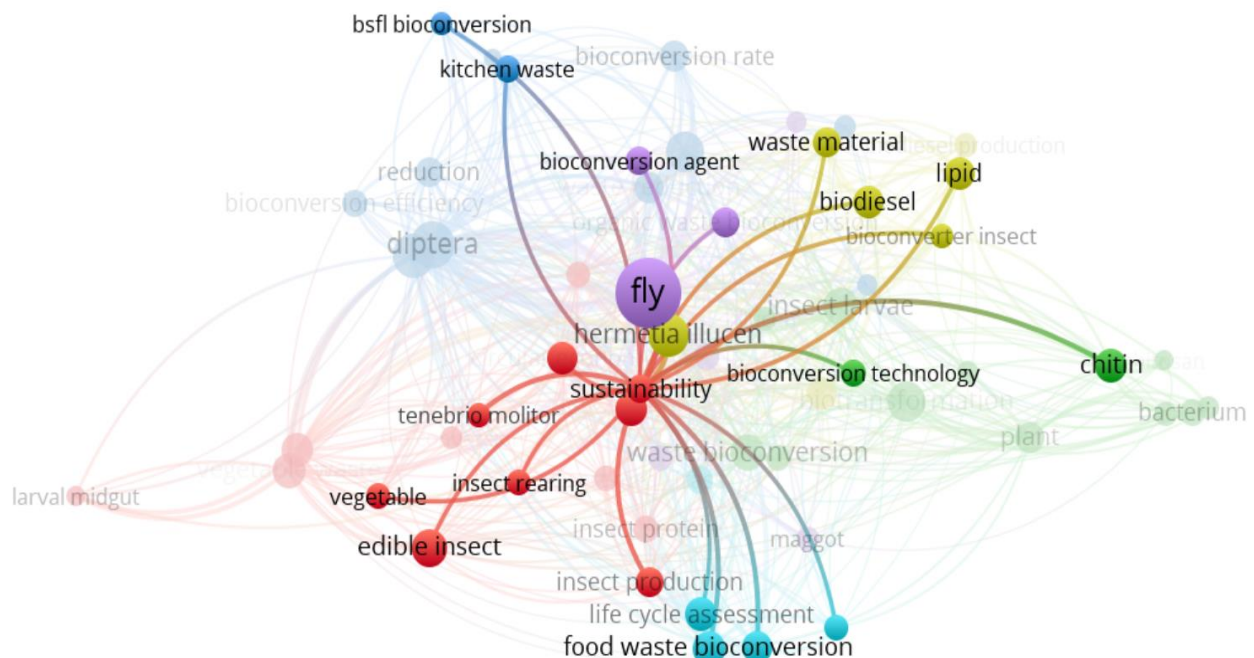


Figure 5. Research on sustainability in waste bioconversion by insects (cluster 1-red color).

Advancement of Studies on Waste Bioconversion Utilizing Insects

A systematic literature review was conducted using a multi-phase process to search for and screen relevant publications. This rigorous approach ensured a comprehensive and unbiased selection of studies. Figure 1 illustrates the search strategy employed during the review process. As a result, 208 publications were identified and selected from three major databases: Scopus, ScienceDirect, and Google Scholar, providing a robust foundation for analysis.

Publication Count and Year

A total of 208 publications, selected from a comprehensive search of studies published between 2013 and 2023, are shown in Figure 6. This figure provides a visual representation of the annual number of publications focusing on waste bioconversion using insects. These data highlight the growing interest and increasing research activity in this field over the past decade. This upward trend underscores the expanding recognition of insect-based waste management as a sustainable solution to the global waste challenges.

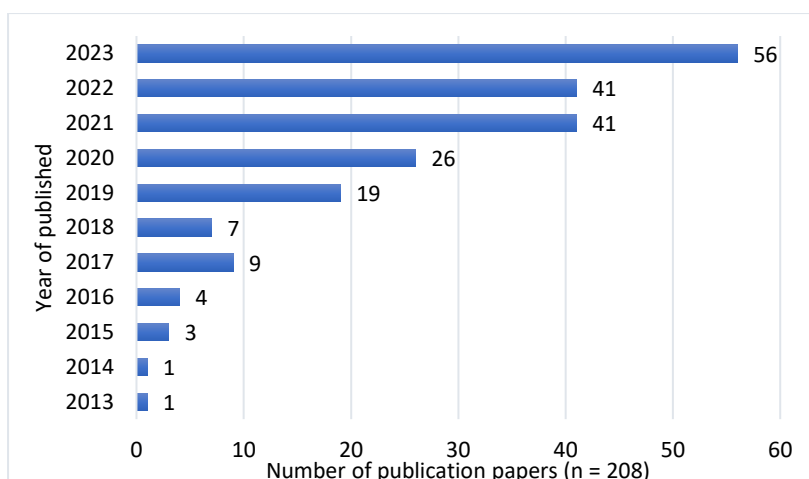


Figure 6. Annual publications on waste bioconversion by insect research from 2013 to 2023.

The graph illustrates an increase in the number of studies on waste bioconversion with insects in 2019. This aligns with the representation on the overlay depicting the year of publication by the VOSviewer bibliometric analysis in Figure 3. In 2023, there was a notable increase in the number of studies. The bar chart shows the annual growth of publications on waste bioconversion by insects from 2013 to 2023. The data reveal a significant increase in research interest, with only one paper published annually in 2013 and 2014, increasing to 56 papers in 2023. Notable jumps occurred between 2019 and 2020, likely driven by the heightened awareness of sustainability and the potential of insect bioconversion technologies to address global waste management challenges. This trend reflects the expanding recognition of the role of insects in circular economies, particularly in food waste recycling and sustainable resource recovery. This surge in recent years has led to ongoing advancements in the field and increased global attention toward practical applications.

Publications and Research Topics in Waste Bioconversion by Insects

A systematic literature review (SLR) revealed that numerous studies on waste bioconversion utilizing insects were conducted between 2013 and 2023. Figure 7 illustrates numerous studies on substrate, growth, nutrition, digestive system, and bioconversion performance. The SLR analysis results align with the density visualization conducted using VOSviewer, as shown in Figure 4.

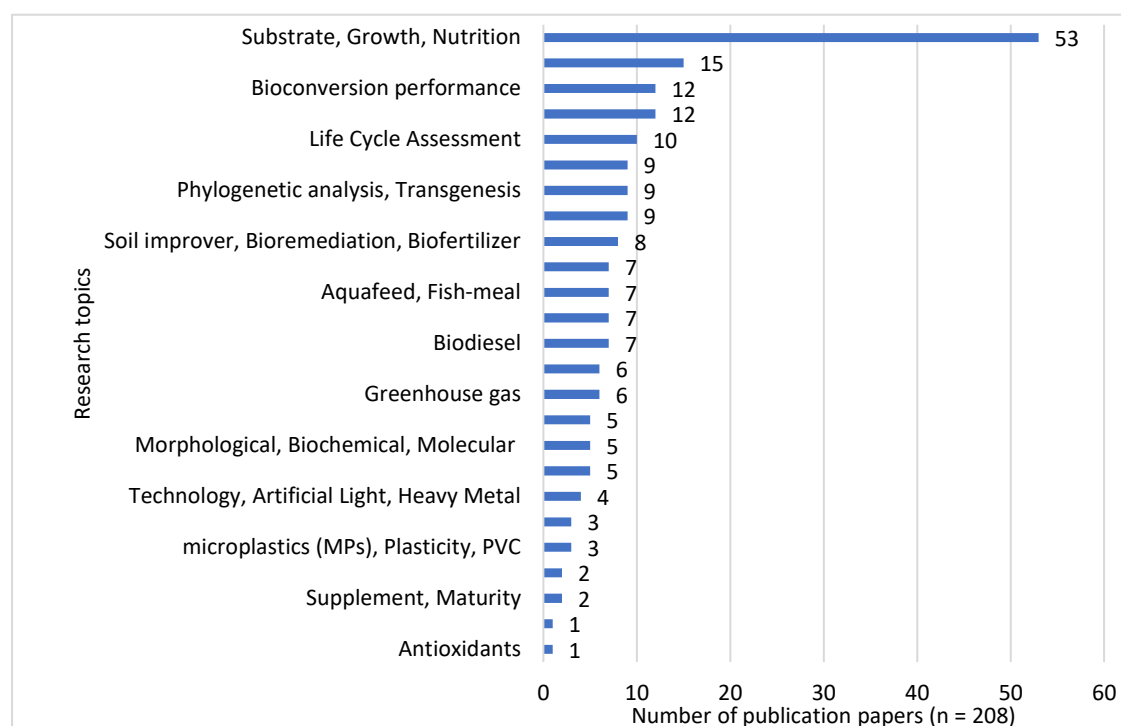


Figure 7. Research on waste bioconversion by insects from 2013 to 2023.

The figure shows the number of publications on insect trash bioconversion across various research topics between 2013 and 2023. The most studied topic is "substrate, growth, nutrition", with 53 publications, followed by "digestive system" (15), and both "bioconversion performance" and "biomass, lignocellulose, chitin, chitosan" tied with 12 publications each. Topics such as "LCA", "valorization, protein", and "waste management, sanitation" each have 9 publications. In contrast, areas such as "circular economy, sustainability", "aquafeed, fish-meal", and "bioreactor, biogas" each accounted for seven publications. Less explored areas included "supply chain" and "willingness to pay", with only one publication each.

Discussion

Waste is a challenge that is accompanied by global population expansion. Several initiatives have been implemented to address these issues, including bioconversion to manage waste. Research on waste bioconversion has focused on reducing waste through insect bioconversion, utilizing different substrates to enhance waste reduction, and improving the quality of insect larvae in terms of their growth and nutritional value [9-23]. Additionally, there is a focus on waste valorization to extract proteins from insects for use as animal feed [24–27]. Black soldier flies can bioconvert various waste microhabitats [28], including human waste [29]. Insects can serve as aquafeeds as well [30–33].

Research has been conducted on the insect's digestive mechanism and enzymes, in addition to studying waste reduction levels [34–38]. Bacteria in insect digestion can break down cellulose and generate chitin and chitosan as biomass [39–45]. Further research on phylogenetic analyses and insect transgenesis is required [46,47]. Biological processes can convert some garbage to produce energy in the form of biogas [48]. Although biogas production yields favorable effects, ammonia emissions from livestock manure and some waste fermentations are significant environmental concerns classified as greenhouse gases [49–51]. Utilizing appropriate organic material in the waste bioconversion process with insects can result in larval excrement that enhances soil quality, aids in bioremediation, and serves as both a solid biofertilizer [52–61] and liquid biofertilizer [62].

Various environmental conditions affect insect development [63]. Factors such as the air circulation requirements, humidity levels, and temperature [64], and illumination are important considerations [65]. Waste bioconversion employing insects in enclosed locations requires artificial lighting for optimal operation [66]. Thermal treatment is necessary to reduce the number of germ cells in food waste [67]. Utilizing insects and microbes for waste bioconversion offers the capacity to transform waste into biomass and reduce environmental contamination [68,69]. BSF can also break down microplastics [70,71]. Biomass larvae generated from waste bioconversion can be utilized for the production of biodiesel and proteins in biorefinery processes [72–78]. Some studies have also assessed farmers' willingness to pay for specific product attributes in bio converted compost by BSF [79].

The LCA approach can be used to compare waste management in different scenarios [80,81]. Regulations concerning the utilization of insects as feed are carefully evaluated from a legal perspective, considering their effects on the environment, safety, and economic factors [82,83]. Effective waste management can lead to a circular economy and sustainability [84]. There is limited research on the bioconversion of insects in high food supply chains compared to their technical or social elements [85]. This distribution shows a growing scientific interest in optimizing substrates and understanding insect growth and nutrition, indicating foundational research for scaling insect bioconversion. The substantial focus on the digestive system and bioconversion performance reflects the need to enhance the efficiency of waste conversion into valuable products. Topics like "LCA" and "circular economy" demonstrate efforts to quantify the sustainability benefits of insect bioconversion technologies. Meanwhile, areas with fewer publications, such as the supply chain and willingness to pay, suggest gaps in research related to commercialization and societal acceptance, which are critical for transitioning this technology from laboratories to large-scale applications.

Insect Taxonomy and Research Locations

Various insect species have been used in waste bioconversion studies. Flies, particularly the BSF (*H. illucens* L.), are the most commonly used insects. This aligns with the density depicted in Figure 4a. House flies (*M. domestica* L.) and blow flies (Diptera: Calliphoridae) are other types of insects that are utilized. Table 2 displays the many types of insects featured in the study. Extensive studies on the bioconversion of garbage to insects have been conducted in multiple locations worldwide (Figure 8). The numbers in the figure represent the number of publications related to insect bioconversion conducted in each country or region.

Table 2. Insect species included in the research.

Insect	Number of Publication
Black soldier fly (<i>Hermetia illucens</i> L.)	169
Yellow mealworm (<i>Tenebrio molitor</i> L.)	6
House fly (<i>Musca domestica</i> L.)	5
Black soldier fly (<i>Hermetia illucens</i> L.), House fly (<i>Musca domestica</i> L.), Yellow mealworm (<i>Tenebrio molitor</i> L.)	3
Black soldier fly (<i>Hermetia illucens</i> L.), Yellow mealworm (<i>Tenebrio molitor</i> L.)	3
Insects	3
Black soldier fly (<i>Hermetia illucens</i> L.), House fly (<i>Musca domestica</i> L.)	2
Edible insect	2
Blow flies (diptera: calliphoridae)	1
The greenhouse camel cricket (<i>Diestrammena asynamora</i>) and the hide beetle (<i>Dermestes maculatus</i>)	1
Super worm (<i>Zophobas morio</i>), Yellow mealworm (<i>Tenebrio molitor</i>), and House cricket (<i>Acheta domesticus</i>)	1
Black soldier fly (<i>Hermetia illucens</i> L.), House fly (<i>Musca domestica</i> L.), Codling moth (<i>Cydia pomonella</i>), Cambodian field cricket (<i>Teleogryllus testaceus</i>), and Yellow mealworm (<i>Tenebrio molitor</i>)	1
Cockroach (<i>Eublabeus</i> sp.)	1
Black soldier fly (<i>Hermetia illucens</i> L.) and House cricket (<i>Acheta domesticus</i>)	1
Yellow mealworm (<i>Tenebrio molitor</i> L.), House cricket (<i>Acheta domesticus</i>), and the Migratory locust (<i>Locusta migratoria</i>)	1
White-spotted flower chafer (<i>Protaetia brevitarsis seulensis</i>)	1
Japanese carpenter bees (<i>Xylocopa appendiculata</i>)	1
Lesser mealworm (<i>Alphitobius diaperinus</i> (Panzer))	1
Yellow mealworm (<i>Tenebrio molitor</i> L.), Super worm (<i>Zophobas morio</i>), <i>Alphitobius diaperinus</i> and House cricket (<i>Acheta domesticus</i>)	1
Black soldier fly (<i>Hermetia illucens</i> L.), Two-spotted crickets (<i>Gryllus bimaculatus</i> De Geer) and (<i>Scapsipedus icipe</i> Hugel and Tanga), Silk moth (<i>Bombyx mori</i> L.), Edible saturniid caterpillar (<i>Gonimbrasia krucki</i> Nudaurelia), mealworm (<i>Tenebrio molitor</i> L.), Desert locust (<i>Schistocerca gregaria</i> Forsskal), African fruit beetle (<i>Pachnoda sinuata</i> L.) and Rhinoceros beetle (<i>Oryctes rhinoceros</i> L.).	1
Fungus-growing Termites	1
The madagascar hissing cockroach (<i>Aeluropoda insignis</i> Butler), the Guyana spotted cockroach (<i>Blaptica dubia</i> Serville) and the Ivory cockroach (<i>Eublabeus</i> sp.)	1
Oriental leafworm (<i>Spodoptera litura</i>)	1
Total	208

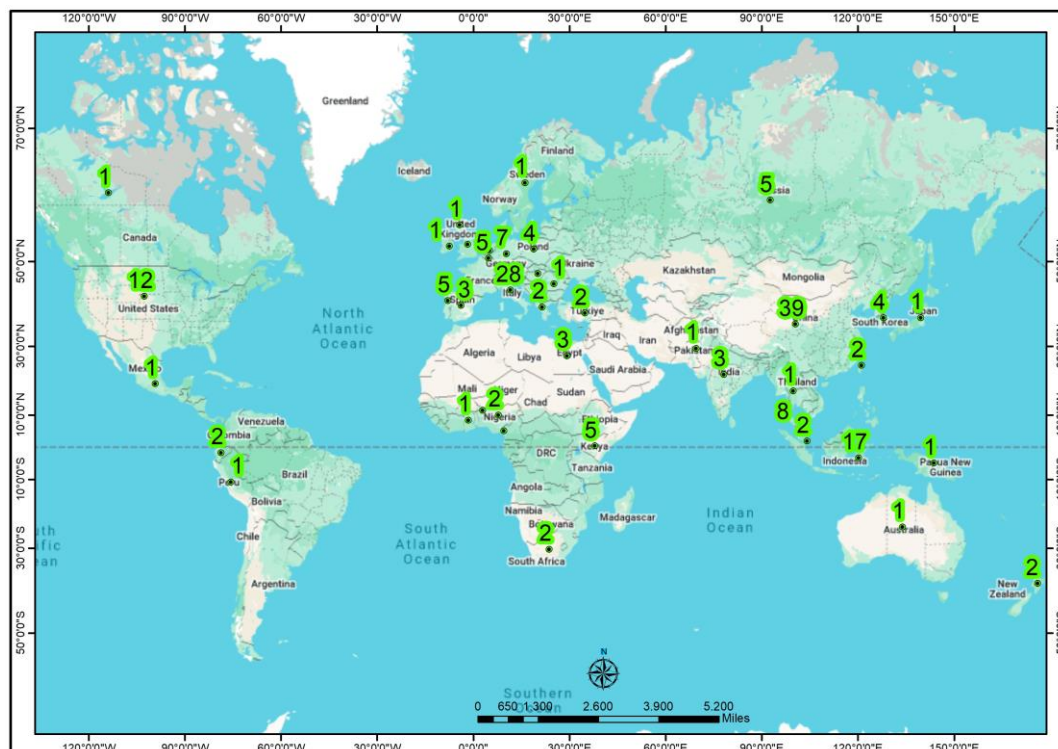


Figure 8. Research map of countries utilizing waste bioconversion by insects.

The systematic literature review from 2013 to 2023 identified the top five countries conducting waste bioconversion research using insects: China (39 publications), Italy (28 publications), Indonesia (17 publications), the USA (12 publications), and the Netherlands (9 publications). The findings highlight the global contributions to insect-based waste bioconversion, with top research countries providing scalable models for addressing organic waste challenges and promoting circular economic practices. Policymakers can leverage these insights to encourage private-sector involvement, develop supportive regulations, and integrate insect bioconversion into environmental management frameworks. This study bridges academic knowledge and practical applications, fostering sustainable waste management solutions worldwide. Research on waste bioconversion by insects is a fascinating area that should be continuously investigated, focusing on insect species, substrates, biotransformation products, and intestinal microbiota.

Conclusions

This study analyzed 208 publications from 2013 to 2023, uncovering key trends in waste bioconversion using insects. The results show a dominant research focus on the BSF, particularly in waste reduction efficiency, substrate optimization, and the generation of high-value by-products like animal feed, biogas, biodiesel, and biomass. However, sustainability considerations, such as environmental impacts, circularity, and social acceptance, remain underexplored. Future research should expand to include a wider range of insect species, integrate LCA to evaluate environmental performance, and explore the development of scalable bioconversion systems. These insights can support advancing sustainable waste management practices and contribute to global priorities such as the circular economy, climate change mitigation, and sustainable agriculture.

Author Contributions

NR: Conceptualization, Methodology, Software, Investigation, Writing - Review & Editing; **AS**: Writing - Review & Editing, Supervision; **AJ**: Writing - Review & Editing, Supervision; **NS**: Writing - Review & Editing, Supervision.

Conflicts of interest

The authors declare no conflict of interest.

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