Global Research Trends on the Utilization of Black Soldier Fly in Ruminant Nutrition (2004–2025): A Scopus-Based Bibliometric Analysis

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Abstract. The growing demand for sustainable protein sources in ruminant production systems has intensified scientific interest in black soldier fly larvae (BSFL; Hermetia illucens L.) as an alternative feed ingredient. This study presents a comprehensive bibliometric analysis of global scientific publications on the use of BSFL in ruminant nutrition. Bibliographic data were retrieved from the Scopus database for the period 2004–2025 and analysed using established bibliometric tools to assess publication trends, citation patterns, collaboration networks, source concentration, and thematic evolution. A total of 194 peer-reviewed documents were identified, published across 115 sources by 903 authors, with a mean of 6.0 authors per article and 36.08% international co-authorship. Publication output increased markedly over the past decade, indicating that BSFL research has emerged as a rapidly developing and multidisciplinary field. Thematic analysis revealed a clear transition from early studies centred on basic biology and waste bioconversion toward applied research addressing ruminant nutrition, feed efficiency, and sustainability. Source analysis further showed that although insect- and feed-specific journals dominate publication volume, environmental journals attract disproportionately higher citation intensity, suggesting that the field remains conceptually anchored in circular-economy frameworks rather than fully integrated into mainstream animal nutrition science.

Keywords: Black soldier fly larvae, ruminant nutrition, insect-based feed, bibliometric, sustainability

Abstrak. Pertumbuhan permintaan terhadap sumber protein yang berkelanjutan dalam sistem produksi ruminansia telah meningkatkan minat ilmiah terhadap larva lalat tentara hitam (*black soldier fly larvae*/BSFL; *Hermetia illucens* L.) sebagai bahan pakan alternatif. Penelitian ini menyajikan analisis bibliometrik yang komprehensif terhadap publikasi ilmiah global mengenai penggunaan BSFL dalam nutrisi ruminansia. Data bibliografi diperoleh dari basis data Scopus untuk periode 2004–2025 dan dianalisis menggunakan perangkat bibliometrik yang telah mapan untuk mengevaluasi tren publikasi, pola sitasi, jaringan kolaborasi, konsentrasi sumber publikasi, serta evolusi tema penelitian. Sebanyak 194 dokumen yang telah melalui proses peer review berhasil diidentifikasi, diterbitkan pada 115 sumber publikasi oleh 903 penulis, dengan rata-rata 6,0 penulis per artikel dan tingkat kolaborasi internasional sebesar 36,08%. Jumlah publikasi meningkat secara signifikan selama satu dekade terakhir, yang menunjukkan bahwa penelitian mengenai BSFL telah berkembang menjadi bidang yang tumbuh pesat dan bersifat multidisipliner. Analisis tematik mengungkapkan adanya pergeseran yang jelas dari penelitian awal yang berfokus pada biologi dasar dan biokonversi limbah menuju penelitian terapan yang membahas nutrisi ruminansia, efisiensi pakan, dan keberlanjutan. Analisis sumber publikasi juga menunjukkan bahwa meskipun jurnal yang berfokus pada serangga dan pakan mendominasi jumlah publikasi, jurnal di bidang lingkungan memperoleh intensitas sitasi yang jauh lebih tinggi. Hal ini mengindikasikan bahwa bidang penelitian ini masih berlandaskan pada kerangka konsep ekonomi sirkular (*circular economy*) dan belum sepenuhnya terintegrasi ke dalam ilmu nutrisi ternak arus utama.

Kata kunci: Larva lalat tentara hitam, nutrisi ruminansia, pakan berbasis serangga, bibliometrik, keberlanjutan

Introduction

The increasing demand for livestock-derived products, coupled with the limited availability of conventional feed resources, has driven the search for sustainable alternative feed ingredients within ruminant production systems. Conventional protein sources, such as soybean

meal and fishmeal, are associated with several challenges, including environmental impacts, competition for arable land with human food production, price volatility, and reliance on imports, particularly in developing countries (Makkar et al., 2014; Van Huis et al., 2013). Consequently, insects have garnered attention as promising alternative protein sources due to their high feed conversion efficiency, rapid growth rates, and relatively low environmental footprint. Among various insect species, Black Soldier Fly larvae (BSFL; *Hermetia illucens L.*) have demonstrated substantial potential in livestock nutrition research. BSFL are rich in crude protein (35–45%) and contain considerable lipid content (25–40%), alongside an amino acid profile conducive to meeting livestock nutritional requirements (Barragan-Fonseca et al., 2017; Spranghers et al., 2017). Moreover, BSFL can be reared on organic waste substrates, contributing to waste bioconversion and the implementation of circular economy principles in agro-industrial systems (Surendra et al., 2016).

Although insect-based feeds have been extensively studied in monogastric animals such as poultry, pigs, and fish, research on BSFL in ruminant nutrition has progressed at a comparatively slower pace, with the majority of published studies focusing on monogastric species, while only a limited number of studies have explored its application in ruminants (Renna et al., 2022). In ruminants, BSFL and their derivatives (defatted meal, oil, or hydrolysates) have been evaluated as protein and lipid sources, as well as functional feed ingredients with potential effects on rumen fermentation, methane emissions, nutrient digestibility, and animal performance (Schiavone et al., 2021; Jayanegara et al., 2017). The medium-chain fatty acid content, particularly lauric acid, has attracted interest due to its antimicrobial properties, which can influence rumen microbial populations (Aduna, 2019). Nevertheless, results on BSFL utilization in ruminant diets remain highly variable, influenced by processing methods, inclusion levels, animal species, and experimental design.

The rapid growth of publications spanning diverse disciplines including animal nutrition, environmental science, biotechnology, and sustainability has led to a fragmented knowledge base that is challenging to synthesize through conventional narrative reviews. Bibliometric analysis offers a quantitative and systematic approach to evaluating the development of scientific publications, collaboration networks, influential authors and institutions, as well as the dynamics and shifts in research themes within a given field (Donthu et al., 2021; Aria and Cuccurullo, 2017). By mapping publication trends and thematic evolution, bibliometric analyses can identify core research topics, knowledge gaps, and future research directions. While some bibliometric studies have addressed insects as livestock feed in general, analyses specifically focusing on BSFL in ruminant nutrition remain scarce.

Therefore, a comprehensive bibliometric review is warranted to elucidate the global research landscape on BSFL utilization in ruminant feeding systems. Such an analysis can provide insights into the temporal evolution of scientific interest, leading countries and institutions, collaboration patterns, and emerging research themes. The present study aims to conduct a bibliometric analysis of global scientific publications on the use of Black Soldier Fly larvae (*Hermetia illucens*) in ruminant nutrition. Specifically, the objectives are to: (1) examine trends in publication growth and citation patterns; (2) identify the most influential authors, institutions, countries, and collaboration networks; and (3) explore the evolution of research themes and emerging topics in this field. The findings are expected to serve as a reference for researchers and stakeholders in guiding future research on sustainable insect-based feeds for ruminant production systems.

Materials and Methods

Study Period and Location

The bibliometric analysis was conducted from November to December 2025 at the Livestock Research Laboratory, Tjut Nyak Dhien University, Medan, Indonesia.

Search Strategy and Data Sources

A systematic and iterative approach was employed to identify and analyze scientific literature relevant to the use of insects in ruminant nutrition. Initial keywords focused on terms related to insects, Black Soldier Fly larvae (BSFL), insect-based feed, ruminant nutrition, and feed sustainability, based on the conceptual framework proposed by Ghavipanje et al. (2026).

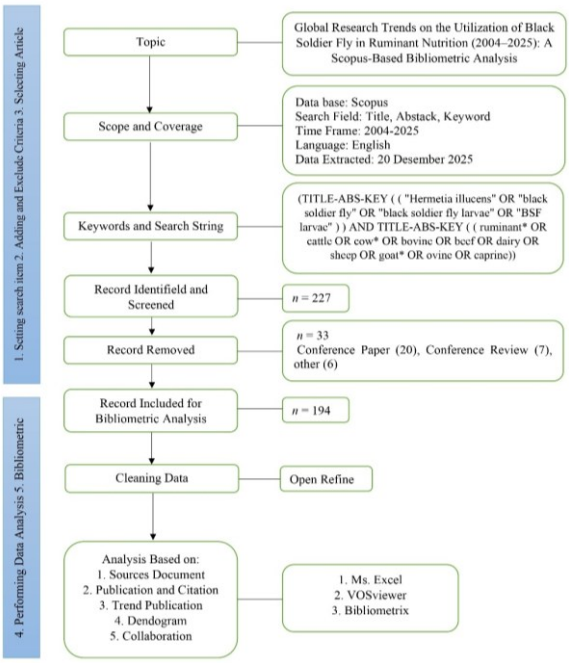

Figure 1. Analysis flow diagram

This study relied solely on the Scopus database because of its extensive journal coverage, high-quality indexing, and detailed citation information, which are essential for bibliometric analysis. Scopus has been widely used in similar studies as a reliable source for mapping research trends. While databases such as Web of Science could complement the dataset, limiting the analysis to a single database minimizes potential inconsistencies and duplication, thereby enhancing the reliability and reproducibility of the results.

The Scopus search string—TITLE-ABS-KEY (("*Hermetia illucens*" OR "black soldier fly" OR "black soldier fly larvae" OR "BSF larvae")) AND TITLE-ABS-KEY ((ruminant* OR cattle OR cow* OR bovine OR beef OR dairy OR sheep OR goat* OR ovine OR caprine))—was designed to target studies examining the use of insects in ruminant feeding.

The analysis followed a six-step systematic protocol: (i) development of search terms, (ii) application of inclusion and exclusion criteria, (iii) document screening, (iv) data cleaning, (v) data analysis, and (vi) visualization of results. A flow diagram of the research process is presented in Figure 1 (Prihambodo et al., 2025).

Inclusion and Exclusion Criteria

Only peer-reviewed research articles and review papers published in English that specifically addressed the use of Black Soldier Fly (BSF) larvae as ruminant feed were included in the analysis. Other document types, such as conference proceedings, non–peer-reviewed publications, and studies not directly focused on BSF utilization in ruminant nutrition, were excluded from the dataset. The literature search initially retrieved 227 documents; 194 articles met the inclusion criteria and were further analyzed.

Data Extraction and Preprocessing

Metadata from Scopus, including author names, titles, publication year, affiliations, keywords, funding sources, countries of origin, and citation counts, were extracted on 20 December 2025 and exported in CSV format. Data preprocessing was conducted using OpenRefine through three main steps: (i) removal of duplicate records, (ii) standardization of author and institution names, and (iii) normalization of keywords to ensure dataset

consistency (Donthu et al., 2021; Mulianda et al., 2025).

Bibliometric and Network Analysis

Comprehensive bibliometric analyses were performed using VOSviewer (version 1.6.20), Bibliometrix R (version 4.2.2), and Microsoft Excel. The analyses included publication productivity, keyword co-occurrence networks, co-authorship patterns, institutional collaborations, and inter-country research linkages. The resulting visualizations provided insights into thematic structures, major contributors, citation landscapes, and the temporal evolution of research in insect-based feed and ruminant nutrition (Prihambodo et al., 2025).

Results and Discussion

Scientific Output and Publication Characteristics (2004–2025)

The bibliometric analysis of Black Soldier Fly (BSF) larvae research in ruminant nutrition (2004–2025; Figure 2) identified 194 documents published across 115 sources with 903 authors, averaging six authors per article and 36.08% international collaboration. Mean citations per document were 42.12, with an average age of 3.97 years, indicating a relatively recent field with high scientific impact. A total of 645 author keywords and 1,573 references were recorded, reflecting the thematic diversity and extensive literature supporting the development of BSFL as a sustainable ruminant feed resource.

Figure 2. General characteristics of the bibliometric dataset

The high level of author collaboration and international cooperation in BSFL research indicates that this topic is evolving as a multidisciplinary and global field, aligning with the growing interest in sustainable and environmentally friendly livestock feeding systems (Makkar et al., 2014; Van Huis et al., 2015).

The relatively high average citation count combined with the young document age suggests that research on BSFL in ruminant nutrition represents an emerging field with strong scientific visibility, a pattern commonly observed in innovative topics within animal nutrition and sustainability (Donthu et al., 2021). The broad diversity of keywords reflects a thematic shift from simple evaluations of nutrient composition toward more complex studies, including effects on rumen fermentation, feed efficiency, and environmental impact mitigation. This pattern illustrates the adaptive evolution of research in response to global challenges in the livestock sector and highlights opportunities for further integrated studies bridging nutrition, microbiology, and sustainable ruminant production systems (Schiavone et al., 2021; Gasco et al., 2020).

Trends in Publication Output and Geographical Citation Impact

The analysis of publication and citation trends (Figure 3) revealed that the number of articles on BSFL utilization in ruminant nutrition was relatively low during the initial period (2004–2015) but has increased consistently since 2018, peaking in the 2021–2025 period. Annual citation patterns exhibited sharp fluctuations, with a substantial citation spike around 2010, reflecting the strong influence of foundational publications that have become key references for subsequent research. Geographic contribution analysis (Table 1) indicated that China and the United States dominate in total citation counts, followed by Thailand, whereas-

Table 1. Top 10 most cited countries

Country	TC	Average Article Citations (%)
China	1495	62.3
USA	1234	53.7
Thailand	352	27.1
Georgia	318	31.8
Switzerland	283	94.3
Indonesia	251	17.9
Netherlands	244	40.7
Italy	238	15.9
Germany	214	30.6
United Kingdom	201	50.2

-several European countries, such as Switzerland and the United Kingdom, show high average citations per article despite having relatively fewer publications.

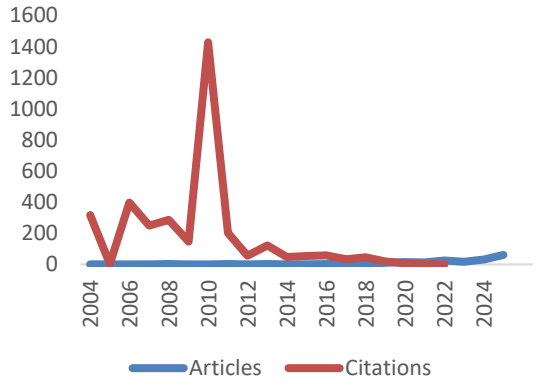

Figure 3. Temporal trends in publications and citations

The growth in publications over the past decade reflects increasing scientific attention to BSFL as a sustainable alternative feed, driven by pressures on protein efficiency and ruminant system sustainability (Henry et al., 2015; Sánchez-Muros et al., 2018). Early citation surges highlight the importance of pioneering studies that established conceptual and methodological frameworks for subsequent research, a common pattern in emerging fields (Zhang et al., 2020). China and the United States dominate total citations due to research capacity, funding, and collaboration networks, while high average citations in some European countries indicate focus on quality and relevance. Overall, BSFL research development is guided by both publication volume and integration with sustainability, feed efficiency, and environmental impact considerations (Halloran et al., 2017; Józefiak et al., 2022).

The average citation values should be interpreted with caution, particularly for countries with a relatively low number of publications. For example, Georgia shows a relatively high average citation (31.8) despite a lower total publication output. This pattern may be influenced by a limited number of publications, where a few highly cited articles can elevate the average citation value. In contrast, countries with larger publication outputs, such as China and the USA, tend to exhibit more stable and representative citation averages due to a broader publication base. A similar consideration applies when comparing countries such as Switzerland, where citation impact may reflect the presence of influential studies rather than overall research volume. Therefore, average citation metrics should be interpreted alongside total publication counts to provide a more balanced understanding of country-level research performance.

Source Concentration and Impact in Insect-Based Feed Research

The distribution of publication sources (Table 2 and Figure 4) reveals a strong concentration of insect-based feed research within a small number of core journals, reflecting both thematic specialization and uneven knowledge diffusion. Journal of Insects as Food and Feed dominates in terms of publication volume and source-level impact, underscoring its role as a primary intellectual hub at the -

Table 2. Top 10 sources by local impact

Source	h_index	g_index	m_index	TC
Journal of Insects as Food and Feed	8	14	0.666	476
Waste Management	6	6	0.375	718
Animals	5	5	0.625	360
Insects	5	7	1	252
Journal of Environmental Management	5	6	0.5	435
Environmental Entomology	4	4	0.210	595
Journal of Cleaner Production	4	4	0.4	407
Animal Bioscience	3	3	0.6	139
Applied Sciences (Switzerland)	3	3	0.6	30
Foods	3	3	0.428	136

-intersection of entomology, feed innovation, and animal nutrition.

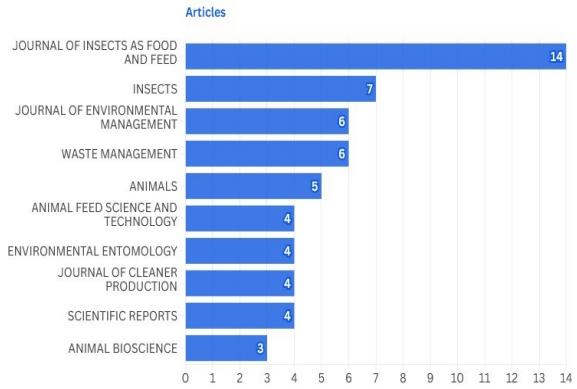

Figure 4. Most relevant sources

This pattern aligns with Bradford's law of source concentration, commonly observed in emerging interdisciplinary fields, where specialized journals function as early consolidators of domain-specific knowledge (Mottet et al., 2018; Gasco et al., 2020). However, despite lower publication counts, multidisciplinary journals such as Waste Management and Journal of Environmental Management exhibit much higher cumulative citations, indicating that insect-based feed studies framed within the context of circular economy and waste valorization resonate more broadly across the scientific community.

The discrepancy between publication productivity and citation impact indicates that Black Soldier Fly (BSF) research remains conceptually anchored in environmental sustainability and is not yet fully integrated into mainstream animal nutrition. High citation intensity in environmental journals highlights BSF's role in global discussions on waste reduction, resource efficiency, and sustainable food systems (Smetana et al., 2019; van Huis & Tomberlin, 2017). In contrast, lower impact in livestock journals suggests that empirical evidence on insect-based feeds improving animal performance and nutrient utilization is still emerging. This imbalance underscores the need for rigorous in vivo studies, meta-analyses, and standardized nutritional assessments to support evidence-based livestock feeding strategies (Nogales-Mérida et al., 2019; Hawkins et al., 2021).

The application of Bradford's law (Figure 5) reveals a clear core–periphery structure in insect-based feed research, where a small set of journals accounts for a disproportionately large share of publications. Journal of Insects as Food and Feed occupies the innermost core, followed by Insects, Journal of Environmental Management, and Waste Management, reflecting strong concentration in specialized, sustainability-oriented outlets. This pattern aligns with productivity rankings of the most relevant sources. It indicates a maturing yet still relatively limited research domain, anchored in journals integrating entomology, feed innovation, and environmental management. Such concentration is consistent with Bradfordian behavior in emerging interdisciplinary fields, where a few journals consolidate primary knowledge (Bradford, 1934; Mottet et al., 2018; Gasco et al., 2020).

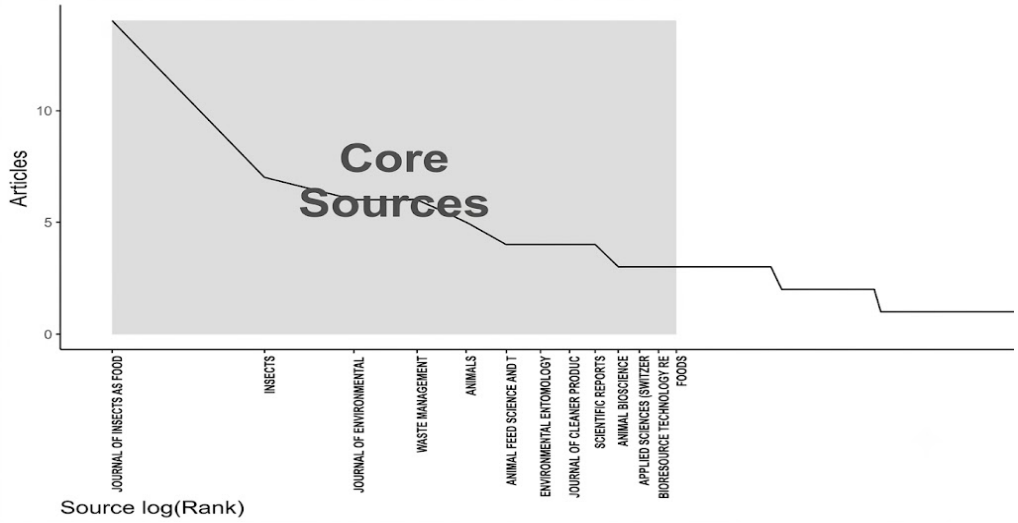

Figure 5. Bradford's law

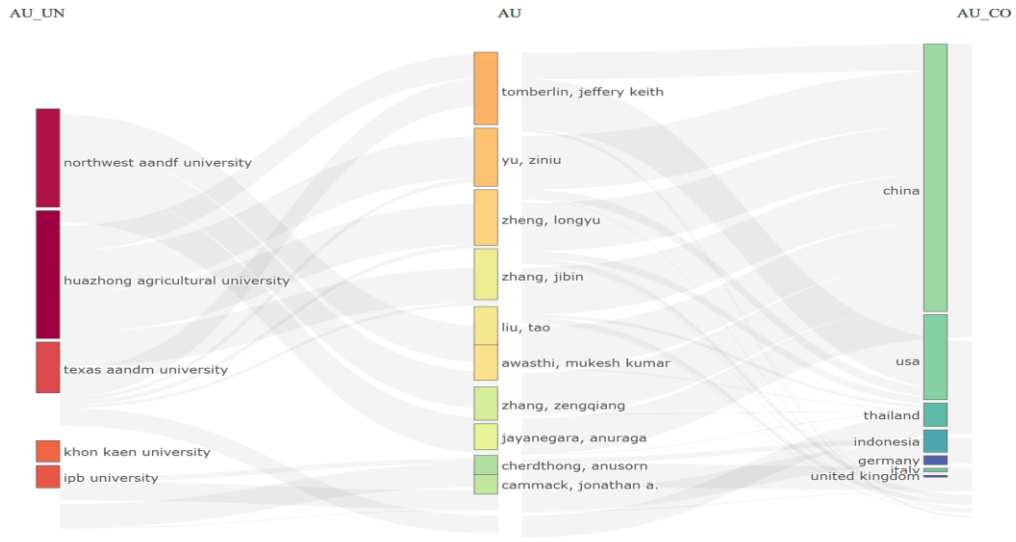

Figure 6. Diagram sankey

Interpreted alongside source-level impact metrics, the Bradford core shows a structural imbalance between productivity and citation influence. While feed- and insect-focused journals dominate publication volume, environmental journals within or near the core exhibit much higher citation intensity, emphasizing their role in enhancing scientific visibility. This suggests that Black Soldier Fly (BSF) and insect-based feed research remain conceptually driven by waste valorization and circular economy frameworks and are not yet fully integrated into mainstream animal nutrition science (van Huis & Tomberlin, 2017; Smetana et al., 2019). Consequently, the Bradford distribution highlights the field's transitional state from environmentally driven innovation toward evidence-based livestock feeding strategies and underscores the need to integrate high-impact experimental studies and meta-analyses in animal science journals (Nogales-Mérida et al., 2019; Hawkins et al., 2021).

Authorship Structure and International Collaboration Patterns

Authorship patterns and international collaboration (Figure 6) reveal a highly concentrated network structure, with China and the United States serving as the primary hubs for

knowledge production and coordination in insect-based feed research. Sankey diagrams highlight strong linkages between influential institutions and authors such as Northwest A&F University, Huazhong Agricultural University, and Texas A&M University forming the core of scientific leadership, whereas Southeast Asian countries, including Indonesia and Thailand, remain emerging contributors. This is further supported by corresponding author analysis, which shows that China and the United States have a high proportion of multiple-country publications, reinforcing their role as global collaboration hubs, while single-country publications predominantly represent developing countries.

The dominance of China and the United States as corresponding authors and contributors to multinational publications (Figure 7) reflects a common pattern in emerging interdisciplinary fields, where countries with high research capacity act as knowledge hubs and primary drivers of global scientific diffusion. In the context of insect-based feed, this leadership is closely linked to substantial research investment, well-established laboratory infrastructure, and a strategic focus on sustainability and circular economy issues. Conversely, the involvement of developing countries, still largely represented by single-country publications, highlights gaps in access to international networks and scientific leadership. This pattern underscores that strengthening cross-country collaboration, particularly through comparative projects, multi-location in vivo studies, and global meta-analyses, is a critical prerequisite for accelerating the integration of insect-based feeds into evidence-based and globally relevant livestock nutrition systems (van Huis & Tomberlin, 2017; Smetana et al., 2019; Gasco et al., 2020).

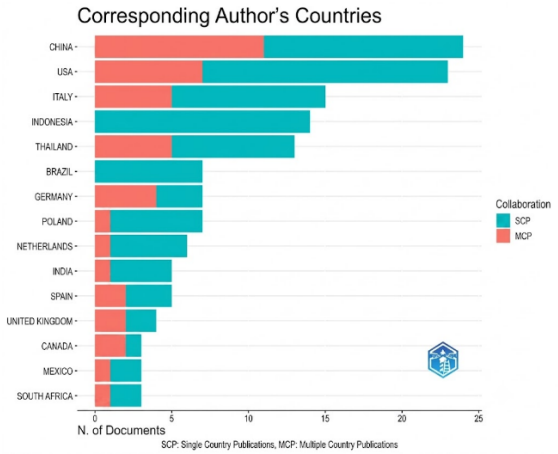

Figure 7. Corresponding authors' countries

Based on Table 3, the ten most relevant institutional affiliations exhibit a relatively even distribution of publication contributions, with no single institution dominating the field. Huazhong Agricultural University ranks highest with 53 articles (5%), followed by Northwest A&F University and Wageningen University & Research, each contributing approximately 4% of the total publications. Other institutions, such as Suranaree University of Technology and Texas A&M University, also make comparable contributions, reflecting active involvement from multiple global research centers.

Table 3. Top 10 most relevant affiliations

Affiliations	Article	Percentage (%)
Huazhong Agricultural University	53	5%
Northwest A&F University	41	4%
Wageningen University and Research	38	4%
Suranaree University of Technology	37	4%
Texas A&M University	37	4%
IPB University	34	3%
Khon Kaen University	33	3%
Università Degli Studi Di Modena E Reggio Emilia	22	2%
Università Degli Studi Di Torino	21	2%
Guizhou University	20	2%

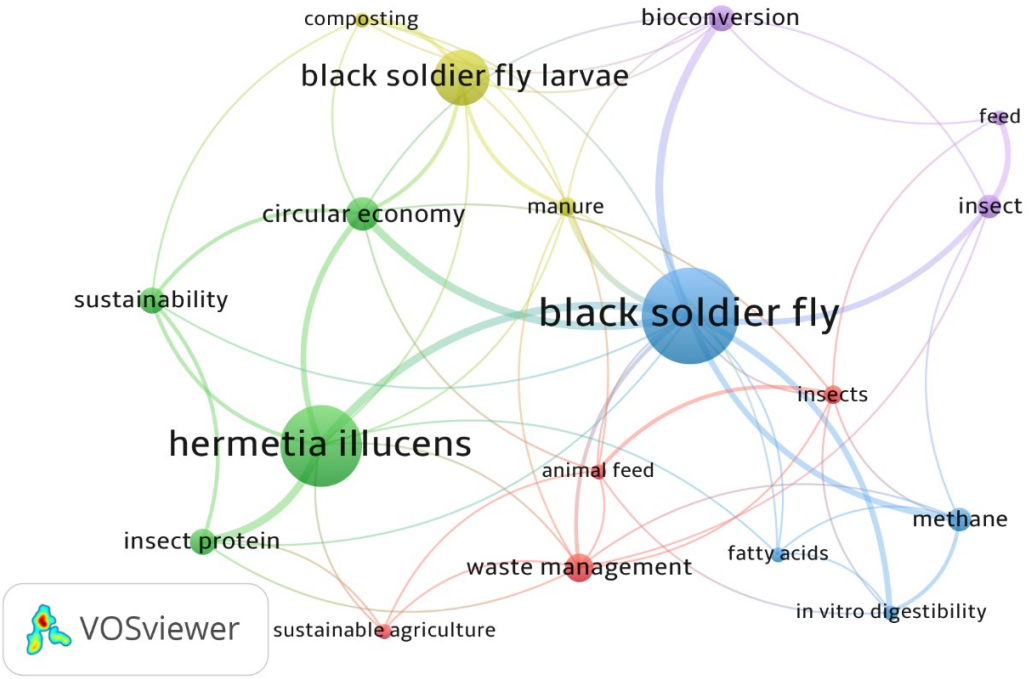

Figure 8. Co-occurrence of author keywords

Geographically, these institutions are located across Asia, Europe, and the Americas, highlighting the international and collaborative nature of this research. The relatively low individual contribution percentages (2–5%) indicate that knowledge development in this field is widely distributed among various institutions, reinforcing the multidisciplinary and global character of the research topic.

Research Trends and Sustainability Implications

The co-occurrence keyword map visualization (Figure 8) indicates that black soldier fly and Hermetia illucens serve as the central focus of research, with strong linkages to several key thematic clusters. These clusters encompass bioconversion and waste management (e.g., bioconversion, manure, waste management, methane), livestock feed utilization and nutritional aspects (animal feed, fatty acids, in vitro digestibility), as well as sustainability and circular economy considerations (sustainability, circular economy, insect protein, composting). The overlapping connections between clusters reflect the multidisciplinary nature of Black Soldier Fly (BSF) research, integrating environmental, biological, and nutritional dimensions within a unified research framework

Meanwhile, the trend topics graph (Figure 9) illustrates a shift in research focus from basic biology and taxonomy in the early period toward more applied studies over the past decade. Since around 2020, topics such as animal feed, ruminant, cattle, and sustainability have shown a marked increase in frequency, reflecting growing attention to the use of BSF as an alternative protein source in sustainable livestock systems. Overall, these visualizations collectively highlight the evolution of BSF research from a fundamental approach toward practical applications that support waste management, circular economy, and global food security.

The shift in Black Soldier Fly (BSF) research focus from basic biological studies toward sustainable applications is reflected in recent literature, which positions *Hermetia illucens* as a potential solution for organic waste management, alternative feed production, and contributions to the circular economy (Larisa, 2025; Kaczor et al., 2023).

Review studies indicate that BSF larvae efficiently convert organic waste into protein-rich biomass and nutrient fractions that can be utilized as livestock feed and organic fertilizer, with lower environmental impacts compared to conventional methods such as composting or anaerobic treatment (Mulianda et al., 2020). Additionally, ongoing research on substrate optimization and rearing conditions aims to enhance BSF productivity and nutritional value, underscoring the importance of a multidisciplinary approach to achieve effective utilization of BSF in sustainable agricultural systems and greenhouse gas mitigation (Mulianda et al., 2021).

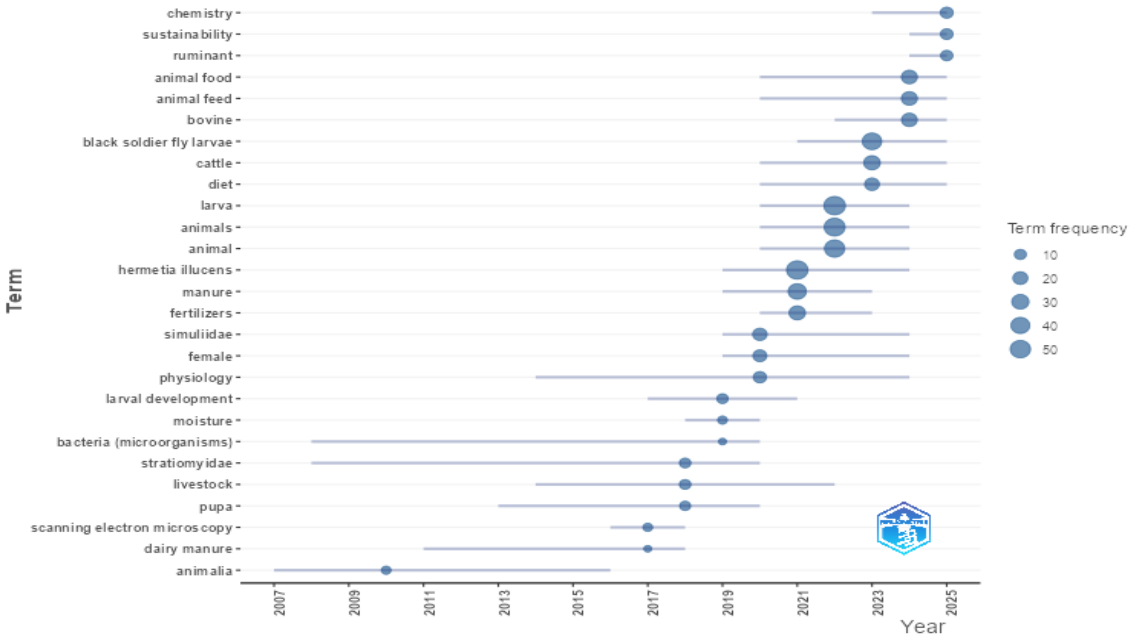

Figure 9. Trend topic analysis

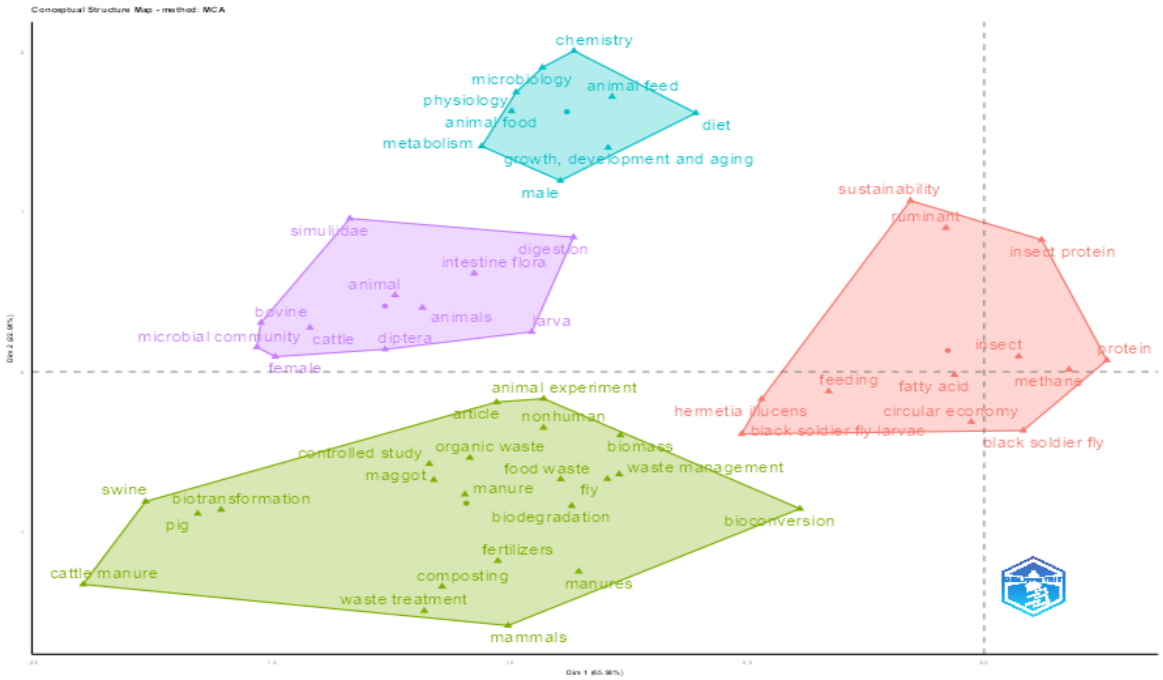

Figure 10. Conceptual structure map

Thematic Evolution and Sustainability Implications of Black Soldier Fly Research

The conceptual structure map (Figure 10) reveals four major thematic clusters in BSF research within ruminant nutrition. The feed- and sustainability-oriented cluster is characterized by keywords such as black soldier fly, black soldier fly larvae, insect protein, fatty acid, feeding, and ruminant, representing the current focus on utilizing BSF as an alternative protein source. Another cluster reflects bioconversion and waste management themes, including organic waste, manure, biodegradation, waste management, and bioconversion. A third cluster encompasses biological and digestive studies, with keywords such as larva, digestion, intestinal flora, and cattle. Finally, the nutrition and physiology cluster is marked by terms such as animal feed, physiology, metabolism, and growth, development, and aging, indicating an experimental approach to evaluating the nutritional value of BSF.

Numerical analysis presented in Table 4 reinforces the separation of these clusters, with keywords related to basic biology and waste management tending to have negative values on Dimension 1, whereas terms associated with insect protein, nutrition, and ruminants are located near or on the positive side of this dimension. Variation along Dimension 2 primarily distinguishes physiology and metabolism-based research from environmental and biotransformation themes. Overall, these results indicate a thematic shift in BSF research from a biological and environmental focus toward ruminant nutrition applications with a sustainability orientation.

Table 4. Trend analysis of research on BSF in Ruminant Nutrition

Word	Dim1	Dim2	Word	Dim1	Dim2
larva	-0.95	0.25	Methane	0.18	0.01
Hermetia illucens	-0.47	-0.17	Biotransformation	-1.6	-0.86
animals	-1.18	0.4	Digestion	-0.86	0.84
animal	-1.24	0.48	physiology	-0.98	1.75
article	-1.03	-0.19	chemistry	-0.86	2.01
diptera	-1.26	0.14	circular economy	-0.03	-0.31
nonhuman	-0.93	-0.35	composting	-1.14	-1.34
bsf	0.08	-0.37	fatty acid	-0.06	-0.02
bsf larvae	-0.51	-0.39	insect protein	0.12	0.83
manure	-1.09	-0.77	protein	0.26	0.07
fly	-0.79	-0.67	bioconversion	-0.39	-0.86
controlled study	-1.17	-0.58	cattle manure	-1.89	-1.33
cattle	-1.42	0.28	growth, development	-0.79	1.4
fertilizers	-1.02	-1.18	male	-0.89	1.2
manures	-0.85	-1.25	metabolism	-1.06	1.41
animal feed	-0.78	1.72	sustainability	-0.16	1.07
animal food	-0.99	1.63	biodegradation	-0.87	-0.84
bovine	-1.52	0.31	intestine flora	-1.07	0.62
insect	0.07	0.1	pig	-1.65	-0.89
waste manage	-0.77	-0.64	ruminant	-0.08	0.9
diet	-0.61	1.62	swine	-1.76	-0.81
biomass	-0.76	-0.4	feeding	-0.33	-0.12
simuliidae	-1.33	0.96	food waste	-0.89	-0.67
animal experiment	-0.93	-0.17	mammals	-1	-1.59
female	-1.49	0.09	microbial community	-1.53	0.15
maggot	-1.16	-0.68	microbiology	-0.93	1.9

Note: Dim1, dimension 1; Dim2, dimension 2

This thematic analysis reflects the significant growth of BSF research over the past decade, particularly on its use as an alternative protein source in sustainable livestock systems. *Hermetia illucens* larvae effectively convert organic waste into nutrient-rich biomass and can enhance feed quality while reducing reliance on conventional proteins such as soybean meal and fishmeal (Makkar et al., 2014; Cullere et al., 2018). Recent studies emphasize the need to consider livestock physiological and metabolic responses to insect protein, affecting digestibility, growth, and feed efficiency (Aksnes et al., 2023; Henry et al., 2015). CA map and Table 4 findings indicate that research now integrates nutritional and environmental aspects, including methane mitigation, supporting BSF's role in circular economy and sustainable agriculture strategies (Smetana et al., 2019; Mulianda et al., 2019).

Conclusions

Global research on Black Soldier Fly (*Hermetia illucens*) in ruminant nutrition has rapidly expanded, supported by increasing international collaboration and multidisciplinary approaches. Research focus has shifted from fundamental biology and waste management toward applied studies on feed efficiency, nutrient utilization, and sustainability. However, several areas remain under-explored, particularly the limited availability of in vivo studies under diverse production systems, the lack of detailed investigations on rumen metabolism and microbial interactions, and the absence of standardized protocols for evaluating BSF-based feeds. In addition, long-term effects on animal performance and product quality are still insufficiently documented.

Based on the observed thematic evolution, future research (2025–2030) is likely to focus on integrating BSF into precision feeding systems, advancing studies on rumen microbiome and metabolic pathways, and evaluating its role in reducing environmental impacts such as methane emissions. These directions are expected to strengthen the scientific basis and support the broader adoption of BSF as a sustainable feed resource in ruminant production systems.

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