J. Entomol. Res. Soc., 25(1): 193-213, 2023 *Research Article*
Doi: 10.51963/jers.v25i1.2340 *Online ISSN:2651-3579*

The Research Hotspots and Frontiers of Black Soldier Fly during 1994-2021: A Bibliometric Analysis

Shuang LIU[1] Huilin LANG[2] Jianwei HAO[3*]
Wenfeng HU[4] Songling LI[5]

[1,2]Institute of Loess Plateau, Shanxi University, Wucheng Road 92, Xiaodian District 030006, Taiyuan, CHINA
[3]Department of Biological Science and Technology, Jinzhong University, Jinzhong 030600, CHINA
[4]College of Food Science, South China Agriculture University, Guangzhou 510642, CHINA
[5]Qinghai Academy of Agricultural and Forestry Sciences, Xining 810000, CHINA
e-mails: [1]liushuang@sxu.edu.cn, [2]1986833496@qq.com, [3]*1346994217@qq.com
[4]johnwfhu@qq.com; [5]465883114@qq.com
ORCID IDs: [1]0000-0001-8148-1974, [2]0009-0003-7839-2876, [3]0009-0002-9390-0149, [4]0009-0004-9290-6674; [5]0009-0001-1334-5257
*Corresponding author

ABSTRACT

Black soldier fly (BSF) studies have attracted increasing scientific attention because of their role in determining sustainability. However, there exists rare quantitative analyses of the scientific literature on research of BSF, especially for visual analyzing from the systematical and bibliometric perspective has not been reported. Therefore, the investigation on the temporal development, scientific collaboration, research hotspots and frontiers in terms of BSF over the last 28 years (1994-2021) is executed for the first time. Combined with the Web of Science Core Collection database, this study collected 914 literatures from 1994 to 2021 that were conducted co-occurrence, co-citation and cluster analysis via CiteSpace software. The main findings are as follows: Firstly, research on BSF has advanced rapidly during the recent five years and Italy, USA and China were the three core force leaders countries with the high publications, centrality and cooperation degrees. In addition, Huazhong Agr Univ showed the core force ranked the third in the world of BSF research, which had high publications and strong cooperation with international institutions. Furthermore, in terms of keyword co-occurrence, time-zone and burst analysis delineated biological characteristics, application and management of BSF larvae were the main research themes. And early studies concentrated on BSF development and breeding, and current hotspots include exploiting BSF larvae as animal feed and recycling organic wastes. Additionally, based on co-cited references cluster analysis, it was concluded that the bioconversion and animal feed using the BSF larvae will still be the focus research fields in the near future, and the technical improvement on the efficiency of bioconversion, integrating the healthy, safety and eco-friendly that future studies should focus on, supporting policy making that indicate the prospective research field on BSF and it's applications.

Keywords: Hermetia illucens, Knowledge Mapping, Evolution of Frontiers, CiteSpace

Liu, S., Lang, H., Hao, J., Hu, W., & Li, S. (2023). The research hotspots and frontiers of black soldier fly during 1994-2021: a bibliometric analysis. *Journal of the Entomological Research Society*, 25(1), 193-213.

Received: September 25, 2022 *Accepted: March 01, 2023*

INTRODUCTION

Rapid worldwide population increase will reach 10 billion by 2050. This rise in global population is causing deep changes from industrialization to urbanization that have not been witnessed in a century, yet it is required to concern about the energy crises and environmental challenges (Zhang et al, 2021). Because of the predicted 58% and 70% increases in milk and meat consumption in 2050 compared to 2010 due to rising per capita income, there would be a massive protein shortage in the world by that year (Makkar, Tran, Heuzé, & Ankers, 2014; Finley, 2020). The vegetable and meat expected to increased 265 million per year, to meet this demand, global feed and food productions would need to increase to 25—70% from existing land and energy resources (Liland et al, 2021; Traksele et al, 2021). The increased demand for meat, milk, and animal byproducts, animal products and livestock output are predicted to increase, as is livestock manure and food waste (Melikoglu, Lin, & Webb, 2013; Makkar, Tran, Heuzé, & Ankers, 2014; Kim et al, 2021), which will result in more serious environmental problems.

Presently, the standard techniques of composting, co-composting, or anaerobic digestion currently only process 20 to 30% of animal and poultry manure (Awasthi et al, 2019). Then using the productions as animals' feed, soil organic fertilizer, or the methane energy production. However, these techniques take a long time, produce low-quality goods, and are constrained by land availability and expensive initial investment costs (Fan, Yang, Fang, & Zhang, 2019). For the food waste, most was treated by landfill disposal and incineration, a small part was treated by anaerobic digestion (Kim et al, 2021). The livestock manure and food waste treated both by traditional method or unprocessed could induce environmental problems, such as pose risks to water, soil and air quality, and the spread of pathogens (Kong et al, 2018; Ravindran et al, 2019). Therefore, there's an increasing demand for better management of livestock manure and food waste. The use of insects, such as the black soldier fly to treat excess manure and recycle nutrients into the food system is therefore gaining popularity.

It is common in tropical and temperate locations, although the black soldier flies (BSF), (*Hermetia illucens* L.) (Diptera: Stratiomyidae) may also be found in a wide range of climates (warm, tropical and subtropical) around the globe (Rozkosny, 1983; Gold, Tomberlin, Diener, Zurbrügg, & Mathys, 2018; Lalander, Diener, Zurbrügg, & Vinnerås, 2019). Organic waste is the primary food source for all four stages of the BSF life cycle: egg, larva, pupa, and imago (Li et al, 2011). According to the relevant literature, the researches about BSF mainly including the following aspects: (*İ*) BSF larvae can consume various decaying organic wastes (e.g., livestock manures, food and kitchen waste, and plant materials etc.) and convert these waste into organic fertilizer containing the antimicrobial peptide activity that can inhibit pathogens (Lalander et al, 2013; Li & Zhao, 2015; Elhag et al, 2017) and with lower content of heavy metal and pathogens in their growing substrate (Wynants et al, 2019; Wu, Liang, Wang, Xie, & Xu, 2021; Wang, Wu, Cai, Geng, & Xu, 2021). Therefore, the BSF shall be deemed as a continuable tool of animal manure management. (*İİ*) The BSF

larvae with the high protein content which can be used as high-quality good nutrition source of animal feed that can better instead of the traditional feed, especially used for feeding the fish (Gao et al, 2019; Lalander, Diener, Zurbrügg, & Vinnerås, 2019). (*iii*) The BSF larvae can collect lipids required for biodiesel production, which is superior to the oil crops that are currently utilized as biodiesel sources due to the BSF's shorter life cycle, greater fertility, and smaller acreage requirements for production (Li et al, 2015; Wang & Shelomi, 2017; Kim et al, 2021).

In the past two decades, there are many research publications on BSF. However, in some degree, it is not easy for researchers to quickly grasp the hotspots and frontiers in the future research trend and direction. Bibliometrics, a new data-driven method (Broadus, 1987; Qin et al, 2021), has assumed an ever-increasing importance in scientific study in recent years (Aleixandre-Benavent, Aleixandre-Tudó, Castelló-Cogollos, & Aleixandre, 2017). For example, it can be used to provide data on the most productive authors, institutions, and countries, in terms of identifying the collaboration between authors, institutions, and countries (Li & Zhao, 2015), determining the of research areas and recognizing the future research trends and fields, and depicting the hotspots and frontiers (Zhi et al, 2015; Zhang, Zhang, Shi, & Yao, 2017). Given that the large mounts of literature need to be analyzed, the computer analysis and mapping software are required, such as the VOSviewer, CitNetExplorer, HistCite and CiteSpace etc. CiteSpace is the current mainstream software due to its' easy operation system and multi-function (Chen, 2006).

Therefore, we use CiteSpace tools and methodology to conduct a bibliometric study of BSF research published between 1994 and 2021 to gain insights into the future of BSF research by evaluating BSF research. The current research hotspots were investigated using the frequency and interactive to analyze the top authors's situation and cooperation, and main institutions and countries/regions. Furthermore, it is possible to identify changes in the BSF's dynamic variation and trend by examining keywords in reference citations and the current research focuses and knowledge gaps. The examination of evolution and the identification of hotspots offers a comprehensive view of the evolution of this issue. Filling the gaps in BSF knowledge, findings and recommendations from the BSF research are provided herein.

METHODS

Data collection and processing

As a component of the Web of ScienceCore Collection (WoSCC), SCI-expand was used to collect data on English-language literature for this investigation. The WoS Core Collection was selected since it contains the most complete database and high-quality research data, and the most influential and relevant journal with a lengthy history (Harzing & Alakangas, 2016; Olawumi & Chan, 2018; Qin et al, 2021). An advanced search was performed in the WoS Core Collection database, the retrieval parameter as Topic (TS) = "black soldier fly" was set to search for literature in the Title, Abstract, Author Keywords and Keywords Plus fields during Jan 1, 1994 to Dec 31, 2021. As

a result, a total of 953 records were obtained, after eliminating the duplicate records, 914 records were ultimately obtained, which including 775 articles, 79 reviews and 40 proceedings papers. Fig. 1 summarizes the acquired search results.

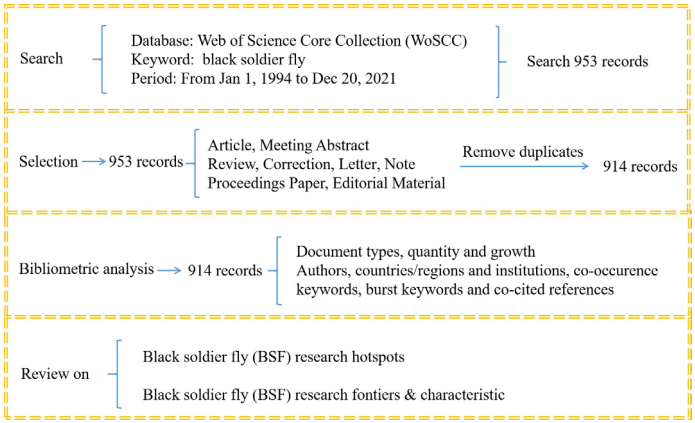

Figure 1. Document selection and flow diagram of BSF.

Bibliometric analysis

Visualization of knowledge can be done with CiteSpace, a software application (Chen, 2004). It can be using for analyzing research hotspots and identifying frontier, and future trend in visualization forms, which based on the co-occurrence analysis, co-citation analysis, and institution and author collaboration analysis (Chen, 2016). Thus, the gathered WoSCC documents were further examined in this study via CiteSpace 5.8 R3. The pruning method was used for the minimum spanning tree and pruning sliced networks, and the thresholds of C, CC, and CCV were set to (2, 2, 20), (4, 3, 30), and (4, 3, 30), where C represents the frequency or lowest cited occurrence, CC represents the co-citation times or collinearity in a particular time slice, and CCV represents the co-citation or collinearity rate (Yang & Meng, 2019). In the visualization analysis, the objects are depicted as nodes, which might represent a keyword, an author, an institution, or a country; the larger the node, the higher the frequency of occurrence of the keyword (Yang & Meng, 2019). A co-citation relationship between two nodes is denoted by a line that connects the two nodes; the line's color signifies the first time that the two nodes are mentioned together, and the line's length and thickness reflect the strength of the link that exists between the two nodes (Xie, 2015; Liu, 2017).

RESULTS AND DISCUSSION

Documents types and quantity analysis

From 1994 to 2021, the WoSCC database yielded a total of 914 documents. The total accumulated quantity of the documents are accumulated year by year (red line) and the quantity of the documents for each year (blue histogram) are summarized (Fig.

2a). Since 1994, the number of publications in the BSF sector has steadily increased, reaching 914 pieces at the end of the year (Fig. 2a). A total of 15 documents were published prior to 2008, indicating that the BSF field was still in its early stages of development. After that, compared to prior years, there was a modest development from 2008 to 2016. This stage saw the publication of a total of 89 documents. For the period from 2017 to 2021, the number of documents published increased significantly, accounting for 88.62% of the whole number, compared to the previous year. According to these findings, BSF is getting more and more popular among academics across the globe.

A total of seven sorts of documents were categorized according to the type of document collected, which included a book chapter and a letter (Fig. 2b). The "article" type came out on top with 84.79 % of the vote, while the "review" type came in second with 8.64 % of the vote. Note that the proportion of "review" type BSF field papers was higher than other categories such as proceeding papers, early access material and editorial content. Researchers in the field of BSF have begun to summarize and draw conclusions based on the current research status, indicating that the field's development and progress have been promoted. This also suggests that future publications will probably concentrate on BSF research.

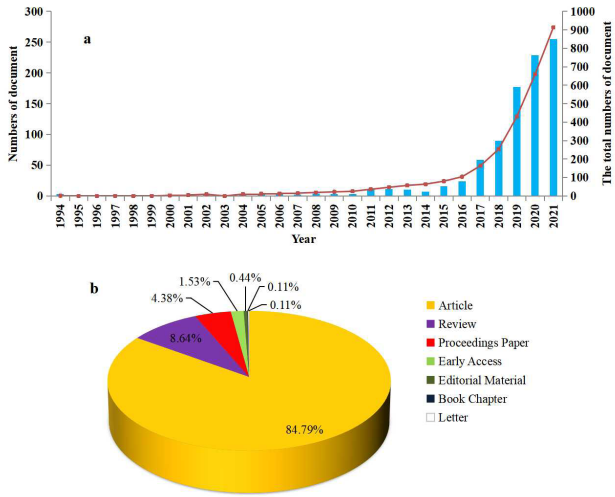

Figure 2. Distribution of the number of BSF-related publications (a) and proportion of publication types (b) during the years of 1994-2021.

The characteristics' analysis of BSF research

The characteristics of author group

A total of 467 authors were found to be involved in BSF research. The top 20 conductive authors are summarized according to numbers (Table 1). Jeffery K Tomberlin was the author with the highest number of publications (52), accounting for 3.43%, followed by Ziniu Yu (34, 2.24%), Laura Gasco (33, 2.18%), Longyu Zheng

(30, 1.98%), and Jibin Zhang (29, 1.91%). As shown in Table 1, The high-yield authors mainly came from Italy, USA and China. Furthermore, Ziniu Yu, Longyu Zheng and Jibin Zhang, three of high conductive authors were all from China, but degrees of centrality were low (0.01, 0.01 and 0.02 respectively). The highest degrees of centrality is 0.13, 0.10 and 0.05 for Jeffery K Tomberlin, Laura Gasco and Chrysantus M Tang, respectively (Table 1), which indicating these authors have a pivotal influence in the BSF research field.

According to author co-appearance analysis, the network has 467 nodes, 1230 lines, and 0.0113 density (Fig. 3). The academic teams of Yu, Zheng, Zhang, and Cai have the most publications and collaboration degrees (52 and 55, respectively) of any of the academic teams in this analysis, who are in close contact with BSF research (Fig. 3; Table 1). The academic teams of Gai, Schiavone, Olivotto, Dabbou, Biasato, and Randazzo are in constant communication and cooperation with the research teams of Gasco, who has the third-highest production and the highest degree of interaction (33, 33). Tang is the seventh most prolific author (20, 18), and the academic research teams in close contact and collaboration are Vanloon, Ekesi, Subramanian, Dicke, and Khamis (Fig. 3; Table 1). It is worth noting that there are primarily three large cooperation author groups, namely Tomberlin, Gasco, and Tang, and that the inter-cooperation of the groups is much stronger, whereas their academic connections are very weak based on the author groups.

Table 1. The performance of top 20 most productive authors.

Rank	Author	Publications	Centrality	Cooperation degree	Proportion (%)
1	JEFFERY K TOMBERLIN	52	0.13	55	3.43
2	ZINIU YU	34	0.01	43	2.24
3	LAURA GASCO	33	0.1	33	2.18
4	LONGYU ZHENG	30	0.01	31	1.98
5	JIBIN ZHANG	29	0.02	24	1.91
6	MINMIN CAI	20	0	20	1.32
7	CHRYSANTUS M TANGA	20	0.05	18	1.32
8	FRANCESCO GAI	19	0	18	1.25
9	ACHILLE SCHIAVONE	19	0	17	1.25
10	JOOP J A VAN LOON	18	0.02	17	1.19
11	IKE OLIVOTTO	16	0.01	16	1.06
12	QING LI	14	0	16	0.92
13	SUNDAY EKESI	13	0	15	0.86
14	SEVGAN SUBRAMANIAN	13	0	15	0.86
15	MARCEL DICKE	13	0	15	0.86
16	SIHEM DABBOU	12	0	15	0.79
17	ILARIA BIASATO	12	0	15	0.79
18	WU LI	11	0	15	0.73
19	BASI LIO RANDAZZO	11	0	15	0.73
20	FATHIYA M KHAMIS	11	0	15	0.73

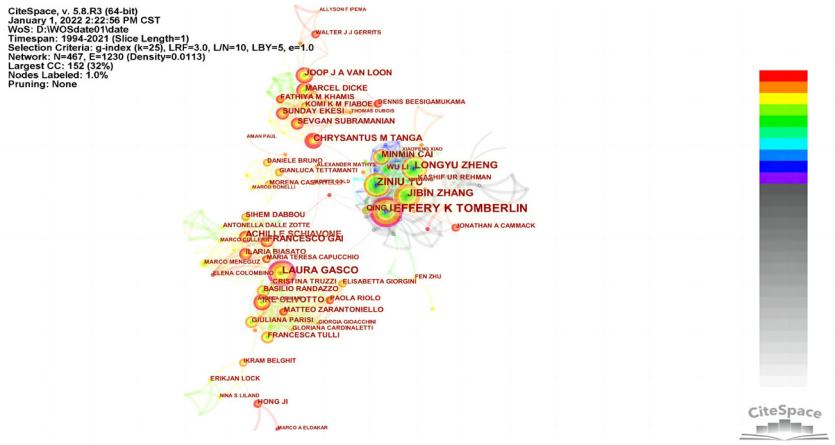

Figure 3. Authors of BSF-related stuides from 1994 to 2021.

The characteristics of different institutions

Findings from this search were depicted in Fig. 4 (320 institutions were found). Since there are 320 nodes and 620 links on the BSF research institution map, it may be concluded that the majority of BSF research institutions are involved in independent research (Fig. 4). It is shown in Table 2 that the top twenty most productive institutions are. Among them, the Texas A&M Univ ranked first with 69 publications, accounting for 5.49%, followed by Huazhong Agr Univ (55, 4.38 %), Univ Turin (32, 2.55%), and Wageningen Univ & Res (32, 2.55%), with the degree of centrality is 0.30, 0.11, 0.14 and 0.13 respectively. The highest centrality indicating these institutions have a pivotal impact in the BSF research field. However, the publications of the other institutions are ranging from 27 to 12, and all the degree of centrality were lower than 0.10 (Table 2). A visual network analysis of co-occurrence of the academic cooperation of institutions showed that the Texas A&M Univ, Huazhong Agr Univ, Univ Turin and Wageningen Univ & Res are closely relevant to international institutions with the cooperation degrees of 44, 26, 25 and 22 respectively. The CNR and Wageningen Univ both ranked 5th in the cooperation network, the other institutions with the publications below or equal to 21 ranked 6th, 7th, 8th and 9th in the cooperation network (Fig. 4; Table 2).

Table 2. The performance of top 20 most productive institutions.

Rank	Institution	Publications	Centrality	Cooperation degree	Proportion (%)
1	Texas A&M Univ	69	0.30	44	5.49
2	Huazhong Agr Univ	55	0.11	26	4.38
3	Univ Turin	32	0.14	25	2.55
4	Wageningen Univ & Res	32	0.13	22	2.55
5	CNR	27	0.01	17	2.15
6	Wageningen Univ	26	0.05	17	2.07
7	Univ Padua	21	0.03	16	1.67
8	Northwest A&F Univ	20	0.00	15	1.59

table continued

Rank	Institution	Publications	Centrality	Cooperation degree	Proportion (%)
9	Univ Modena & Reggio Emilia	18	0.01	15	1.43
10	Univ Milan	17	0.03	15	1.35
11	Inst Marine Res	17	0.03	14	1.35
12	Int Ctr Insect Physiol & Ecol	15	0.01	14	1.19
13	Univ Politecn Marche	14	0.01	14	1.11
14	Eawag Swiss Fed Inst Aquat Sci & Technol	14	0.07	13	1.11
15	Univ Udine	14	0.00	13	1.11
16	Swedish Univ Agr Sci	14	0.02	13	1.11
17	Univ Parma	13	0.02	13	1.04
18	Chinese Acad Sci	13	0.03	13	1.04
19	Katholieke Univ Leuven	13	0.02	13	1.04
20	Univ Ghent	12	0.01	13	0.96

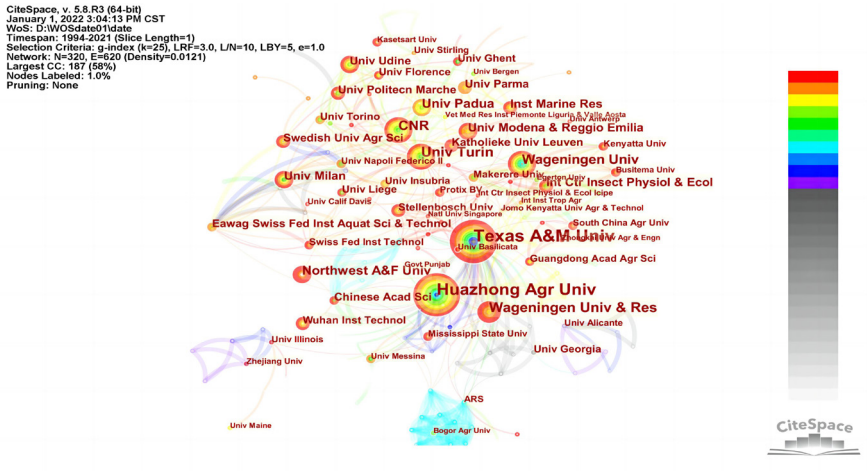

Figure 4. Institutions of BSF-related stuides from 1994 to 2021.

The characteristics of different countries/regions

BSF-related articles have been submitted by researchers in 85 different countries throughout the world. Countries and regions with the most productive economies are listed in Table 3. Italy published the most publications (161), accounting for 11.54%, higher than that of USA (155, 11.11%) and China (the third, 147, 10.54%), followed by the Netherlands (80, 5.73%), Germany (53, 3.80%) and Belgium (53, 3.80%). Italy, USA and China with the degree of centrality is 0.29, 0.15 and 0.13 respectively, indicating that these three country have a pivotal impact in the BSF research field. Although the publications of GERMANY (53 publications), KENYA (32 publications), ENGLAND (29 publications) and SOUTH AFRICA (25 publications) was not so abundant, but the degree of centrality is 0. 11, 0.14, 0.14 and 0.10, which means these countries also have a pivotal impact in the BSF research field (Table 3; Fig. 5). However, the publications of NETHERLANDS, BELGIUM, SWITZERLAND and MALAYSIA were abundant enough (ranging from 29 to 80 publications), all the degree of centrality were

lower than 0.10 the centrality (ranging from 0.05 to 0.09). The cooperation degrees of ITALY, USA and CHINA were 37, 31 and 30 respectively, indicating they all have strong cooperation with other countries/regions (Table 3; Fig. 5). Although the KENYA, ENGLAND and SOUTH AFRICA have higher centrality values, the cooperation degrees were only ranging from 19 to 22, which indicating that these countries also need to improve their cooperation with other countries. Developing countries/regions account for only six of the top twenty countries/regions, lagging behind developed countries/regions somewhat. Therefore, researchers in developing countries shall work along with those in developed ones to improve their research capabilities in BSF.

Table 3. The performance of top 20 most productive countries.

Rank	Country	Publications	Centrality	Cooperation degree	Proportion (%)
1	ITALY	161	0. 29	37	11.54
2	USA	155	0. 15	31	11.11
3	PEOPLES R CHINA	147	0. 13	30	10.54
4	NETHERLANDS	80	0. 08	29	5.73
5	GERMANY	53	0. 11	28	3.80
6	BELGIUM	53	0. 06	26	3.80
7	SWITZERLAND	38	0. 09	25	2.72
8	MALAYSIA	34	0. 05	23	2.44
9	KENYA	32	0. 14	22	2.29
10	ENGLAND	29	0. 14	22	2.08
11	AUSTRALIA	28	0.02	22	2.01
12	SPAIN	27	0. 03	21	1.94
13	INDONESIA	26	0.01	21	1.86
14	POLAND	25	0.00	20	1.79
15	SOUTH KOREA	25	0.00	20	1.79
16	CANADA	25	0. 02	20	1.79
17	SOUTH AFRICA	25	0. 10	19	1.79
18	NORWAY	25	0.00	19	1.79
19	TAIWAN	24	0. 02	19	1.72
20	BRAZIL	23	0. 02	18	1.65

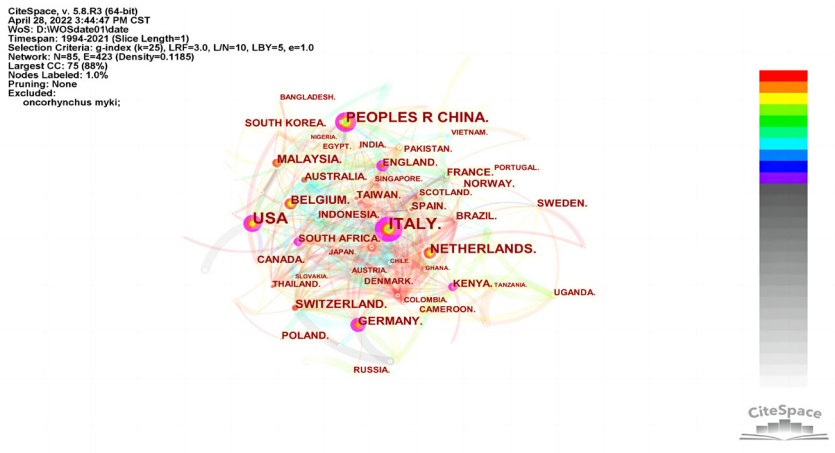

Figure 5. Countries of BSF-related studies from 1994 to 2021.

Hotspots and frontiers of BSF Research

Keywords co-occurrence

Keywords can not only reflect the hot spots and topics but also reflect the direction and the development of research frontiers over a period. Fig. 6 showed the keywords co-occurrence networks for three time periods. A total of 438 keywords were obtained. The first time period from 1994 to 2007 network consisted of 38 nodes and 114 links, and only 38 keywords were obtained in this time period. The keywords of “diptera”, “fly”, “fly diptera” and “hermetia illucen” had a total frequency of 10. The second high frequency keyword was “larvae (Frequency=6)” (Fig. 6a; Table S1). The second time period from 2008 to 2016 network consisted of 173 nodes and 699 links, and a total of 173 keywords were obtained in this time period. The keywords of “black soldier fly”, “flies diptera”, “stratiomyidae”, “diptera”, “hermetia illucen”, “fly”, “hermetia illucens diptera” and “diptera stratiomyidae” had a total frequency of 85. The second high frequency word was “larvae (Frequency=21)” (Fig. 6b; Table S1). However, the third time period from 2017 to 2021 network consisted of 327 nodes and 1887 links, and a total of 334 keywords were obtained in this time period. The keywords of “black soldier fly”, “hermetia illucen”, “diptera stratiomyidae” and “diptera” had a total frequency of 493. The followed keywords of “growth performance”, “growth” and “performance” had a total frequency of 243. Other high frequency keywords were “insect (119)”, “food (115)”, “feed (107)”, “larvae (103)”, “protein (88)”, “rainbow trout (77)”, “fish meal (72)” (Fig. 6c; Table S1).

Table S1. The performance of top 20 keywords for 1994 to 2007, 2008 to 2016 and 2017 to 2021 time periods.

1994-2007				2008-2016				2017-2021			
NO.	Freq.	Keyword	Cent.	NO.	Freq.	Keyword	Cent.	NO.	Freq.	Keyword	Cent.
1	6	larvae	1.06	1	21	black soldier fly	0.40	1	176	black soldier fly	0.05
2	4	diptera	1.02	2	21	larvae	0.31	2	144	hermetia illucens l.	0.02
3	4	management	0.03	3	15	flies diptera	0.20	3	125	growth performance	0.07
4	2	behavior	0.29	4	14	stratiomyidae	0.15	4	119	insect	0.03
5	2	fly	0.11	5	12	oviposition	0.16	5	115	food	0.03
6	2	milk	0	6	11	escherichia coli	0.18	6	107	feed	0.03
7	2	hermetia illucen	0	7	11	diptera	0.18	7	103	larvae	0.06
8	2	pupae	0	8	10	postmortem interval	0.01	8	88	protein	0.05
9	2	fly diptera	0	9	8	hermetia illucen	0.16	9	77	rainbow trout	0.05
10	1	atlantic salmon	0.15	10	7	growth	0.05	10	72	fish meal	0.03
11	1	acid	0.15	11	6	fly	0.05	11	71	tenebrio molitor	0.04
12	1	diet	0.15	12	6	hermetia illucens diptera	0.09	12	66	conversion	0.05
13	1	bacteria	0.01	13	5	manure	0.01	13	65	growth	0.05
14	1	calliphora erythrocephala	0.01	14	5	meal	0.05	14	64	escherichia coli	0.05
15	1	bovine manure	0.01	15	5	rainbow trout	0.10	15	60	diet	0.04
16	1	insect	0.01	16	5	life history	0.07	16	55	diptera stratiomyidae	0.04
17	1	destruction	0.01	17	4	carrion	0	17	53	performance	0.02
18	1	oviposition	0	18	4	food	0.03	18	53	diptera	0.02
19	1	fish	0	19	4	diptera stratiomyidae	0.04	19	51	prepupae	0.02
20	1	feed	0	20	4	conversion	0.01	20	49	waste	0.02

Freq.= Frequency; Cent.= Centrality

From the analysis above, we found that during the whole time (from 1994 to 2021), the keywords both focused on “larvae” and “diptera”, “fly diptera”, “hermetia illucen”, “black soldier fly”, “fly” and “diptera stratiomyidae” etc. that related to “black soldier fly”, which have high frequencies and represent the research on biological characteristics of BSF and the application of it’s larvae, especially on BSF growth and breeding including “oviposition”, “growth”, “pupae”, “prepupae” and “life history” (Fig. 6; Table S1). In addition, from other keywords such as “protein”, “food”, “feed”, “meal”, “fish meal” and “rainbow trout” that with relatively high frequency, we found that more and more researches focused on the applications of BSF larvae, especially on the nutrition of BSF as the feed of animals, especially as fish feed (Fig. 6b, c; Table S1). Notably, other keywords related to BSF larvae applications including “manure”, “dairy manure”, “waste”, “food waste”, “conversion”, “nutrient digestibility” and “biodiesel production”, which indicated that the applying the BSF to deal with organic waste (food and manure) and to produce the biodiesel attract researchers’ attention.

Keywords time-zone visualization

The analysis of changes of keywords over time (1994-2021) (Fig. 7; Table S2) was performed to determine the overall trend of BSF research. The results showed that there were various high frequency hot keywords in BSF research, with the exception of the period between 1995 and 2006. The following is evidenced by the findings that are presented in Fig. 7: (*İ*) The focus on BSF development and breeding shows that BSF research is biological. For instance, Tomberlin, Sheppard, & Joyce (2002) fed BSF three different larval diets to study preimaginal development and adult life-history features. Diet had little effect on preimaginal development or survival past the prepupal stage, according to the findings. However, all diets had lower adult emergence rates than the wild population. It took 40 to 43 days from egg to adult for individuals raised at 27°C, with the larval stage lasting between 22 and 24 days. Furthermore, 96% of larvae reached the prepupal stage, however only 21-27% of adults emerged from the eggs. (*İİ*) Studies on the usage of BSF larvae in various applications have been rising since 2007, notably with regard to the management of organic waste and as animal feed. For instance, Wang & Shelomi (2017) studied BSF’s that are capable of efficiently converting diverse organic resources, including food waste and manure, into insect biomass. Researchers Murawska and colleagues (2021) discovered that supplementing soybean meal protein with BSF larvae meal in broiler chicken diets at a percentage of more than 50% deteriorated carcass quality and meat sensory quality. (*İİİ*) New research focus at BSF include biodiesel, essential oils, greenhouse gas emissions, antibacterial peptides, and genes that confer resistance to antibiotics. For example, when employing non-catalytic transesterification to extract BSF larval lipids, Jung et al (2022) obtained 94.1 wt% biodiesel, and the fuel characteristics of BSF larvae were in line with Korea and EU biodiesel fuel specifications. Through *Hermetia illucens* larvae, Matos et al (2021) found that methane emissions from the bioconversion of animal dung were 86% lower than those from controls. Fig. 7 also

shows that, the number of studies on BSF is increasing significantly since 2007. As research has become more in-depth, studies on BSF have become increasingly detailed, diverse, and systematic.

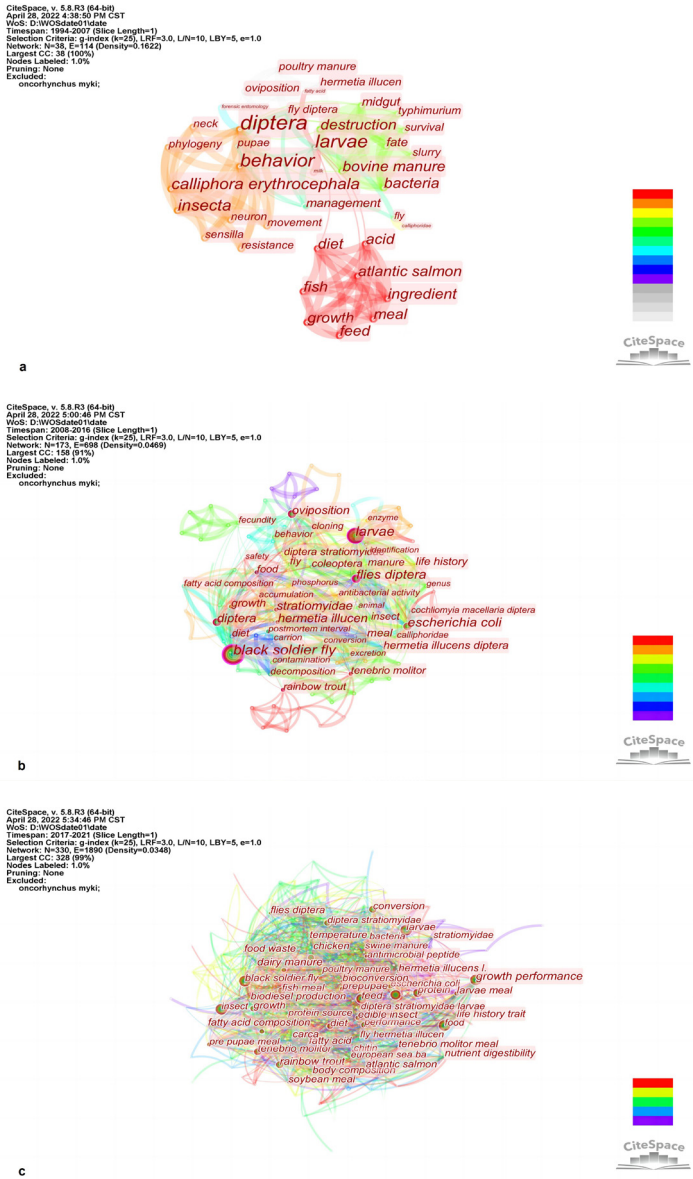

Figure 6. Keywords co-occurrence maps of publications in BSF-related studies for different time periods. a) Initial budding phase from 1994 to 2007. b) Primary growth phase from 2008 to 2016. c) Rapid development phase from 2017 to 2021.

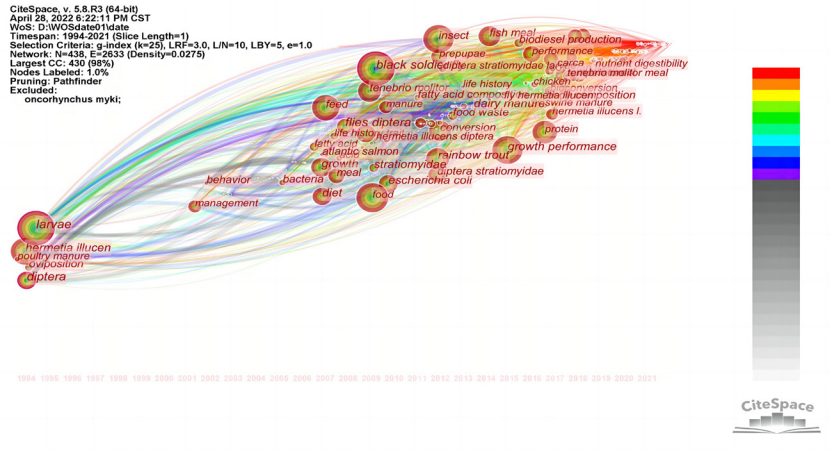

Figure 7. The time-zone view of WoS BSF hotspots keywords from 1994 to 2021.

Table S2. The information related to the keywords from 1994 to 2021.

Freq.	Cent.	Keyword	Year
197	0.16	black soldier fly	2009
154	0.05	hermetia illucen	1994
130	0.16	larvae	1994
127	0.06	growth performance	2015
122	0.04	insect	2012
119	0.03	food	2009
110	0.03	feed	2007
88	0.03	protein	2017
82	0.07	rainbow trout	2012
75	0.04	tenebrio molitor	2009
75	0.09	escherichia coli	2010
73	0.03	fish meal	2014
73	0.07	growth	2007
70	0.04	conversion	2012
68	0.15	diptera	1994
65	0.04	diet	2007
59	0.04	diptera stratiomyidae	2012
55	0.02	performance	2016
53	0.02	prepupae	2012
51	0.09	flies diptera	2008
50	0.02/0.01	manure/waste	2010/2009
46	0	nutritional value	2018
41	0.07/0.04/0.02	stratiomyidae/meal/management	2009/2007/2001
40	0.02	larvae meal	2017
39	0.01/0.01	pre pupae meal/digestibility	2018/2017
38	0.01	chitin	2017
37	0.03	hermetia illucens l.	2017
34	0.03	edible insect	2017

table continued

Freq.	Cent.	Keyword	Year
33	0.01/0.01	extraction/chicken manure	2017/2011
30	0.02/0.01	protein source/soybean meal	2018/2017
27	0.02/0.01/0.01/0.01/0.03/0.02	quality/reduction/replacement/bioconversion/life history trait/fatty acid	2018/2018/2018/2017/ 2008/2007
26	0.01/0.05	life cycle assessment/food waste	2018/2012
25	0.05	oviposition	1994
23	0.03/0.06/0.05	body composition/biodiesel production/bacteria	2016/2015/2004
22	0.04/0.04	temperature/acid	2017/2007
20	0.03/0.03/0.01	diptera stratiomyidae larvae/lipid/diversity	2015/2011/2011
18	0.03/0.02/0.04/0.02/0.02/0.05	nutrient digestibility/oil/chicken/chitosan/postmortem interval/atlantic salmon	2018/2018/2016/2016/ 2015/2009/2007
17	0.01/0.03	european sea ba/life history	2019/2013
16	0.01/0.01/0.05/0.05	impact/expression/dairy manure/hermetia illucens diptera	2019/2015/2013/2009
15	0.01/0.02/0.02/0.01/0.01/0.01	musca domestica/nutritional composition/carca/heavy metal/amino acid/animal feed	2019/2018/2017/2017/ 2016/2013
14	0/0.01/0.02/0.07	nitrogen/gut microbiota/decomposition/behavior	2017/2011/2009/2002
13	0.01/0/0.02/0.02	efficiency/insect meal/tenebrio molitor meal/swine manure	2020/2018/2017/2015

Freq.= Frequency; Cent.= Centrality

Burst keywords analysis

The analysis of burst keywords can quantitatively the focus and emerging hotspots and research frontiers. The burst keywords with the strength citation bursts implies the focus intensity of the field. We found that studies related to biological characteristics of BSF were the main topics during the whole time (1994-2021) especially before 2018, among which “oviposition” (strength: 6.59 in 1994-2016), “behavior” (strength: 2.14 in 2002-2016), “black soldier fly” (strength: 1.91, 2010-2013), “soldier fly diptera” (strength: 2.16, 2017-2018) ,“larvae”(strength: 5.37 in 2013-2016) and “life history” (strength: 2.52 in 2013-2016), “life history trait” (strength: 2.83 in 2017-2018),“escherichia coli”(strength: 3.35 in 2010-2015) received major focus. The applications of BSF larvae were also the research hotspots and frontiers, especially using as animal feed, the keywords “meal” with strength of 1.92 during 2007-2018, and studies related to other applications such as “rice straw”, “microalgae”, “food”, and “dairy manure”, “food waste”, “nutrient digestibility”, “nutrient composition” and “optimization” were the emerging active topics, especially in the last five years from 2017 to 2021 (Fig. 8). In addition, some new burst keywords emerged as the active topics, such as “accumulation” (strength: 2.16) emerged in 2015-2018, and “safety”

(strength: 3.3) emerged in 2016-2017.

NO.	Keyword	Strength	Begin	End	1994-2021
1	oviposition	6,59	1994	2016	
2	management	2,69	2001	2002	
3	fly	4,51	2002	2016	
4	behavior	2,14	2002	2016	
5	fly diptera	1,98	2002	2010	
6	calliphoridae	2,41	2005	2016	
7	meal	1,92	2007	2018	
8	flies diptera	7,38	2008	2018	
9	stratiomyidae	7,43	2009	2017	
10	postmortem interval	6,22	2009	2013	
11	hermetia illucens	3,4	2009	2014	
12	carrion	2,71	2009	2011	
13	coleoptera	1,67	2009	2016	
14	escherichia coli	3,35	2010	2015	
15	black soldier fly	1,91	2010	2013	
16	identification	3,05	2011	2018	
17	cloning	1,92	2011	2015	
18	cochliomyia macellaria	1,86	2011	2016	
19	diptera	4	2012	2017	
20	larvae	5,37	2013	2016	
21	life history	2,52	2013	2016	
22	accumulation	2,16	2015	2018	
23	safety	3,3	2016	2017	
24	rice straw	3,79	2017	2018	
25	life history trait	2,83	2017	2018	
26	microalgae	2,71	2017	2018	
27	carca	2,57	2017	2018	
28	soldier fly diptera	2,16	2017	2018	
29	food	1,95	2017	2018	
30	evolution	1,73	2017	2019	
31	dairy manure	2,33	2018	2019	
32	food waste	2,23	2018	2019	
33	water	2,1	2018	2019	
34	larvae tenebrio molitor	2,03	2018	2019	
35	trout oncorhynchus myki	2,03	2018	2019	
36	co digestion	2,03	2018	2019	
37	fatty acid	1,94	2018	2019	
38	nutrient digestibility	1,75	2018	2019	
39	optimization	2,15	2019	2021	
40	nutrient composition	1,72	2019	2021	

Figure 8. The top 40 keywords with the strongest citation bursts from 1994 to 2021.

Co-cited references timeline visualization

The BSF research literature has grown since 2007, mainly focusing on cluster #0, bioconversion; cluster #1, insect meal; cluster #2, meat quality; cluster #3, lipids; cluster #4, contaminants; cluster #5, organic solid waste; cluster #6, biodiesel; cluster #7, waste conversion (Fig. 9). Lee, Chen, & Tsai (2016) reported that the values of the silhouettes for each cluster were greater than 0.5, indicating that the results were reliable and significant. Therefore, the results in Table 4 were reliable and significant. The largest cluster, #0, has a size of 134 and a Silhouette value of 0.776; the LLR algorithm's label is a bioconversion. Thomas Spranghers and Yu-Shiang Wang are the most notable authors, as they focus their study on the bioconversion of various organic wastes by BSF larvae. Spranghers et al (2017), for instance, used BSF larvae to convert four types of organic waste (chicken feed, vegetable waste, biogas

digestate, and restaurant waste) and concluded that protein content and quality were high and comparable for prepupae reared on different substrates, suggesting that BSF could be an interesting source of protein for animal feeds. Wang & Shelomi (2017) evaluate the literature on BSFs that are capable of efficiently converting a wide range of organic resources, including food waste and manure, into insect biomass. The results revealed that BSF larvae have 42% crude protein and 29% fat, but do not concentrate pesticides or mycotoxins. BSF are already cultivated and approved for use as animal feed, albeit subject to regional legal constraints. "insect meal" (#1) and "lipids" (#3) were the most recent clusters, while "organic solid waste" (#5) was the oldest. In addition, the "insect meal (#1)" cluster was the most recent and relatively larger (98), therefore we concentrated on examining it. The most notable writers are Makkar and Renna, whose study focuses on the ability of BSF larvae to serve as animal feed. For instance, Makkar, Tran, Heuzé, & Ankers (2014) investigated the nutritional value of black soldier fly larvae and its application as a substitute for soymeal and fishmeal in the diets of chickens, pigs, fish species, and ruminants. The results indicated that the crude protein and lipid contents are high, with unsaturated fatty acid concentrations ranging from 19 to 37 percent, confirming that the palatability of BSF larvae as an alternative feed for animals is excellent and that it can replace 25 to 100 percent of soymeal or fishmeal, depending on the animal species. Renna et al (2017) evaluated the suitability of BSF larvae meal as an ingredient for rainbow trout diets. The results indicated that a partially defatted BSF larvae meal can be used as a feed ingredient in trout diets up to 40 percent without affecting survival, growth performance, condition factor, somatic indices, dorsal fillet physical quality parameters, or intestinal morphology of the fish. To mitigate the reported deleterious effects of insect meal on the fatty acid content of dorsal muscle, however, more research into specialized feeding procedures and diet compositions is required.

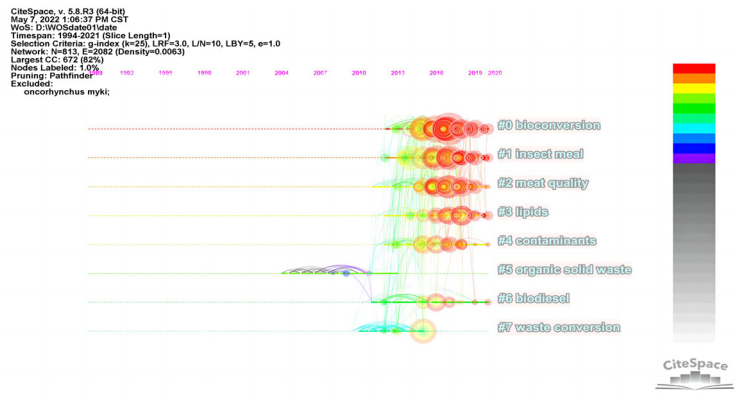

Figure 9. Timeline view analysis of co-cited references cluster.

Highly co-cited references

The 10 top co-cited references with different emphasis can be obtained from Fig. 10

and Table 5. The first and second highly cited references were published by Spranghers et al (2017) and Wang & Shelomi (2017) in cluster #0, with a citation counts of 205 and 152 respectively. The third most highly cited reference was published by Makkar, Tran, Heuzé, & Ankers (2014) in cluster #1, with a citation counts of 135, followed by Barragan-Fonseca, Dicke, & van Loon (2017), Liland et al. (2017), Lalander, Diener, Zurbrügg, & Vinnerås (2019), Xguyen, Tomberlin, & Vanlaerhoven (2015), Meneguz et al (2018), Surendra, Olivier, Tomberlin, Jha, & Khanal (2016) and Renna et al (2017), with the citation counts ranging from 103 to 125. There are eight references belong to cluster #0, and two references belong to cluster #1, therefore, these references were mainly divided into two categories, i.e. bioconversion and insect meal, which was in accordance with the results in the co-citation cluster timeline analysis. Firstly, using the BSF larvae to converse different organic waste attracted widespread attention. Secondly, researches related on the ability of using BSF larvae as the animal feed. Therefore, the bioconversion and animal feed using the BSF larvae will still be the focus research fields and will be continuously improved the research depth especially on the technical improvement on the efficiency of bioconversion.

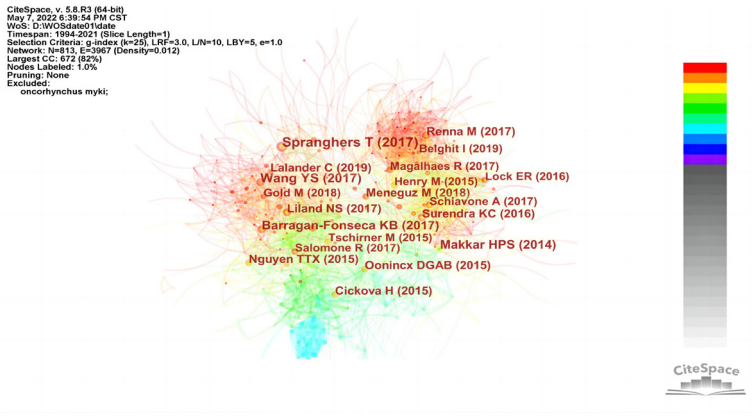

Figure 10. Network of co-cited references from 1994 to 2021.

SUMMARY AND CONCLUSIONS

This is the first time that scientometric analysis has been used to provide a complete overview of the black soldier fly (BSF) and its progress, hotspots, and future research directions. It is clear that research on BSF has progressed swiftly in the last five years, since the number of publications on this issue has increased significantly since 2007, with most of these articles coming in the form of Article and Review. The top 20 authors in BSF related studies also have high cooperation with other authors. The countries with the most publications and centrality were Italy, the United States, and China. With a significant number of publications and close ties to foreign institutions, Huazhong Agr Univ in China was the driving force behind BSF research in China. In terms of keyword co-occurrence and time-zone analysis delineated two main research themes

during the study period: biological characteristics, application and management of BSF larvae. Research on BSF larvae as animal feed and organic waste conversion were found to be two of the most popular topics in recent studies, according on a burst keyword analysis. Finally, using co-cited references cluster analysis, the eight greatest clusters could be identified. The top six clusters were bioconversion, insect meal, meat quality, lipids, contaminants and organic solid waste. Therefore, the bioconversion and animal feed using the BSF larvae will still be the focus research fields in the near future, and the technical improvement on the efficiency of bioconversion, integrating the healthy, safety and eco-friendly will attract more attentions. In addition, it could aid in the formulation of policies indicating the future direction of BSF research and it's applications.

ACKNOWLEDGMENTS

We acknowledge the funding supported by the Scientific and Technological Cooperation and Exchange program of Science and Technology Agency of Shanxi (Grant number 202104041101044), Scientific and Technological Innovation Program of Higher Education Institutions in Shanxi Province (grant number 2022L499) and the Shanxi Scholarship Council of China (grant number 2022-022).

REFERENCES

Aleixandre-Benavent, R., Aleixandre-Tudó, J.L., Castelló-Cogollos, L., & Aleixandre, J.L. (2017). Trends in scientific research on climate change in agriculture and forestry subject areas (2005-2014). *Journal of Cleaner Production*, 147, 406-418.

Awasthi, M.K., Sarsaiya, S., Wainaina, S., Rajendran, K., Kumar, S., Wang, Q., Duan, Y.M., Awasthi, S.K., Chen, H.Y., Pandey, A., Zhang, Z.Q., Jain, A., & Taherzadeh, M.J. (2019). A critical review of organic manure biorefinery models toward sustainable circular bioeconomy: Technological challenges, advancements, innovations, and future perspectives. *Renewable & Sustainable Energy Reviews*, 111, 115-131.

Barragan-Fonseca, K. B., Dicke, M., & van Loon, J.J.A. (2017). Nutritional value of the black soldier fly (*Hermetia illucens L.*) and its suitability as animal feed - a review. *Journal of Insects as Food and Feed*, 3 (2), 105-120.

Broadus, R.N. (1987). Toward a definition of "bibliometrics". *Scientometrics, 12 (5*-6*)*, 373-379.

Chen, C. (2004). Searching for intellectual turning points: Progressive knowledge domain visualization. *Proceedings of the National Academy of Sciences,* 101 (suppl_1), 5303-5310.

Chen, C. (2006). CiteSpace II: detecting and visualizing emerging trends and transient patterns in scientific literature. *Journal of the American Society for Information Science and Technology*, 57(3), 359-377.

Chen, C. (2016). CiteSpace: A practical guide for mapping scientific literature. Nova Science Publishers, Incorporated.

Elhag, O., Zhou, D.Z., Song, Q., Soomro, A.A., Cai, M.M., Zheng, L.Y., Yu, Z.N., & Zhang, J.B. (2017). Screening, expression, purification and functional characterization of novel antimicrobial peptide genes from *Hermetia illucens* (L.). *PloS One* 12(1), e0169582.

Fan, L.X., Yang, Z.M., Fang, Y., & Zhang, W.D. (2019). Utilization status and development suggestion of livestock manure. *Modern Agricultural Science and Technology*, 1, 175-181. (in Chinese)

Finley, J.W. (2020). Evolution and future needs of food chemistry in a changing world. *Journal of Agricultural and Food Chemistry*, 68, 12956-12971.

Gao, Z.H., Wang, W.Q., Lu, X.H., Zhu, F., Liu, W., Wang, X.P., & Lei, C.L. (2019). Bioconversion performance and life table of black soldier fly (*Hermetia illucens*) on fermented maize straw. *Journal of Cleaner Production*, 230, 974e980.

Gold, M., Tomberlin, J.K., Diener, S., Zurbrügg, C., & Mathys, A. (2018). Decomposition of biowaste macronutrients, microbes, and chemicals in black soldier fly larval treatment: a review. *Waste Management,* 82, 302e318.

Harzing, A.W., & Alakangas, S. (2016). Google scholar, scopus and the web of science: a longitudinal and cross-disciplinary comparison. *Scientometrics,* 106, 787-804.

Jung, S., Jung, J.M., Tsang, Y.F., Bhatnagar, A., Chen, W.H., Lin, K.Y.A., & Kwon, E.E. (2022). Biodiesel production from black soldier fly larvae derived from food waste by non-catalytic transesterification. *Energy,* 238, 121700.

Kim, C.H., Ryu, J., Lee, J., Ko, K., Lee, J.Y., Park, K.Y., & Chung, H. (2021). Use of black soldier fly larvae for food waste treatment and energy production in Asian countries: A Review. *Processes*, 9, 161.

Kong, Z.J., Wang, X.Q., Liu, Q.M., Li, T., Chen, X., Chai, L.F., Liu, D.Y., & Shen, Q.R. (2018). Evolution of various fractions during the windrow composting of chicken manure with rice chaff. *Journal of Environmental Management,* 207, 366-377.

Lalander, C., Diener, S., Magri, M.E., Zurbrügg, C., Lindström, A., & Vinnerås, B. (2013). Faecal sludge management with the larvae of the black soldier fly (*Hermetia illucens*)-from a hygiene aspect. *Science of the Total Environment*, 458-460, 312-318.

Lalander, C., Diener, S., Zurbrügg, C., & Vinnerås, B. (2019). Effects of feedstock on larval development and process efficiency in waste treatment with black soldier fly (*Hermetia illucens*). *Journal of Cleaner Production,* 208, 211-219.

Lee, Y.C., Chen, C.M., & Tsai, X.T., 2016. Visualizing the knowledge domain of nanoparticle drug delivery technologies: a scientometric review. *Applied Sciences*, 6(1), 11.

Li, W. & Zhao, Y. (2015). Bibliometric analysis of global environmental assessment research in a 20-year period. *Environmental Impact Assessment Review,* 50, 158-166.

Li, Q., Zheng, L.Y., Qiu, N., Cai, H., Tomberlin, J.K., & Yu, Z.N. (2011). Bioconversion of dairy manure by black soldier fly (Diptera: Stratiomyidae) for biodiesel and sugar production. *Waste Management,* 31(6), 1316-1320.

Li, W., Li, Q., Zheng, L.Y., Wang, Y.Y., Zhang, J.B., Yu, Z.N., & Zhang, Y.L. (2015). Potential biodiesel and biogas production from corncob by anaerobic fermentation and black soldier fly. *Bioresource Technology*, 194, 276-282.

Liland, N.S., Biancarosa, I., Araujo, P., Biemans, D., Bruckner, C.G., Waagbø, R., Torstensen, B.E., & Lock, E.J. (2017). Modulation of nutrient composition of black soldier fly (*Hermetia illucens*) larvae by feeding seaweed-enriched media. *PloS One,* 12(8), e0183188.

Liland, N.S., Araujo, P., Xu, X.X., Lock, E.J., Radhakrishnan, G., Prabhu, A.J.P., & Belghit, I. (2021). A meta-analysis on the nutritional value of insects in aquafeeds. *Journal of Insects as Food and Feed,* 7(5), 743-759.

Liu, G.Y. (2017). The spread track of CiteSpace application in China—based on the statistical and visual analysis of cross-database data from 2006 to 2015.*Intelligence, Information & Sharing,* 35(2), 60-74. (in Chinese)

Makkar, H.P.S., Tran, G., Heuzé, V., & Ankers, P. (2014). State-of-theart on use of insects as animal feed. *Animal Feed Science and Technology*, 197, 1–33.

Matos, J.S., de Aráujo, L.P., Allaman, I.B., Lôbo, I.P., de Oliva, S.T., Tavares, T.M., & de Almeida Neto, J.A. (2021). Evaluation of the reduction of methane emission in swine and bovine manure treated with black soldier fly larvae (*Hermetia illucens* L.). *Environmental Monitoring and Assessment*, 193, 480.

Melikoglu, M., Lin, C.S.K., & Webb, C. (2013). Analysing global food waste problem: Pinpointing the facts and estimating the energy content. *Central European Journal of Engineering*, 3(2), 157-164.

Meneguz, M., Schiavone, A., Gai, F., Dama, A., Lussiana, C., Renna, M., & Gasco, L. (2018). Effect of rearing substrate on growth performance, waste reduction efficiency and chemical composition of black soldier fly (*Hermetia illucens*) larvae. *Journal of the Science of Food and Agriculture*, 98, 5776–5784.

Murawska, D., Daszkiewicz, T., Sobotka, W., Gesek, M., Witkowska, D., Matusevicius, P., & Bakuła, T. (2021). Partial and total replacement of soybean meal with full-fat black soldier fly (*Hermetia illucens* L.) larvae meal in broiler chicken diets: impact on growth performance, carcass quality and meat quality. *Animals,* 11(9), 2715.

Olawumi, T.O. & Chan, D.W.M. (2018). A scientometric review of global research on sustainability and sustainable development. *Journal of Cleaner Production*, 183, 231-250.

Qin, F.Z., Li, J.L., Zhang, C., Zeng, G.M., Huang, D.L., Tan, X.F., Qin, D.Y., & Tan, H. (2021). Biochar in the 21st century: A data-driven visualization of collaboration, frontier identification, and future trend. *Science of the Total Environment*, 818, 151774.

Ravindran, B., Nguyen, D.D., Chaudhary, D.K., Chang, S.W., Kim, J., Lee, S.R., Shin, J., Jeon, B.H., Chung, S., & Lee, J. (2019). Influence of biochar on physico-chemical and microbial community during swine manure composting process. *Journal of Environmental Management,* 232, 592-599.

Renna, M., Schiavone, A., Gai, F., Dabbou, S., Lussiana, C., Malfatto, V., Prearo, M., Capucchio, M.T., Biasato, I., Biasibetti, E., De Marco, M., Brugiapaglia, A., Zoccarato, I., & Gasco, L. (2017). Evaluation of the suitability of a partially defatted black soldier fly (*Hermetia illucens* L.) larvae meal as ingredient for rainbow trout (Oncorhynchus mykiss Walbaum) diets. *Journal of Animal Science and Biotechnology*, 8, 957-969.

Rozkosny, R. (1983). *A Biosystematic Study of the European Stratiomyidae (Diptera): Volume 2 Clitellariinae, Hermetiinae, Pachygasterinae and Bibliography*, Series Entomologica. Springer Science & Business Media.

Spranghers, T., Ottoboni, M., Klootwijk, C., Ovyn, A., Deboosere, S., De Meulenaer, B., Michiels, J., Eeckhout, M., De Clercq, P., & De Smet, S. (2017). Nutritional composition of black soldier fly (*Hermetia illucens*) prepupae reared on different organic waste substrates. *Journal of the Science of Food and Agriculture*, 97(8), 2594-2600.

Surendra, K.C., Olivier, R., Tomberlin, J.K., Jha, R., & Khanal, S.K. (2016). Bioconversion of organic wastes into biodiesel and animal feed via insect farming. *Renewable Energy,* 98, 197-202.

Tomberlin, J.K., Sheppard, D.C., & Joyce, J.A. (2002). Selected life-history traits of black soldier flies (Diptera: Stratiomyidae) reared on three artificial diets. *Annals of the Entomological Society of America,* 95(3), 379-386.

Traksele, L., Speiciene, V., Smicius, R., Alencikiene, G., Salaseviciene, A., Garmiene, G., Zigmantaite, V., Grigaleviciute, R., & Kucinskas, A. (2021). Investigation of in vitro and in vivo digestibility of black soldier fly (*Hermetia illucens* L.) larvae protein. *Journal of Functional Foods* 79, 104402.

Wang, X.B., Wu, N., Cai, R.J., Geng, W.N., & Xu, X.Y. (2021). Changes in speciation, mobility and bioavailability of Cd, Cr and As during the transformation process of pig manure by black soldier fly larvae (*Hermetia illucens*). *Journal of Integrative Agriculture*, 20(5), 1157-1166.

Wang, Y.S., & Shelomi, M. (2017). Review of Black Soldier Fly (*Hermetia illucens*) as Animal Feed and Human Food. *Foods,* 6(10), 91.

Wu, N., Liang, J.Q., Wang, X.B., Xie, S.Y., & Xu, X.Y. (2021). Copper stimulates the incidence of antibiotic resistance, metal resistance and potential pathogens in the gut of black soldier fly larvae. *Journal of Environmental Sciences,* 107, 150-159.

Wynants, E., Frooninckx, L., Crauwels, S., Verreth, C., De Smet, J., Sandrock, C., Wohlfahrt, J., Van Schelt, J., Depraetere, S., Lievens, B., Van Miert, S., Claes, J., & Van Campenhout, L. (2019). Assessing the microbiota of black soldier fly larvae (*Hermetia illucens*) reared on organic waste streams on four different locations at laboratory and large scale. *Microbial Biotechnology* 77, 913-930.

Xguyen, T.T.X., Tomberlin, J.K., & Vanlaerhoven, S. (2015). Ability of black soldier fly (Diptera: Stratiomyidae) larvae to recycle food waste. *Environmental Entomology*, 44(2), 406-410.

Xie, P. (2015). Study of international anticancer research trends via co-word and document co-citation visualization analysis. *Scientometrics,* 105(1), 611-622.

Yang, Y. & Meng, G.F. (2019). A bibliometric analysis of comparative research on the evolution of international and Chinese ecological footprint research hotspots and frontiers since 2000. E*cological Indicators,* 102, 650-665.

Zhang, Y.B., Zhang, Y.L., Shi, K., & Yao, X.L. (2017). Research development, current hotspots, and future directions of water research based on MODIS images: a critical review with a bibliometric analysis. *Environmental science and pollution research international,* 24(18), 15226-15239.

Zhang, J.B., Zhang, J., Li, J.H., Tomerlin J.K., Xiao, X.P., Ur Rehman, K., Cai, M.M., Zheng, L.Y., & Yu, Z.N. (2021). Black soldier fly: A new vista for livestock and poultry manure management. *Journal of Integrative Agriculture*, 20(5), 1167-1179.

Zhi, W., Yuan, L., Ji, G.D., Liu, Y.S., Cai, Z., & Chen, X. (2015). A bibliometric review on carbon cycling research during 1993-2013. *Environmental Earth Sciences,* 74(7), 6065-6075.