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MAPPING BIOLOGICAL CONTROL RESEARCH ON *SPODOPTERA EXIGUA*: A BIBLIOMETRIC ANALYSIS OF SCOPUS-INDEXED

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Abstrak

Pengendalian hayati *Spodoptera exigua* merupakan alternatif penting untuk mengurangi ketergantungan pada insektisida kimia, namun struktur dan perkembangan bidang riset ini belum banyak dipetakan secara kuantitatif. Penelitian ini memetakan literatur akses terbuka terindeks Scopus periode 2015–2025 dengan pendekatan bibliometrik. Pencarian awal menghasilkan 166 artikel berbahasa Inggris; setelah screening relevansi judul dan abstrak menggunakan kriteria yang telah ditetapkan, 109 artikel dianalisis. Analisis mencakup tren publikasi, produktivitas sumber dan penulis, sitasi, serta ko-kemunculan author keywords menggunakan VOSviewer 1.6.21. Jaringan akhir terdiri atas 56 kata kunci, delapan klaster, 200 links, dan total link strength 343. Baculovirus dan *SeMNPV* menjadi tema sentral, disertai biological control, *Beauveria bassiana*, *Bacillus thuringiensis*, dan tema parasitoid. Hasil menunjukkan dominasi pengendalian mikroba serta peluang penguatan integrasi IPM, validasi lapang, dan implementasi.

Kata Kunci: *Bibliometrik; Pengendalian Hayati; Spodoptera Exigua; Baculovirus; Vosviewer*

Abstract

Biological control of Spodoptera exigua is an important alternative for reducing reliance on chemical insecticides, yet the structure and development of this research field remain incompletely mapped. This study mapped Scopus-indexed open-access literature published from 2015–2025 using a bibliometric approach. The initial search retrieved 166 English-language articles; after title–abstract relevance screening against prespecified criteria, 109 records were analyzed. Analyses covered publication trends, source and author productivity, citations, and author-keyword co-occurrence using VOSviewer 1.6.21. The final network contained 56 keywords, eight clusters, 200 links, and a total link strength of 343. Baculovirus and SeMNPV formed the conceptual core, together with biological control, Beauveria bassiana, Bacillus thuringiensis, and parasitoid-related themes. The findings indicate the dominance of microbial control and highlight opportunities for stronger IPM integration, field validation, and implementation.

Keywords: *Bibliometric Analysis; Biological Control; Spodoptera Exigua; Baculovirus; Vosviewer*

A. Introduction

The beet armyworm, *Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae), is a highly polyphagous pest that attacks a wide range of economically important crops. Its management is difficult because populations can develop resistance to several insecticide classes, while repeated chemical applications may disrupt natural enemies and increase ecological costs (Huang et al., 2021; Hafeez et al., 2022). These constraints strengthen the need for pest-management strategies that reduce chemical dependence without sacrificing control reliability.

Biological control provides several complementary pathways for managing *S. exigua*. Research has examined parasitoids and predators, microbial agents such as *Bacillus thuringiensis*, entomopathogenic fungi such as *Beauveria bassiana*, entomopathogenic nematodes, and insect-pathogenic viruses, particularly *Spodoptera exigua* multiple nucleopolyhedrovirus (SeMNPV). Studies also address compatibility between biological agents and other crop-protection tactics, including insecticides, mycorrhiza-induced resistance, and tritrophic interactions (Liu et al., 2016; Gutiérrez-Cárdenas et al., 2020; Frattini et al., 2022).

Within this broad research space, baculovirus-based control has generated a particularly diverse body of work, ranging from transmission biology and host manipulation to formulation, storage stability, and combined applications. For example, baculovirus-induced climbing and necrophagy can enhance horizontal transmission (Rebolledo et al., 2015), while later studies have addressed contamination management in SeMNPV preparations (Presa-Parra et al., 2020), microencapsulation for ultraviolet protection and controlled release (Luo et al., 2022), and combined use of SeMNPV with insecticides for resistance management (Zhou et al., 2023). At the same time, parasitoid ecology and fungal entomopathogens remain important but comparatively distinct lines of investigation (Cusumano et al., 2015; Jirakkakul et al., 2021; Magaña et al., 2022).

Because this literature spans virology, microbial ecology, entomology, plant-mediated interactions, and integrated pest management, a conventional narrative description alone may not reveal how these themes are connected. Bibliometric analysis is useful for examining scientific production, influential contributions, and the conceptual structure of a research field, while science mapping can reveal relationships among recurring terms and themes (Donthu et al., 2021). VOSviewer further supports visualization of keyword co-occurrence networks, temporal overlays, and density patterns (Van Eck & Waltman, 2010).

Accordingly, this study aimed to map biological-control research on *S. exigua*

published between 2015 and 2025 by addressing the following research questions: (RQ1) What are the publication and citation trends in biological-control research on *S. exigua* during 2015–2025? (RQ2) Which journals and authors are the most productive in this research field? (RQ3) Which publications have received the greatest citation impact? (RQ4) What is the co-occurrence structure of author keywords in the literature? and (RQ5) How have dominant and emerging research themes evolved over the study period? The analysis was designed as a focused bibliometric study rather than a systematic evidence review; therefore, its emphasis is on the structure and evolution of the literature rather than pooled estimates of biological-control efficacy.

B. Methodology

Research design and data source

This study used a descriptive bibliometric design combining performance analysis with science mapping. Scopus was selected as the bibliographic source because it provides standardized metadata for journal articles, including authors, publication year, source title, citations, abstracts, and author keywords. The search was conducted on 10 September 2026, while the publication window was deliberately restricted to complete calendar years from 2015 through 2025.

Search strategy

The search was conducted in TITLE-ABS-KEY using the target-pest concept ("*Spodoptera exigua*" OR "beet armyworm") combined with biological-control terms: "biological control", biocontrol, "natural enemy", parasitoid, parasitism, predator, predation, entomopathogen, "microbial control", "microbial insecticide", biopesticide, bioinsecticide, "entomopathogenic fungus", "entomopathogenic fungi", "entomopathogenic nematode", baculovirus, nucleopolyhedrovirus, "conservation biological control", "augmentative biological control", and "classical biological control". Filters were then applied for publication years 2015–2025, document type Article, English language, and All Open Access. The search returned 166 records. Because open access was part of the predefined retrieval strategy, the resulting analysis represents the Scopus-indexed open-access literature rather than the complete Scopus literature on the topic.

Relevance cleaning

Before bibliometric mapping, the 166 records underwent title–abstract relevance screening using prespecified rules. A record was retained when *S. exigua* was an explicit study target or host and the study addressed a recognized biological-control agent or strategy, natural-enemy interaction, compatibility/non-target dimension, formulation or production

issue, or a mechanistic process directly related to biological-control performance. Molecular or mechanistic studies were retained when they directly examined infectivity, virulence, transmission, host response, production, or action of a recognized biological-control agent involving *S. exigua*. Records were excluded when they focused on a different primary pest, mentioned *S. exigua* only incidentally, or addressed chemical or botanical insecticides alone, host-plant resistance alone, RNA interference/genetic control, physical control, purified toxin studies without a microbial-agent context, or basic biotechnology/virology without a direct *S. exigua* biological-control link. Exclusion decisions were documented using standardized reasons. Fifty-seven records were excluded and 109 records formed the final bibliometric corpus; no duplicate DOI was detected.

Bibliometric indicators and VOSviewer settings

Performance indicators were calculated from the cleaned Scopus metadata and included annual scientific production, source productivity, author productivity, total citations, mean and median citations, and the corpus h-index. Science mapping was performed in VOSviewer version 1.6.21. Co-occurrence analysis used Author Keywords, full counting, and a minimum occurrence threshold of two. A thesaurus was applied to merge obvious variants, including beet armyworm with *Spodoptera exigua*, biocontrol with biological control, and spelling or abbreviation variants of *SeMNPV*. Network, overlay, and density visualizations were examined. In the network view, node size represents occurrence, links represent co-occurrence relationships, and cluster colors indicate algorithmic grouping. In the overlay view, colors represent the average publication year of each keyword.

Table 1

Search and relevance-cleaning profile

Item	Specification / count
Database	Scopus
Search date	10 September 2026
Publication window	2015–2025
Document type	Article
Language	English
Access	All Open Access
Retrieved	166 records
Excluded after title–abstract screening	57 records
Final corpus	109 records

C. Results and Discussion

Publication Profile and Temporal Trend

The final corpus consisted of 109 publications. Annual output fluctuated across the study period rather than increasing linearly. Publication counts were 8 in 2015, 11 in 2016, 4 in 2017, 12 in 2018, 7 in 2019, 10 in 2020, 12 in 2021, 14 in 2022, 13 in 2023, 6 in 2024, and 12 in 2025.

The highest annual output occurred in 2022, followed closely by 2023. The marked decline in 2024, followed by a return to 12 publications in 2025, may reflect normal year-to-year variation in research and publication cycles, including differences in project completion and manuscript publication timing, rather than a sustained decline in scientific interest. The rebound in 2025 suggests that research activity in this field remained substantial.

At the time of Scopus export, the 109 documents had accumulated 1,351 citations, corresponding to a mean of 12.4 citations per article and a median of 8. The corpus h-index was 20. These values indicate that the field contains a mix of highly visible foundational studies and a larger body of more specialized work. Because citation counts are time-dependent, these indicators should be interpreted as a snapshot of influence at the date of data collection rather than as fixed measures of quality.

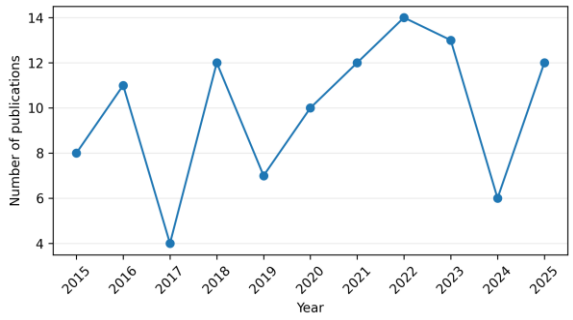

Figure 1
Annual scientific production on biological control of Spodoptera exigua in the final corpus (2015–2025).

Productive Sources, Authors, and Influential Papers

The literature was distributed across entomology, virology, microbiology, ecology, and pest-management journals. Insects and Viruses were the most productive sources, with nine articles each, followed by Scientific Reports with seven. Frontiers in Microbiology, Biological Control, and PLoS ONE each contributed five articles. This distribution confirms the multidisciplinary character of *S. exigua* biological-control research: no single disciplinary outlet dominates the corpus.

Author productivity was more concentrated. Herrero S. appeared in 12 publications, Caballero P. in 11, and Williams T. in 8, while Li J. and Ros V. I. D. each appeared in six. Several additional authors contributed five papers. The recurrent presence of a relatively small core of authors, particularly in baculovirus and host–pathogen research, suggests sustained research programs rather than isolated studies.

The most cited document in the cleaned corpus was Cusumano et al. (2015), which examined parasitoid attraction to induced plant volatiles in a multi-herbivore context and had 63 Scopus citations at the time of data collection. Gasmi et al. (2019), addressing herbivore-induced volatiles and susceptibility to natural pathogens, had 53 citations. Other highly cited papers focused on virus–host biology,

antimicrobial responses, and natural-enemy compatibility. These citation counts indicate visibility within the corpus but should not be interpreted as direct measures of methodological quality or biological-control effectiveness.

Keyword Co-occurrence and Thematic Structure

After thesaurus normalization and application of the minimum-occurrence threshold, the VOSviewer network contained 56 author keywords organized into eight algorithmic clusters, connected by 200 links with a total link strength of 343. *Spodoptera exigua* was the dominant node, occurring in 43 documents after normalization. Baculovirus occurred 23 times, *SeMNPV* 14 times, and biological control 12 times. Other recurrent terms included *AcMNPV* (7), *Beauveria bassiana* (6), *Bacillus thuringiensis* (5), apoptosis (4), iflavirus (4), entomopathogenic fungi (3), and IPM (3). Because clustering is algorithmic, the eight clusters were interpreted as connected thematic groupings rather than as mutually exclusive biological-control categories.

Although VOSviewer produced eight algorithmic clusters, the map can be interpreted as several broader thematic domains. The first and most prominent domain centers on baculovirus and SeMNPV, linking viral pathogenicity, infection, mortality, behavior, and pest control. This prominence is consistent with the long history of SeMNPV as a species-specific microbial-control agent and with recent efforts to improve delivery, stability, persistence, and compatibility (Rebolledo et al., 2015; Presa-Parra et al., 2020; Luo et al., 2022; Zhou et al., 2023).

A second domain involves molecular and host–pathogen mechanisms, including AcMNPV, apoptosis, viral proteins, and related infection processes. Mechanistic studies have also examined antimicrobial responses and host–pathogen interactions following exposure to *Bacillus thuringiensis* toxins and baculovirus, illustrating the close connection between insect immunity and microbial biological control (Crava et al., 2015). Mechanistic work is relevant because virus performance can be shaped by host immunity, virus–virus interactions, and changes in host physiology. The strong connection between mechanistic terms and the central baculovirus nodes indicates that fundamental virology and applied microbial control are not separate literatures but closely linked components of the same research trajectory.

A third domain contains microbial and fungal biological-control themes. *Beauveria bassiana*, entomopathogenic fungi, *Bacillus thuringiensis*, pathogenicity, virulence, and chitinase appear within or near this region. Studies such as Jirakkakul et al. (2021) demonstrate how fungal physiology can alter virulence against *S.*

exigua, while newer work on *Cordyceps*-related metabolites extends this line toward metabolomic and mechanism-informed biocontrol development (Charria-Girón et al., 2025).

A fourth, more peripheral domain captures parasitoid, host-parasite, herbivore, aphid, and apparent-competition relationships. Its spatial separation from the baculovirus core suggests that conservation biological control and tritrophic ecology form a relatively distinct research tradition. Apparent competition mediated by shared predators further illustrates how community-level interactions can indirectly suppress *S. exigua* populations (Ramirez & Eubanks, 2016). The cluster is nevertheless conceptually important because it highlights indirect pest suppression and community interactions that cannot be represented by pathogen efficacy alone. Work on parasitoid attraction and mass-rearing potential illustrates the relevance of these ecological and operational dimensions (Cusumano et al., 2015; Magaña et al., 2022).

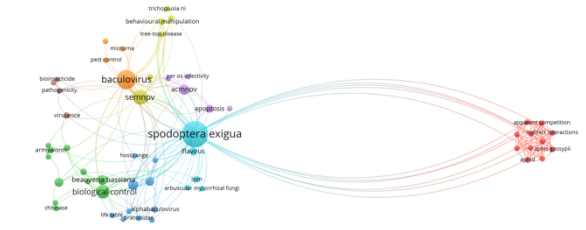

Figure 2
Author-keyword co-occurrence network (full counting; minimum occurrence = 2; 56 keywords; 8 clusters).

Temporal Evolution of Research Themes

Overlay visualization showed a temporal gradient across the network. Several ecological interaction terms, including aphid, *Aphis gossypii*, apparent competition, and behavioral manipulation, were associated with earlier average publication years around 2016. In contrast, biological control, *Beauveria bassiana*, alphabaculovirus, bioinsecticide-related terms, and IPM were positioned toward more recent average publication years, generally around 2021–2023. These patterns describe changes in keyword use within the corpus and should not be interpreted as proof that older research themes have disappeared.

This shift should not be interpreted as the disappearance of older topics. Instead, it suggests a broadening of the research agenda from early emphasis on ecological interactions and virus-induced phenotypes toward more integrated microbial-control, formulation, compatibility, and IPM-oriented questions. The centrality of SeMNPV remained strong throughout the period, indicating continuity within the field even as newer themes emerged around integration and application.

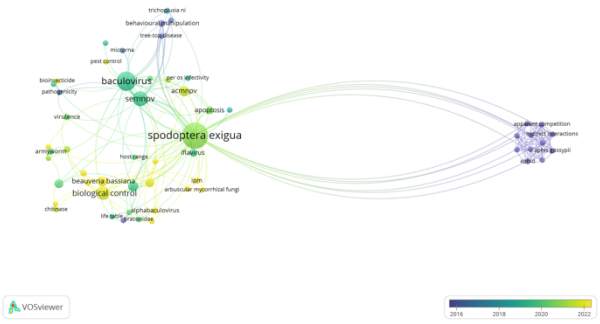

Figure 3
Overlay visualization of author keywords by average publication year.

Research Gaps and Implications

The density visualization indicates that the most concentrated knowledge base lies around *S. exigua*, baculovirus/*SeMNPV*, and biological control. The lower density of fungal, parasitoid, and ecological-interaction themes suggests that these topics are less recurrent in the keyword network. Implementation-oriented terms such as field efficacy, mass production, economics, adoption, and farmer participation did not reach the minimum occurrence threshold. This finding should be interpreted as low recurrence in author-keyword vocabulary, not as evidence that implementation studies are entirely absent from the literature.

Future work could therefore strengthen three connections. First, microbial-control research should continue moving from mechanism toward formulation, persistence, field reliability, and resistance-management compatibility. Second, parasitoids, predators, entomopathogenic fungi, and viruses should be studied more often as components of integrated programs rather than as isolated agents. Third, bibliometric patterns suggest a need for greater attention to operational outcomes, including production scalability, cost, crop protection under field conditions, and integration with farmer decision-making. These priorities are consistent with the broader rationale for reducing dependence on conventional insecticides in *S. exigua* management (Hafeez et al., 2022).

This study has several limitations. It used a single database, included only English-language journal articles, and applied an All Open Access filter; therefore, influential non-open-access publications and records indexed outside Scopus may be missing. Citation counts favor older publications because they have had more time to accumulate citations. Keyword networks also depend on author terminology, the minimum-occurrence threshold, and thesaurus decisions. Title–abstract relevance screening improved thematic specificity but did not constitute a systematic review of biological-control efficacy, and no risk-of-bias assessment was performed. Accordingly, the findings should be interpreted as a map of the open-access research landscape rather than as

evidence that one biological-control agent is superior to another.

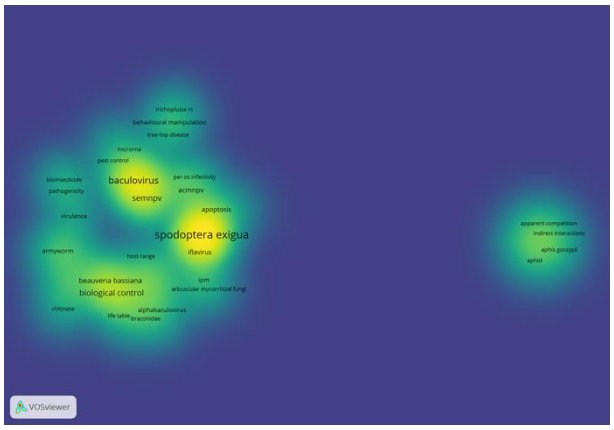

Figure 4

Density visualization showing the most concentrated keyword regions in the network.

D. Conclusion

This bibliometric analysis mapped 109 Scopus-indexed open-access articles on biological control of *Spodoptera exigua* published from 2015 to 2025. Regarding RQ1, scientific output was sustained but fluctuating, peaking in 2022; the corpus accumulated 1,351 citations, with a mean of 12.4 citations per article, a median of 8, and an h-index of 20. Regarding RQ2, Insects and Viruses were the most productive sources, while Herrero S., Caballero P., and Williams T. were the most productive authors. Regarding RQ3, Cusumano et al. (2015) was the most highly cited publication in the corpus, followed by Gasmi et al. (2019). These findings describe the Scopus-indexed open-access corpus and should be interpreted within the database, language, and access restrictions applied in this study.

Regarding RQ4, author-keyword co-occurrence analysis identified 56 recurrent terms organized into eight clusters, with baculovirus and *SeMNPV* forming the conceptual center of the field. Entomopathogenic fungi, *Bacillus thuringiensis*, parasitoids, and ecological interactions formed additional thematic domains. Regarding RQ5, temporal mapping indicated a broadening of the research agenda from earlier emphasis on ecological interactions and virus-related phenomena toward more recent themes involving biological-control integration, microbial agents, formulation, compatibility, bioinsecticides, and IPM. Overall, future research may benefit from greater attention to field reliability, scalable production, multi-agent compatibility, and implementation-oriented outcomes.

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