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A bibliometric analysis of botanical insecticides for Lepidopteran insects over the period 1985-2022

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Abstract

Lepidoptera is an economically important insect pest that attacks many commercially important crops. Synthetic insecticides are currently most extensively utilized to control this pest. The use of massive doses of synthetic pesticides has resulted in resistance and resurgence. Therefore, developing an environmentally acceptable technique for controlling insect pest populations, such as using natural plant components as insecticides, can assist in mitigating the negative impacts of synthetic pesticides. Plant pesticides or botanical insecticides are becoming increasingly popular. This bibliometric research aimed to demonstrate the growth, awareness, importance, international cooperation or collaboration and knowledge gaps in developing synthetic botanical insect pesticides in the future. Information used in this research was culled from 138 scientific papers (Scopus database) and analyzed using VOSviewer 1.6.17. Descriptive statistics was used to identify the rate of botanical insecticide development in controlling these insect pests by analyzing the contributing documents by year, country and bibliometric analysis of country and keyword co-occurrence. The research started in 1985 and exponential growth occurred after 2006. In addition, the trend peaked in 2020 and is currently being maintained. The scientific papers were distributed from 41 countries, with Brazil being the most productive. The bibliographical network shows the relatedness of information about keywords between countries. The results obtained can help recognize existing knowledge gaps that need to be addressed and considered in developing botanical insecticides to control this lepidopteran pest.

Keywords

Bibliometric analysis, botanical insecticide, Lepidoptera, plant insecticide, vosviewer

Introduction

Lepidoptera is a large and diverse class of agricultural insect pests that harm food and fiber crops, fruit trees, forests and stored grains. They exhibit a wide range of interactions with various plants, parasites, or diseases (1). Tobacco cutworm (*Spodoptera litura* (Fabricius)) (Lepidoptera: Noctuidae); maize/sorghum stem borer (*Chilo partellus* (Swinhoe)) (Lepidoptera: Crambidae); diamondback moth (*Plutella xylostella* (Linnaeus)) (Lepidoptera: Plutellidae); and legume pod borer (*Maruca vitrata*) insect pests have been implicated in significant yield losses in numerous places in the world (2-5). *S. litura* (Fabricius) is a severe pest that attacks cotton, soybeans, groundnuts, tobacco and vegetables among other economically important crops. On occasion, it has been reported to produce a 26–100% yield reduction in the field (2). In Africa, India and Southeast Asia, the spotted stem borer (*C.*

partellus (Swinhoe)) (Lepidoptera: Pyralidae), is the most devastating pest of maize and sorghum. Furthermore, *C. partellus* infestations in maize might result in annual losses of up to 50% (3, 6, 7).

Synthetic pesticides are employed to control pests. However, they have negative impacts on beneficial organisms, humans, and the environment (3). There has been increased concern about the overuse of chemical pesticides and their impact on nature and natural resources, including human health (8, 9). Chemical pesticides have been shown to have harmful effects on plant and animal biodiversity, as well as terrestrial and marine ecosystems (10). Due to the negative consequences of synthetic pesticides, greener and more environmentally friendly alternatives are required. Botanical insecticides are less harmful, environmentally safe and safe for human and non-target organisms (10, 11). Since the 17th century, botanical insecticides have been used in agriculture by ancient India, Greece, Egypt and China (10, 12).

Previous research has been conducted on botanical insecticides against lepidopteran insect pests. For example, research on the insecticidal activity of ethanolic and hexane extracts from fresh and dehydrated leaves of *Piper auritum* Kunth (Piperales: Piperaceae), *Piper umbellatum* L.(Piperales:Piperaceae),*Cedrela odorata* L. (Sapindales: Meliaceae) on the first instar larvae of *Spodoptera frugiperda* was done (13). *Desmosstachya bipinnata* (L.) Stapf., a perennial grass was analyzed and a chemical component with activity on *S. litura* larvae (Lepidoptera: Noctuidae) was isolated (14). In addition, a crude extract obtained from *Solanum nigrum* altered the physiology of *Galleria mellonella* (Lepidoptera) (15). Under laboratory conditions, essential oils of *Ocimum gratissimum* and *Ocimum kilimandscharicum* were analyzed for repellent and fumigant toxicity in adult stages of *Tuta absoluta* (Meyrick) (16). Although several tests have been conducted, the best botanical insecticide is still being sought after.

This is the first and only global biopesticide research on the use of botanical insecticides for lepidopteran insects despite increased interest in biopesticides. The bibliometric analysis was used to identify a framework in a citation for knowledge mapping, such as evaluating published research to describe and review the outcomes, authors, universities and journal articles within specific aspects of research and then analyzing knowledge sharing within topic areas. The findings contribute to the existing literature, play an important role in policy creation, and assist funding agencies and policymakers in making important decisions about funding priority, future trends, and collaboration with other institutions (17-19). Bibliometric approaches were employed in this research to assess the expansion of biopesticide research journals since 1985, as well as the present state of publication trends, research scopes and collaboration patterns.

Materials and Methods

Data Sources and Scientific Paper Selection Strategy

The scientific papers for this research were extracted from the Scopus database. However, the Scopus library Metabase (www.scopus.com) was used to find literature due to its coverage. This database offers certain benefits over more accessible databases like Google Scholar, which has a broader coverage but is less accurate (20, 21). "Botanical insecticide" or "plant insecticide" and "lepidoptera" were among the keywords used. A screening procedure was used to select 138 papers based on the following criteria, namely article document type, final publication stage, the use of English language only and research on botanical or plant insecticides for Lepidoptera.

Data Analysis

The eligible scientific papers were exported and saved as comma-separated values (CSV). MS Excel was used to summarize the data and statistical analysis was conducted using Graphpad Prism and Vosviewer 1.6.17. Graphpad Prism was used to analyze contributing documents by year and analyze the contributing country. VOSviewer was used for bibliometric analysis of country and keyword co-occurrence.

Results & Discussion

Trends in General Data Description and Publication

The search for scientific papers yielded 163 papers. After screening and careful reading, 138 papers published from 1985 to 2022 were found, as shown in Fig. 1. The research on botanical or plant insecticide for Lepidoptera started in 1985 and experienced exponential growth after 2006. The trend peaked in 2020 and is currently being maintained. The oldest document was published in 1985 and described a triterpenoid compound derived from the neem tree, Azadirachta indica A. Juss., Meliaceae, that has antifeedant and insecticidal activities against the European corn borer Ostrinia nubilalis Hübner (22).

A total of 3 papers published from 1996 to 2000 discussed preliminary investigations of plant extracts, the deposition, persistence, translocation and bioactivity of the botanical insecticide and a field experiment to find an

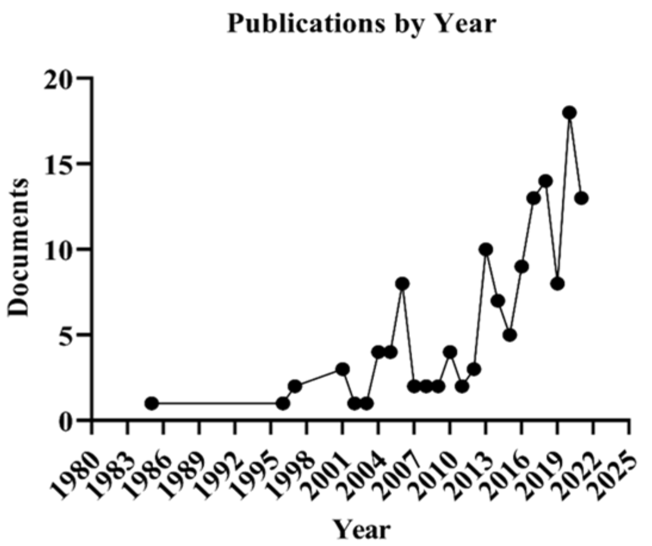

Fig. 1. Number of publications by year on botanical or plant insecticide on Lepidoptera.

effective and economical insecticide (23, 24). Between 2001 to 2005, 13 papers were published that discussed larvae activity in terms of food uptake, utilization, and detoxifying enzymes, growth inhibition, mortality, abnormalities, behavioral responses, and lethal effects of some crude extracts of botanical insecticides (25-32).

Between 2006 to 2010, 18 papers were published discussing the effects of nutritional physiology, enzyme activity and enzymatic digestion profiles of crude extracts, fractions and isolated components of botanical insecticides, antifeedant, growth inhibition, oviposition deterrent, toxic effects, stomach poison, contact toxicant, insect growth inhibitor and changes in the distributions of 6 inorganic cations (Li+, Na+, NH4+, K+, Mg2+, and Ca2+) (33-43).

From 2011 to 2015, 27 papers were published discussing the effects of crude and fractional extracts on development, reproduction, cuticular protein, ultrastructural effects on the midgut epithelial cells, development cycle, feeding habits, larval mortality, pupal mortality, adult malformation, nanoformulations of plant extract, evaluation of physicochemical properties of microemulsion formulation, essential oils providing insecticidal and feeding deterrent properties, the antifeedant activity of crude extract and fraction extract, embryonic development of insects, proteomic and properties analysis of botanical insecticide, physiological and biological impacts on secondary metabolites sesquiterpene alkaloids: separation and insecticidal activity (44-52).

Between 2016 to 2020, 62 papers were published discussing the chemical characterization of plant derivatives, composition and bioactivity of the constituents, as well as the primary constituents' comparative and synergistic relationships of the plant extracts, the insecticidal and cytotoxic activities of individual constituents of essential oils, metabolic profiling plant extract, sublethal effects of essential oils, contact toxicity, antifeedant activity, repellency and growth regulatory activity, Life-history features, fertility, and immunological parameters are all factors to consider, effect of plant extract on physiological performance, on antioxidant and immune system, on the embryonic development, on the development and mortality, ovicidal effect, fractions of plant extract, process optimization and insecticidal activity of alkaloids, storage temperature of botanical insecticide, isolated alkane compounds and crude extracts research from botanical insecticide, insecticidal activity of thyme esters synthesized, nanotechnology (16,53-73).

Publications after 2020 included 14 papers discussing the regulation of feeding and metabolism of insects, antifeeding and insecticidal activity of botanical insecticide, the developmental response of insects to plant extract, the molecular process that causes growth regulation by botanical insecticide, systematic phytochemical screening of plant extract, mechanism of botanical insecticide, oviposition behavior and electrophysiological responses to chemical constituents and essential oils, the toxicity of essential oils on biological and reproduction variables, biocidal efficacy of plant extract and its influence on immune cells and expression of growth-blocking and neuroglia peptides, examining changes in hemolymph metabolite and fat body and midgut ultrastructure, the isolation, and bioactivity of a chemical compound, phytochemicals classified, plant essential oils' chemical constitution and bioactivities (13-15, 74-80).

This section describes the advancement of research on botanical insecticides. The research began with exploring various types of plant extracts as botanical insecticides by focusing on crude extracts with mortality, antifeedant, repellent, and sublethal effects. However, the focus of research has shifted to the fractionation and isolation of compounds that act as botanical insecticides and have effects on insect physiology, such as enzyme activity and proteomic analysis of botanical insecticides against target insects. In addition, many methods have been developed for the metabolic profiling of plant and insect targets. Recent research have also analyzed the immune system of target insects, molecular mechanisms of botanical insecticides and nanotechnology of botanical insecticides.

In 1985, biopesticide research had publications on only biological and agricultural subjects, however, by 2020, this increased to 14 subjects (Biochemistry, Genetics and Molecular Biology; Medicine; Pharmacology, Toxicology and Pharmaceutics; Agricultural and Biological Sciences; Environmental Science; Biochemistry, Genetics and Molecular Biology; Medicine; Pharmacology, Toxicology and Pharmaceutics; Multidisciplinary; Chemistry Immunology and Microbiology; Veterinary Medicine; Energy; Materials Science; Physics and Astronomy; Social Scienc Enhanced laboratories), indicating its gradual maturity. The number of subject areas under which a field's research articles are distributed is a measure of its maturity. This means the more developed a discipline is, the more detail and depth will be examined (9, 81). In contrast, the number of publications in each journal has gradually increased. It is also worth mentioning that, while annual scientific production is steadily increasing, there are occasional yearly fluctuations. Enhanced laboratories, the emergence of new scientists, the development of fresh methods of research and financial support are all possible factors to increase the number of journal publication (10, 82). The top five highly-cited articles in botanical insecticides for lepidopteran insect showed in (Table 1).

Analysis of Contributing Countries

From the research conducted in 41 countries, 138 papers were published, with Brazil being the most productive, as shown in Fig. 2. Brazil is the world's most prolific country, with 32 publications. China and India are ranked second and third, with 23 and 17 publications respectively. Research on plant insecticides in Brazil was documented from 2001 to 2021. This includes research on the chemical components of *Aristolochia pubescens* that have an insecticidal effect on *Anticarsia gemmatalis* larvae (29), essential oils from *Eucalyptus staigeriana* (Myrtales: Myrtaceae), *Ocimum gratissimum* (Lamiales: Lamiaceae), and *Foeniculum vulgare* (Apiales: Apiaceae) have sublethal effects on the metabolism of *Spodoptera frugiperda* (Lepidoptera:

Table 1. The Top Five Highly-cited Articles in Botanical Insecticides for Lepidopteran Insect

No.	Author	Year	Total number of citation	Document title	Journal name
1.	Senthil-Nathan, Sengottayan	2013	171	Physiological and biochemical effect of neem and other Meliaceae plants secondary metabolites against Lepidopteran insects	Frontiers in Physiology
2.	Martinez, S.S., Van Emden, H.F.	2001	106	Growth disruption, abnormalities and mortality of *Spodoptera littoralis* (Boisduval) (Lepidoptera: Noctuidae) caused by azadirachtin	Neotropical Entomology
3.	Tak, J.-H., Jovel, E., Isman, M.B.	2016	103	Comparative and synergistic activity of *Rosmarinus officinalis* L. essential oil constituents against the larvae and an ovarian cell line of the cabbage looper, *Trichoplusia ni* (Lepidoptera: Noctuidae)	Pest Management Science
4.	Nathan, S.S.	2006	86	Effects of Melia azedarach on nutritional physiology and enzyme activities of the rice leaffolder *Cnaphalocrocis medinalis* (Guenée) (Lepidoptera: Pyralidae)	Pesticide Biochemistry and Physiology
5.	Leatemia, J.A., Isman, M.B.	2004	77	Insecticidal Activity of Crude Seed Extracts of *Annona* spp., *Lansium domesticum* and *Sandoricum koetjape* Against Lepidopteran Larvae	Phytoparasitica

Noctuidae) (67), the control of *P. xylostella* L., chemical components and bioactivity of aqueous extracts of *Alibertia* spp. (Lepidoptera: Plutellidae) (84), *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) is affected by phenylpropanoids produced by *Duguetia lanceolata* A. St.-Hil. stem bark (85), the immunological system of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) immatures was studied using *Azadirachta indica* (Sapindales: Meliaceae) oil (62), *Alabama argillacea* (Lepidoptera: Erebidae) egg-laying behavior and electrophysiological sensitivity to essential oils and chemical compounds (85).

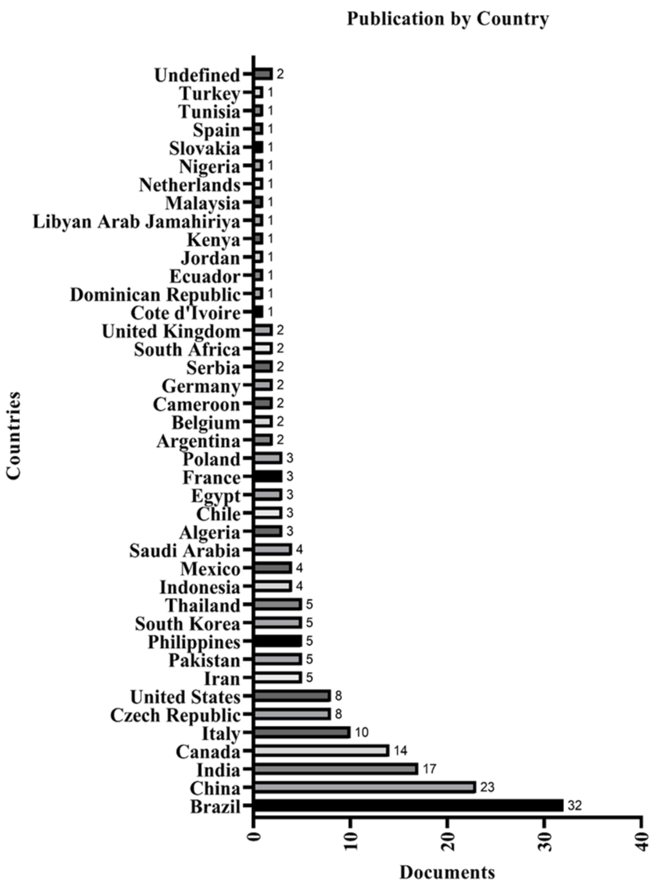

Fig. 2. Distribution of Lepidoptera concerning botanical or plant insecticide among countries studied from 1985 to 2022.

Pollen grains are prolate, tricolporate wth radial symmetry and reticulate to perforate surface in all accessions of *A. gangetica* and *A. gangetica* var. *krishnae.* Thus, the palynological traits are more or less consistent. The seed surface architecture shows a uniform pattern having raised patches with tubercles all over the surface in most of the accessions except for Accession 7 and *A. gangetica* var. *krishnae*. The seed surface of Accession 7 has eruptive patches of irregularly varying sizes having highly convoluted surface without tubercles. *A. gangetica* var. *krishnae* (Accessions 8) have an entirely different surface architecture with narrowly ovate -polygonal shaped cells in a compact reticulate pattern having sparsely distributed tubercles (Fig. 3).

Reports are on the factors behind the maintenance of flower color variations within populations (13). Flower color is traditionally considered as an adaptation to pollinator visual perception. Non pollinator agents of selection are likely to play a role in populations exhibiting either discrete or continuous color variations. Generally, presence or absence of anthocyanins affects the coloration of the floral display and this is related to flavonoid biosynthetic pathway. In *Clematis patens*, the anthocyanins for flower color variations have been identified as delphinidin and cyanidin glycosides (14). Later, reports are on the detection of anthocyanin and 4 flavonols from the petals of 3 species of *Hibiscus* (15). Further, CHS- D is suggested as the CHS gene solely responsible for anthocyanin production in the floral limbs (16, 17). The biochemical pathways behind the flower color phenotypes in *Ipomoea purpurea* has been traced from the molecular and genetic levels and suggested the possibility to associate discrete floral phenotypes with individual genes (16).

In *Limonium wrightii*, intraspecific variation of flower color and its distribution has been evaluated (18). Allopatric geographical distribution has been recorded for the frequently observed pink and yellow flower color morphs. Further, the observed orange flower color morphs has been suggested as the hybridization product of pink and yellow flower color morphs. The flower color variations in other plant taxa has also became the subject of research (19). Recently, the flower color variations in *Impatiens balsamina* has reported usage as alternative ecofriendly natural acid- base indicators (20).

Basic flower color in *A. gangetica* is governed by 3 sets of genes- P (producing purple pigments in the inner epidermis of the limb), B (producing purple in the outer epidermis of the limb and back of the tube) and Y (producing yellow in the entire limb) which are independent of one another and inherited in a simple Mendelian fashion (21). The genetic variability among the various flower color morphs of *A. gangetica* from Thailand has been analysed using RAPD markers (22) and the study con

oils from *Eucalyptus staigeriana* (Myrtales: Myrtaceae), *Ocimum gratissimum* (Lamiales: Lamiaceae), and *Foeniculum vulgare* (Apiales: Apiaceae) have sublethal effects on the metabolism of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) (67), the control of *P. xylostella* L., chemical components and bioactivity of aqueous extracts of *Alibertia* spp. (Lepidoptera: Plutellidae) (84), *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) is affected by phenylpropanoids produced by *Duguetia lanceolata* A. St.-Hil. stem bark (85), the immunological system of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) immatures was studied using *Azadirachta indica* (Sapindales: Meliaceae) oil (62), *Alabama argillacea* (Lepidoptera: Erebidae) egg-laying behavior and electrophysiological sensitivity to essential oils and chemical compounds (85).

In Indonesia, research on plant insecticides for Lepidoptera is still limited. There were only four publications recorded between 2013 and 2018. The research includes research on the insecticidal properties of *Barringtonia sarcostachys* bark extract on the cabbage head caterpillar *Crocidolomia pavonana* (F.) (86), antifeedant effect, and toxicity of Pontianak citrus peel extract on *S. litura* Fab (Lepidoptera: Noctuidae) (87), *Piper aduncum* fruit and *Tephrosia vogelii* leaf combined formulations show insecticidal action against *P. xylostella* (L.) (Lepidoptera: Plutellidae) (88), the effect of storage temperature on the effectiveness of botanical insecticide combination formulations against *Cocidolomia pavonana* (F.) (Lepidoptera: Crambidae) (56). Based on the data above, it is clear that the research opportunities on insecticide plants for Lepidoptera in Indonesia remain extensive and open. In Indonesia, there is an encouragement to learn more about the compounds that make up the extract, the compounds isolated from the extract, and the mode of action of plant extracts against Lepidoptera pest.

Country Co-Authorship Network

Collaboration has become increasingly important in current research. This is typically represented as international co-authored publications or locally produced interinstitutional research. A bibliometric technique can trace this pattern of collaboration (9, 90). The country co-authorship network on botanical insecticide for Lepidoptera is shown in Fig. 3. The colored circles indicate the countries and the size of the circles indicates the number of international collaborations. The bibliometric analysis revealed that the ticker lines between them represent countries' collaboration strength. Fig. 3 illustrates the frequency and network of past collaboration. According to the findings, the country's co-authorship network is divided into 6 clusters. Cluster one (red nodes) comprises Egypt, India, the Philippines, Saudi Arabia, South Korea and Thailand. Cluster two

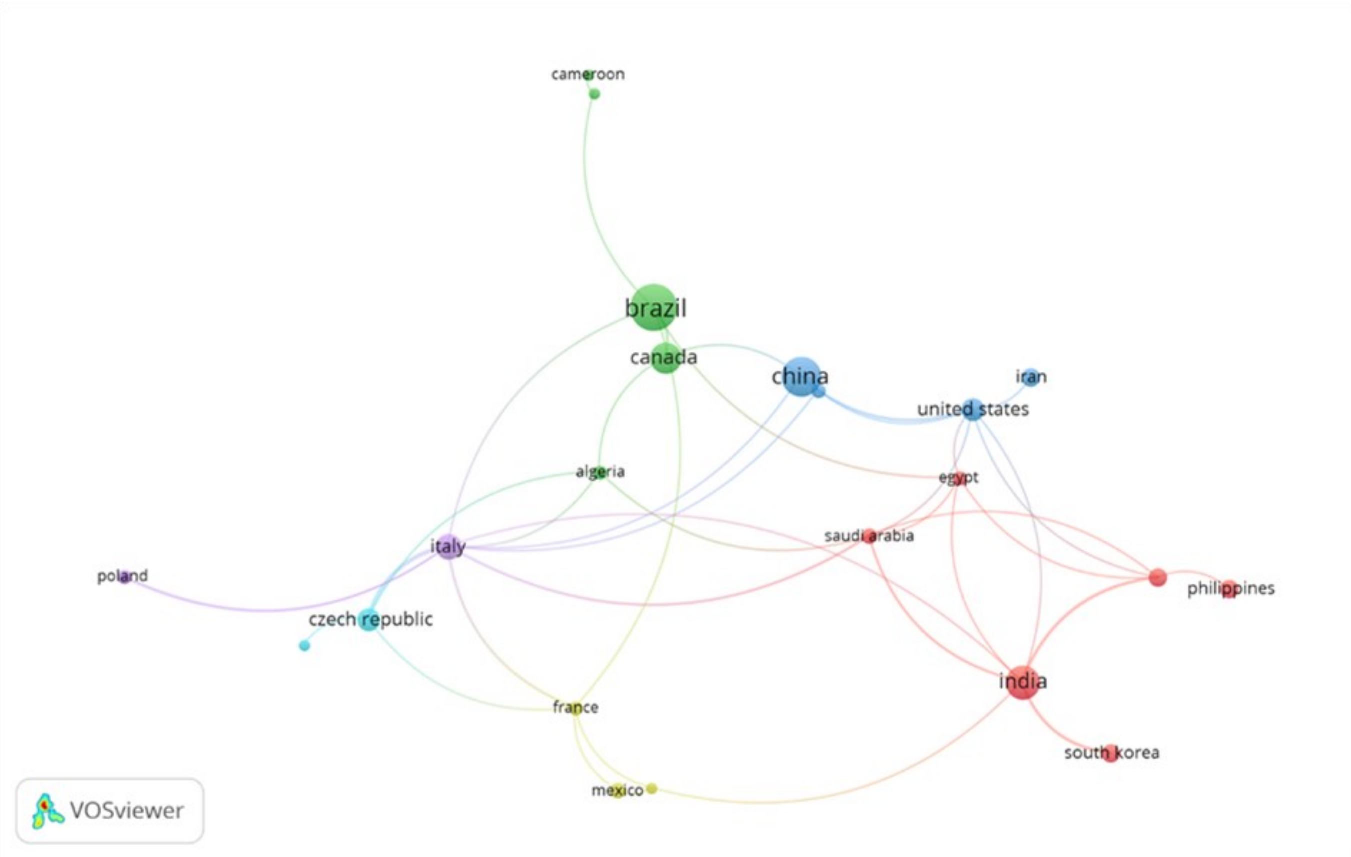

Fig. 3. Co-authorship network between countries from 1985 to 2022 analyzed using VOS clustering.

(green nodes) includes Algeria, Brazil, Cameroon, Canada and United Kingdom. Cluster three (dark blue nodes) comprises Chile, China, Iran and the United States. Cluster four (yellow nodes) includes France, Germany and Mexico. Cluster 5 (purple nodes) includes Italy, Poland and South Africa. Cluster six (light blue nodes) comprises the Czech Republic and Serbia. Some of these countries' collaborative strengths can be attributed to their specific histories of pesticide use and government financing that encourages collaboration (18).

Knowledge of the collaboration between countries researching botanical insecticides for Lepidoptera will make it easier for future researchers to conduct further research collaborations. According to Lee and Bozeman, scientific collaboration in research has become the standard (10, 90). The interdisciplinary and complicated nature of modern science fosters research collaboration. In addition, many funding sources promote collaborative research by making it a requirement for funding (10, 90). Collaboration has a significant impact on the citation rate of a document; international co-authored papers, in particular, have been shown to receive twice as many citations as local co-authored publications (10, 92).

Keyword Co-Occurrence Network

The analysis of author keywords and title words provides useful information about the direction of the research (9, 92), as well as reveals subjective focus (9, 93). The length between nodes and the size of nodes in the keyword co-occurrence network, as shown in Fig. 4, revealed keyword relatedness information and keyword frequency information (19, 94). From the analyses, the keyword co-occurrence network consists of nine clusters, based on the relatedness information between keywords.

Cluster one (56-item keywords and red nodes) used different botanical insecticides for lepidopteran control and toxicity test, cluster two (49-item keywords and green nodes) focuses on botanical insecticides, chemical analysis, and chemical composition, cluster three (49-item keywords and dark blue nodes) encompasses chemical compounds and their effect on insect pests, cluster four (43-item keywords and yellow nodes) focuses on secondary metabolism and biological activity, cluster five (35-item keywords and purple nodes) showed the mode of action of botanical insecticides, cluster six (32-item and light blue nodes) encompasses drug screening from part of the plant (leaf/root), cluster seven (31-item keywords and orange) focuses on the dose-response relationship between botanical insecticides, cluster eight (10-item keywords and brown nodes) showed botanical pesticides and their activity, and cluster nine (8-item keywords and pink nodes) encompasses solvent and entomopathogenic organisms. In addition, the most in-demand research subjects can be found, as shown in Fig. 4. Lepidoptera pests in network clustering include *Mythimna separate*, armyworm, and *Spodoptera frugiferda*. Based on the node's size, *Spodoptera frugiferda* has the largest, which indicates that Spodoptera has a higher keyword frequency than other Lepidoptera (94).

By observing the most researched keywords, opportunities to study and conduct additional research on minor

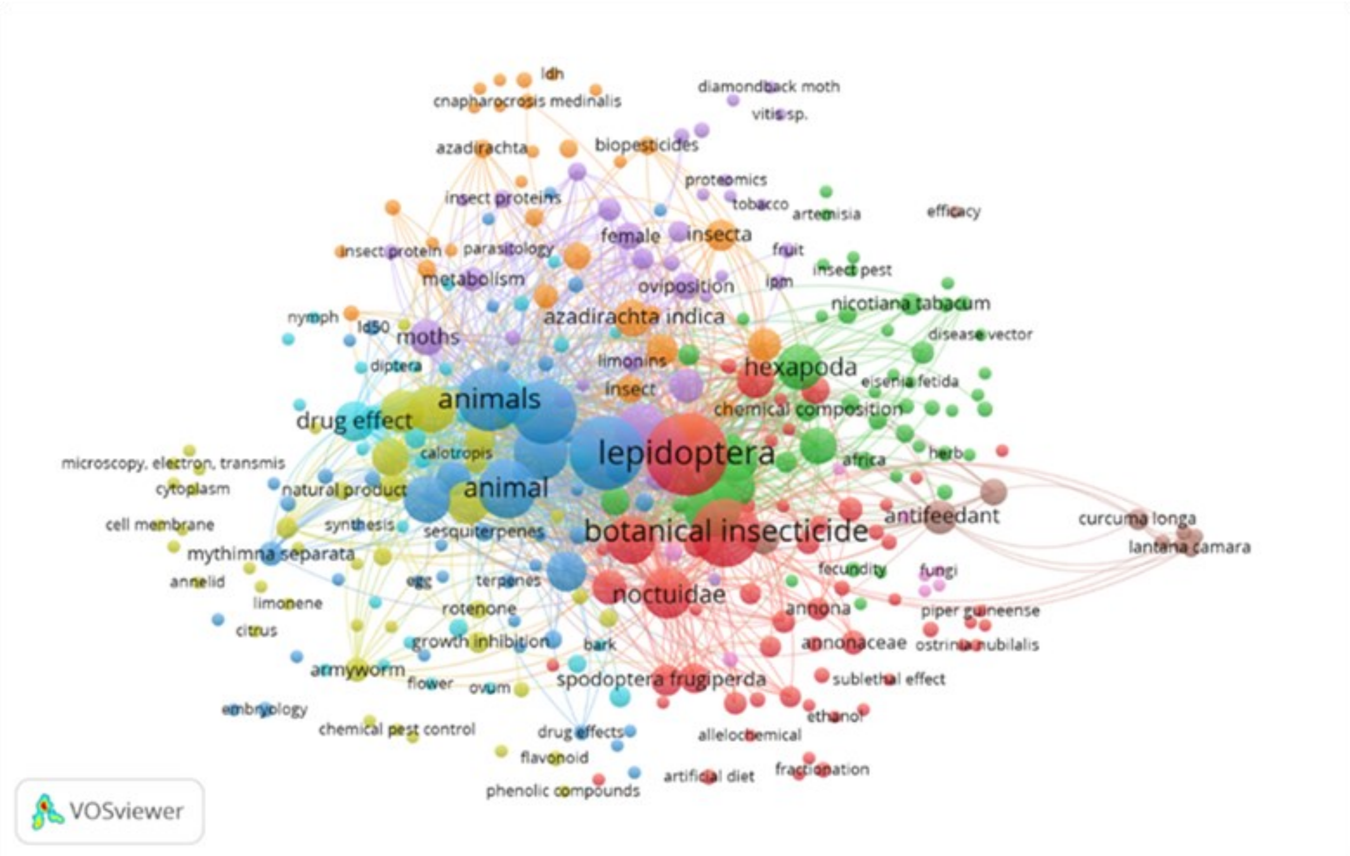

Fig. 4. Keyword co-occurrence network analyzed using VOS clustering from 1985 to 2022.

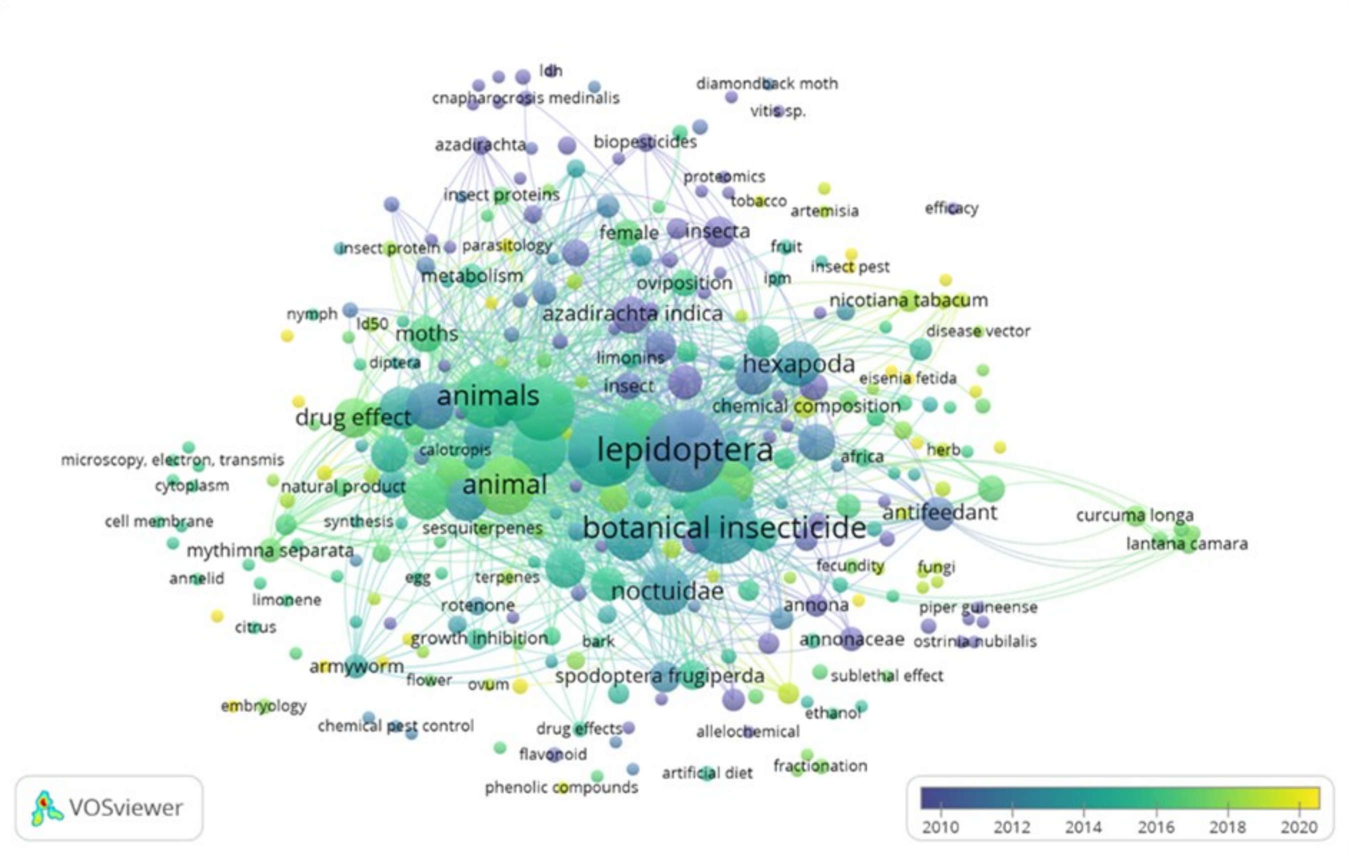

Fig. 5. Overlay visualization of keyword co-occurrence analyzed using VOS clustering from 1985 to 2022.

or rarely researched areas can be discovered, such as "fractionation" in cluster one (red nodes). Understanding the frequency of these keywords can help determine which parts of the research have not been thoroughly investigated. The overlay visualization of the keyword co-occurrence network can be used to find a keyword with much attention and power. Immediate, objective and repeatable insights into the primary research subjects of the field might also be provided (19, 95, 96).

A temporal keywords co-occurrence network based on bibliometric data was developed over the last decade to analyze the research trends in studying botanical insecticides shown in Fig. 5. The node sizes indicate how frequently a keyword appeared. The different node colors represent the average number of publications for each keyword per year, such as purple for articles in 2010, purple-blue for papers in 2012, green-yellow for articles in 2018, and yellow for articles in 2020. Around 2010, keywords such as Annonaceae, antifeedant, insect and botanical insecticides emerged, while insecticidal activity, Noctuidae, enzyme activity and feeding behavior appeared from 2012 to 2014. In addition, Insect protein, chemical structure, essential oil and toxicity testing were used between 2016 and 2018 and around 2020, keywords relating to *Ocimum gratissimum*, ovicidal activity, green pesticide, and molecular structure occurred. It is evident that the research of botanical insecticide has attracted much attention in recent years. As previously discussed, the research trend of botanical insecticides has evolved, beginning with antifeedant activity and progressing to enzyme activity, insect protein and molecular structure.

Conclusion

The research revealed significant trends in biopesticide research. A bibliometric analysis of botanical insecticides for Lepidopteran insects found very few scientific papers. The research began in 1985 and experienced exponential growth after 2006. In addition, the bibliographical network shows the relatedness information about keywords between countries. The information gained contributes to providing a clearer picture of how botanical insecticides will be developed in the future, particularly for lepidopteran insects.

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Authors contributions

NSSS designed the study, managed the analysis of the study, and wrote the first draft of the manuscript. HA performed the statistical analysis. SS, TRN, LHN designed and supervised the study. All authors wrote, read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None.

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