REVIEW

Trends and research hotspots in principal genera of Platypodinae-fungi association: a bibliometric analysis on *Euplatypus, Megaplatypus* and *Platypus* (Coleoptera: Platypodinae)

Tendencias y principales áreas de investigación en los principales géneros de Platypodinae-hongos asociados, un análisis bibliométrico sobre *Euplatypus*, *Megaplatypus* y *Platypus* (Coleoptera: Platypodinae)

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Originales: *Recepción:* 13/09/2023 - *Aceptación:* 24/07/2024

INDEX

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Abstract

Ambrosia beetles of the subfamily Platypodinae are symbiotically associated with fungi, which provide them with food and benefit their establishment and growth. In the present study, our interest centers on the principal genera of Platypodinae: *Euplatypus*, *Megaplatypus* and *Platypus*, the most relevant symbionts being species of *Fusarium*, *Graphium* and *Raffaelea*. The objective of this work is to update the description of fungal associations on those species of interest to the scientific community, ONGs and funding institutions. An exhaustive search was performed to cover all scientific studies from 1900 to 2024 on the co-occurrence or relationship between members of the above-mentioned Platypodinae and fungi. Records of insect and fungal species, host plants and geographic locations were collected. A bibliometric analysis was conducted to characterize the overall status, general trends and current research hotspots of fungi associated with these ambrosia beetles. Eighty percent of the publications retrieved explored the association of *Platypus* spp. with different fungi. *Raffaelea* was the fungal genus showing the highest number of records and worldwide distribution. Five countries from four continents currently lead research on these associations. However, greater insights into these interactions would improve decision-making on managing these pests.

Keywords

ambrosia • beetles • *Fusarium* • *Graphium* • *Raffaelea* • Google Scholar • Scopus • Web of Science

Resumen

Los escarabajos de ambrosía de la subfamilia Platypodinae están asociados simbióticamente con hongos que les proporcionan alimento y benefician su establecimiento y crecimiento. En el presente trabajo, los principales géneros de interés de Platypodinae son *Euplatypus*, *Megaplatypus* y *Platypus*, y los simbiontes más relevantes son especies de *Fusarium*, *Graphium* y *Raffaelea.* El objetivo del trabajo es ofrecer una síntesis actualizada de la información sobre esas especies de interés, para la comunidad científica, las ONG e instituciones financiadoras. Se realizó una búsqueda exhaustiva de todos los estudios científicos desde 1900 hasta 2024 con datos sobre coocurrencia o relaciones entre los Platypodinae antes mencionados y hongos, recogiéndose los registros de especies de insectos y hongos, planta hospedante y localización geográfica. Se realizó un análisis bibliométrico para caracterizar el estado global, las tendencias generales y las áreas de investigación con mayor incidencia sobre hongos asociados a estos escarabajos de ambrosía. El ochenta por ciento de las publicaciones recuperadas exploran la asociación de *Platypus* spp. con diferentes hongos. *Raffaelea* fue el género fúngico con mayor número de registros, con distribución mundial. Cinco países, de cuatro continentes, lideran actualmente la investigación de estas asociaciones. Sin embargo, un mayor conocimiento de estas interacciones ayudaría en la toma de decisiones sobre la gestión de estas plagas.

Palabras clave

ambrosia • escarabajos • *Fusarium* • *Graphium* • *Raffaelea* • Google Scholar • Scopus • Web of Science

Introduction

Platypodinae (pinhole borers) is a subfamily of wood-boring beetles that belong to the Curculionidae family. Most species of this subfamily are members of the artificial group named ambrosia beetles, which form a mutualistic symbiosis with ambrosia fungi, in which fungi are vectored and inoculated directly into wood by the beetle. Timber quality is affected by the staining produced by ambrosia fungi and gallery systems that extend deep into wood (10). Ambrosia beetles feed on fungi growing on sapwood, which provide nutrients and suitable moisture for the development of larvae and pupae (8).

Several Platypodinae species are of particular importance to forest health and have a significant economic impact on forest and fruit tree production in tropical and subtropical countries. Polyphagous species of *Euplatypus* S.L. Wood (*Euplatypus parallelus* Bright & Skidmore), *Megaplatypus* S.L. Wood (*Megaplatypus mutatus* Chapuis) and *Platypus* J.F.W. Herbst (*Platypus cylindrus* J.C. Fabricius*, Platypus koryoensis* Wood & Bright and *Platypus quercivorus* Murayama) cause high economic loss after attacking forest or fruit plantations (9, 29, 30, 31, 34, 95).

Examples of fungi found in association with platypodine beetles include *Fusarium* spp. (17, 18), whose functional roles as a source of nutrition or essential compounds for beetle development have been proposed (15, 33, 68). Species of *Graphium* Corda (Microascales) have been related to Platypodinae (17, 65). For example, *Graphium basitruncatum* (Matsush.) Seifert & G. Okada has been linked with *M. mutatus* males and galleries (18), suggesting that this fungus is a regular associate rather than a primary nutritional ambrosia fungus (17, 19). The synnematous anamorphs of *Ophiostoma* Syd. & P. Syd. and *Pseudallescheria* Negr. & I. Fisch., among other genera, which can be dominant in bark beetle galleries, were often classified as *Graphium* in the past (21).

Raffaelea Arx & Hennebert (Ophiostomatales) is another important associate of Platypodinae. This genus is one of the most widespread ambrosial mutualist genera. The genus has colonized many independent beetle groups throughout its evolution (24). *Raffaelea* species constitute three clades: *Raffaelea sensu stricto*, *Raffaelea lauricola* complex and *Raffaelea sulphurea* complex. Several of these species belong to the genus *Harringtonia* (22). *Raffaelea lauricola* T.C. Harr., Fraedrich & Aghayeva, the etiological agent of laurel wilt, is associated with several ambrosia beetles and attacks lauraceous species (38, 75). Within the *R. sulphurea* complex, *Raffaelea quercivora* Kubono & Shin. Ito is responsible for Japanese oak wilt and associated with *P. quercivorus* (59).

Although numerous studies are exploring fungi associated with *Euplatypus* spp., *Megaplatypus* spp. and *Platypus* spp., these Platypodinae genera, here referred to as EMP, no comprehensive overview of these interactions has yet been compiled.

Scientific databases enable modern research, offering a major reservoir of knowledge and insights across disciplines. They have organized vast amounts of scholarly literature, experimental data and research findings. This is the first time that an EMP and associated fungi database is created to provide an updated database that compiles trends and research hotspots among EMP species within the genera *Fusarium*, *Graphium* and *Raffaelea* and other fungi, enhancing data-sharing to advance science.

Methodology

A search was conducted in the Global Biodiversity Information Facility (GBIF) database (www.gbif.org) and the Bark and Ambrosia Beetles of North and Central America (BAB) database (www.barkbeetles.info) to identify world records of species of the genera EMP. An extensive literature search was performed using Google Scholar (www.scholar.google.com), Scopus (www.scopus.com) and Web of Science (WoS) (www.mjl.clarivate.com) until March 2024. The search included all species previously retrieved from GBIF-BAB and was based on keywords: [each species] *Euplatypus* OR [each species] *Megaplatypus* OR [each species] *Platypus*, plus (+) '*Fusarium*' OR '*Graphium*' OR '*Raffaelea*' OR "Fungi', the last including other fungal genera (e.g. minus (-) '*Fusarium*' - '*Graphium*' - '*Raffaelea*') (figure 1, page 149).

An additional investigation of GBIF was performed to find synonyms for EMP species. Only English-written publications were included in this analysis. In the present study, current species of *Harringtonia*, such as *Harringtonia lauricola* (T.C. Harr., Fraedrich & Aghayeva) Z.W. de Beer & M. Procter (23) were considered within the genus *Raffaelea* due to their historical relevance. Searches covered the last 124 years.

Retrieved publications were screened to meet specific criteria for EMP, which included: 1) record(s) of the beetle-fungus association; 2) geographical reference; and 3) the identity of plant hosts attacked by the insect. The results of this bibliographic research were analyzed using R Studio (2021) on a curated dataset.

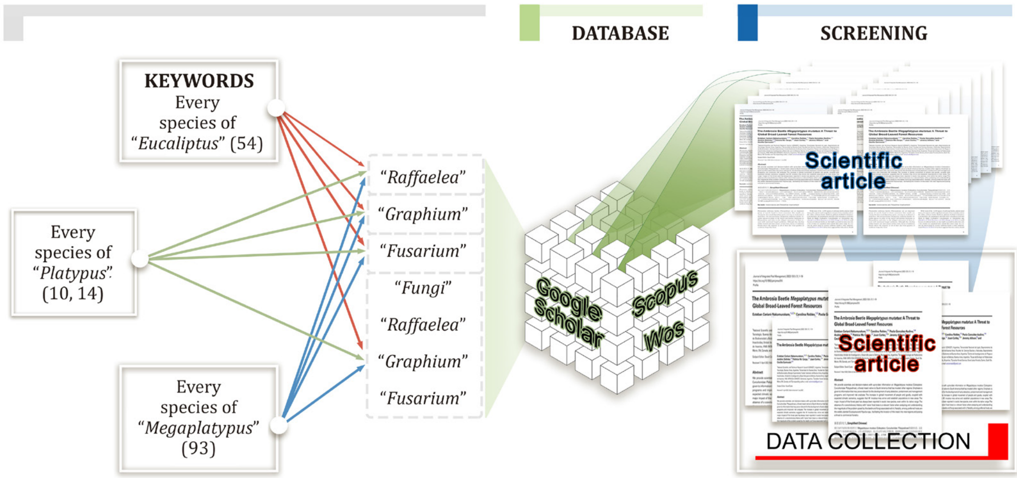


Figure 1. Workflow of search combinations in database search. Numbers in parentheses indicate the number of species within each genus.

Figura 1. Flujo de trabajo realizado mediante combinaciones de búsqueda en diferentes buscadores. Los números entre paréntesis indican el número de especies dentro de cada género.

All the publications of the bibliographic search were grouped under the following categories: *genus of the beetle, species of the beetle, fungal genus, fungal species, region, author, year, longitude* and *latitude*. Categories of fungal species were *Fusarium, Graphium, Raffaelea* and '*Other fungi*', which included the rest of fungal genera. The category *Author* comprised the author of each record or the author of the publication when the record was not registered by the finder. Category *Year* included year of registration or year of publication. The longitude and latitude of the distribution data were obtained using Google Earth 7.1.3. Several reports included only the country; yet, some cases, the province or city was also informed. The map of records was drawn on the MapChart website (www.mapchart.net), where cities, provinces or countries were painted on the map. An additional pie chart was added to each record on the map to show the percentage of fungal records.

VOSviewer version 1.6.19 (2023) was used to build up a network with leading authors, countries, institutions and keywords; it was set up as follows: co-authorship analysis, without clusters, no-normalization, attraction 8 and repulsion 1; co-occurrence analysis for all keywords, without clusters Linlog/modularity, attraction 5 and repulsion 0 (23). In the network map made by this software, each node represents elements, such as authors or countries; the size of nodes represents frequency of occurrence; the color of nodes shows affiliation according to co-authorship and co-occurrence analysis, respectively. The links between two nodes establish collaborative relationships between elements, such as authors or institutions. The thickness of the connecting lines increases with higher collaboration frequencies, and papers with no connections were disregarded by the software.

We selected for further analysis only studies where the association between beetles and fungi was described; studies where the beetle-fungi association was not reported as a new record were dismissed.

Sources and Results

Searches with Google Scholar retrieved more results than those with Scopus or WoS (figure 2). Google Scholar found fifty-six species of *Euplatypus,* ninety-five species of *Megaplatypus* and over one thousand species of *Platypus* in 2,481 publications: 219 publications for *Euplatypus*, 205 for *Megaplatypus,* and 2,057 for *Platypus.* Scopus retrieved 166 publications: 21 for *Euplatypus*, 11 for *Megaplatypus* and 134 for *Platypus*. WoS showed 124 publications: 20 for *Euplatypus,* 16 for *Megaplatypus* and 88 for *Platypus* (figure 2).

Google Scholar found sixty-eight publications on fungi related to EMP, Scopus showed fifty-two and WoS retrieved forty-two. All publications found via Scopus and WoS were also identified by Google Scholar. Most (55 publications) were related to *Platypus* spp. and their associated fungi (82%). Nine publications reported *Euplatypus* and their associated fungi (12%) and the remaining five publications (6%) dealt with *Megaplatypus* and their associated fungi (figure 3).

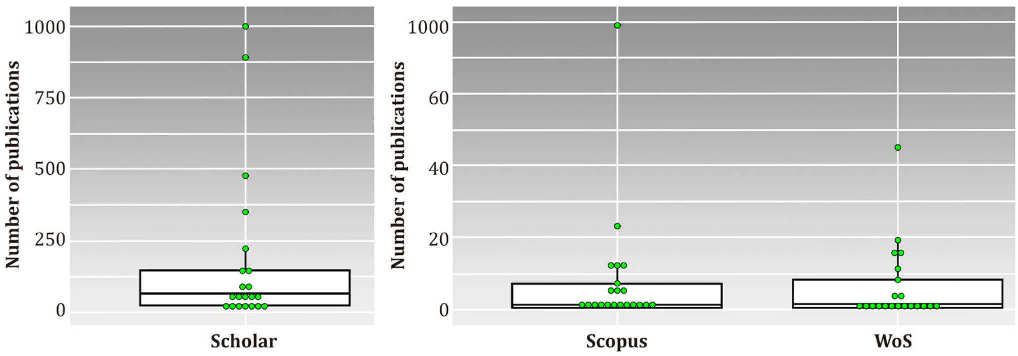


Figure 2. Publications shown for each search combination (figure 1, page 149) in each search engine (Google Scholar, Scopus and WoS).

Figura 2. Número de publicaciones obtenidas para cada combinación de búsqueda (figura 1, pág. 149) en cada buscador (Google Scholar, Scopus and WoS).

Available data range from 1945 to date (no records from 1900-1940 are available; data not shown); (B) Number of publications on *Euplatypus* and *Megaplatypus*; (C) Pie chart represents the percentage of publications for each beetle genus.

Los datos disponibles abarcan desde 1945 hasta la actualidad (no se dispone de registros para el periodo 1900-1940, datos no mostrados); (B) Número de publicaciones de *Euplatypus* y *Megaplatypus*. (C) El gráfico de torta indica el porcentaje de publicaciones para cada género de escarabajos.

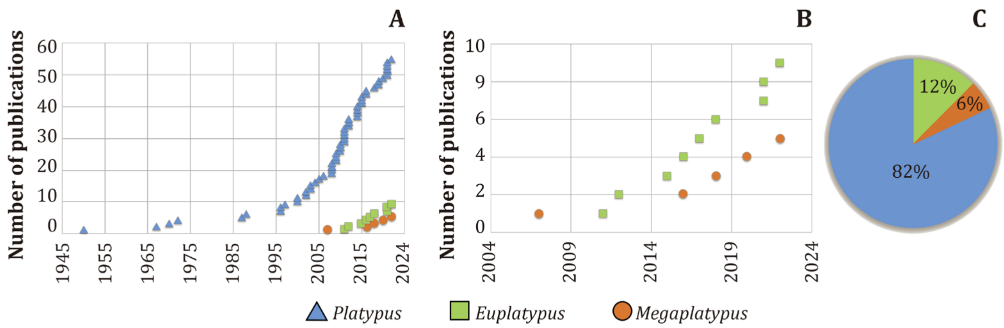


Figure 3. (A) Publications on the association between *Fusarium-Graphium-Raffaelea* (fungi) and *Platypus-Euplatypus-Megaplatypus* (Platypodinae genera).

Figura 3. (A) Publicaciones registradas sobre asociaciones entre *Fusarium-Graphium-Raffaelea* y *Platypus-Euplatypus-Megaplatypus* (géneros de Platypodinae).

Most publications focused on the association of Platypodinae with *Raffaelea,* followed by studies on the association of Platypodinae genera with *Fusarium* spp. The specific *Platypus-Raffaelea* combination was reported in the largest number of publications, followed by the *Platypus-Other fungi* combination (figure 4). Conversely, research on Platypodinae and *Graphium*, especially *Euplatypus-Graphium* and *Megaplatypus-Graphium*, is limited (figure 4).

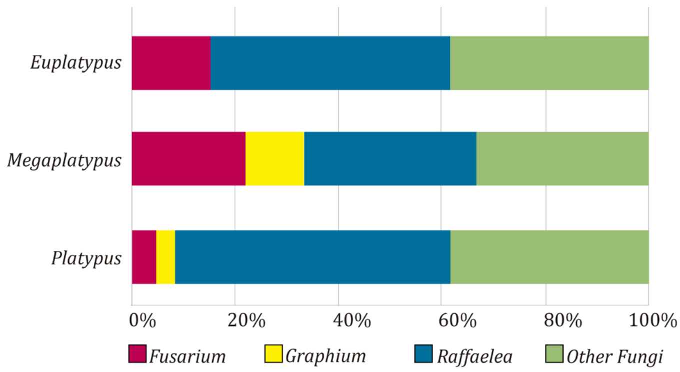


Figure 4. Percentage of publications for each beetle genus–fungal genus combination retrieved from Google Scholar.

Figura 4. Porcentaje de publicaciones para cada combinación de géneros de escarabajo-género fúngico recuperadas de Google Scholar.

Nine publications associated *Euplatypus* with fungi; the beetle species were *Euplatypus compositus* Say & T., *Euplatypus longius* Bright & Skidmore, *E. parallelus, Euplatypus segnis* Bright & Skidmore and other undescribed species of *Euplatypus*. Four publications linked *M. mutatus* or *Megaplatypus godmanii* Bright & Skidmore to fungi, *M. mutatus* being the species most widely studied within the genus. Fifty-five publications related *Platypus* to fungi. Ten species of *Platypus* were included in these studies*: Platypus calamus* Blandford*, P. cylindrus, Platypus externedentatus* Faimare*, Platypus flavicornis* Dalman*, P. koryoensis, Platypus oxyurus* Dufour*, P. quercivorus, Platypus solidus* F. Walker*, Platypus subgranosus* Schedl.*, Platypus wilsoni* J. M. Swaine*,* together with undescribed species of *Platypus.*

Fungi associated with EMP were *Fusarium oxysporum* Schltdl.*, Fusarium solani* (Mart.) Sacc. and undescribed species of *Fusarium*; *Graphium basitruncatum* (Matsush.) Seifert & G. Okada and undescribed species of *Graphium*; *Raffaelea albimanens* D.B. Scott & J.W. du Toit, *Raffaelea ambrosiae* Arx & Hennebert, *Raffaelea campbellii* D.R. Simmons, A. Campb. & R.C. Ploetz*, Raffaelea canadensis* L.R. Batra, *Raffaelea cyclorhipidii* D.R. Simmons & Y.T. Huang, *Raffaelea hennebertii* D.B. Scott & J.W. du Toit, *R. lauricola, Raffaelea montetyi* M. Morelet, *Raffaelea quercina M*.L. Inácio, E. Sousa & F. Nóbrega, *R. quercivora, Raffaelea quercus-mongolicae* K.H. Kim, Y.J. Choi & H.D. Shin, *Raffaelea rapaneae* Musvuugwa, Z.W. de Beer, Dreyer & Roets, *Raffaelea santoroi* Guerrero*, Raffaelea subalba* T.C. Harr., Aghayeva & Fraedrich and undescribed species of *Raffaelea.* Other genera were also sporadically obtained: *Penicillium* Link and *Ceratocystis* Ellis & Halst., among others (figure 5, page 152).

Most of the studies retrieved in this research involved interaction between *P. quercivorus* - *R. quercivora* (72 records, 17 publications) and *P. koryoensis* - *R. quercus-mongolicae* (62 records, 7 publications): two specific associations*.* Another well-documented association was found between *P. cylindrus-R. ambrosiae*, *R. canadensis* and *R. montetyi* (53 records, 15 publications). *Platypus cylindrus* has been reported in Algeria, Canada, England, France, Portugal and Tunisia.

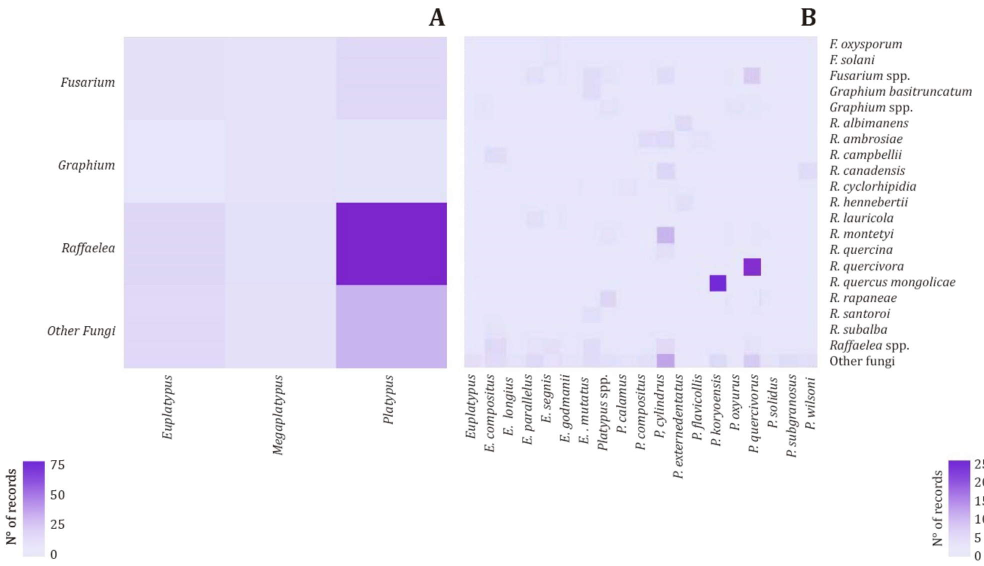


Figure 5. Heatmap of the relationship between (A) beetle genus-fungal genus and (B) fungal species and beetle species.

Figura 5. Mapa de calor sobre asociaciones entre: (A) géneros de escarabajo-género fúngico; (B) especies de escarabajo-especie fúngica.

Darker colors denote more publications in each combination.

La intensidad del color refleja un mayor número de publicaciones en cada combinación.

Concerning *Euplatypus,* most of the records of this genus include species of *Fusarium* and *Raffaelea*. *Euplatypus compositus* (16 records, 6 publications) has been related to *Raffaelea* spp. and other fungi, while *E. paralellus* (9 records, 6 publications) and *E. segnis* (5 records, 2 publications) have been linked to *Fusarium* spp.*, Raffaelea* spp. and other fungi. Most records of *Euplatypus* come from the USA and Mexico, with a few from Southeast Asia and Central America (Belice).

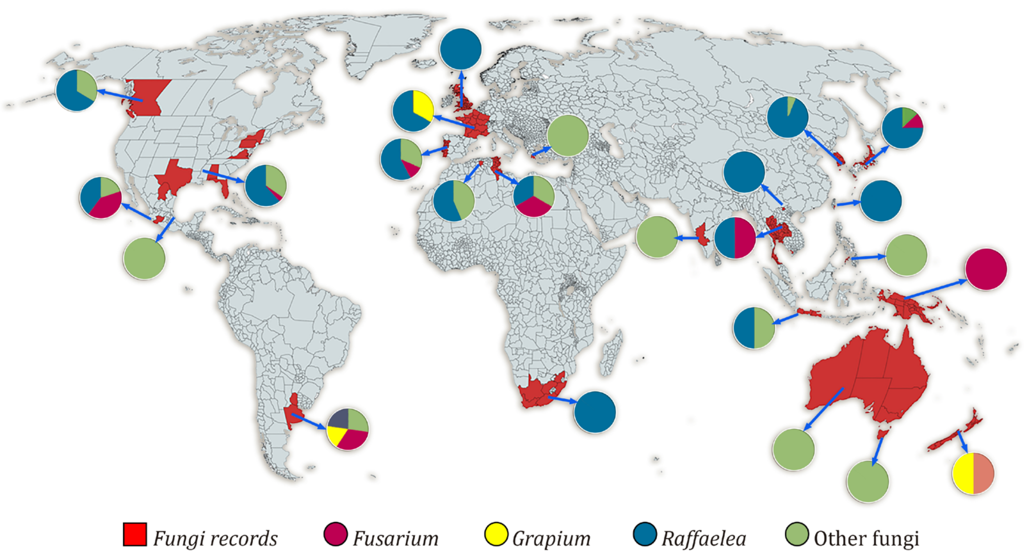
In the case of *M. mutatus,* several studies have related this beetle to undescribed species of *Fusarium* and *Raffaelea, R. santoroi* and *G. basitruncatum* (2, 17, 18, 19). This beetle has been found in many countries; however, reports of its associated fungi are currently limited to Argentina (2). Although this genus has 95 registered species, association with fungi (23 records, 5 publications) has only been found in two, *M. godmani* and *M. mutatus*, both considered as forest pests. The remaining species have not been registered as pests or linked with fungi.

After reviewing the results of bibliometric analysis for countries and authors, our findings suggest that Argentina, Japan, Portugal, South Korea and the USA (alphabetically) are the five countries leading research into ambrosia fungi-Platypodinae (figure 6, page 153).

A total of 23 plant genera were recorded as affected by the ambrosia beetle-fungi association (table 1, page 153-154-155), mainly angiosperms, with *Carya* Nutt.*, Castanopsis* (D. Don) Spach*, Casuarina* L.*, Nothofagus* Blume*, Persea* Mill.*, Populus* L. and *Quercus* L. being the genera most commonly cited. However, most records belong to *Quercus*, with 198 records distributed across 13 countries worldwide.

Through a map of density on Vosviewer, 17 countries seemed to be the most relevant for authors and institutions. A higher density shown by a more intense color and larger bubbles represented greater participation of that country in studies on ambrosia beetles and their associated fungi. Japan, Portugal, South Korea and the USA showed the highest number of publications on ambrosia beetle-fungi within Platypodinae (figure 7, page 156).

As a result of the keyword analysis, the nine most important words were identified: Fungi, Coleoptera, Platypodidae, Scolytinae, Curculionidae, classification, phylogeny, *Platypus quercivorus* and Ophiostomaceae (figure 8, page 156).



Co-authorship was the type of analysis. Countries were the units of analysis. Density view was selected.

La coautoría fue el tipo de análisis. Los países fueron las unidades de análisis. La visualización fue elegida por vista de densidad.

Figure 6. Map based on bibliographic data from selected publications.
Figura 6. Mapa basado en datos bibliográficos, a partir de publicaciones seleccionadas.

Table 1. Summarizes the records from 69 publications, with 53 authors of records, from 22 countries, covering the period from the beginning of the last century to the present.
Tabla 1. Resume la información sobre los registros contenidos en 69 publicaciones, con 53 autores de registros, entre 22 países, abarcando el período desde el inicio del siglo pasado hasta la actualidad.

Beetle genus	Beetle species	Fungal species	Country	Host plant	Reference
Euplatypus	*E. compositus*	*R. ambrosiae*	USA	*Quercus* sp.	(8)
		R. ambrosiae	USA	*Carya* sp.	(37)
		R. campbellii	USA	*Quercus* sp.	(62)
		R. campbellii	USA	--	(85)
		R. subalba	USA	--	(85)
		Raffaelea sp.	USA	*Quercus* sp.	(62)
		Other fungi	USA	*Liquidambar* sp.	(8)
		Other fungi	USA	*Quercus* sp.	(8, 62)
	E. longius	Other fungi	Belice	*Quercus* sp.	(6)
	E. paralellus	*Fusarium* sp.	Thailand	*Pterocarpus* sp.	(41)
		Fusarium sp.	USA	*Quercus* sp.	(62)
		R. lauricola	USA	*Persea* sp.	(67, 74)
		Other fungi	Indonesia	*Pterocarpus* sp.	(89)
		Other fungi	USA	*Quercus* sp.	(6, 62)
	E. segnis	*F. oxysporum*	Mexico	*Carya* sp.	(3)
		F. solani	Mexico	*Carya* sp.	(3)
		Raffaelea sp.	Mexico	*Persea* sp.	(5)
		Other fungi	Mexico	*Carya* sp.	(3)
	Euplatypus sp.	Other fungi	Philippines	*Pinus* sp.	(63)

Detailed data for each record can be found in Table 1S.

Los datos detallados de cada registro se pueden encontrar en la Tabla 1S.

Beetle genus	Beetle species	Fungal species	Country	Host plant	Reference
Megaplatypus	*M. godmanii*	Other fungi	Belice	*Quercus* sp.	(6)
	M. mutatus	*Graphium* sp.	Argentina	*Populus* sp.	(18)
		G. basitruncatum	Argentina	*Populus* sp.	(17, 19)
		G. basitruncatum	Argentina	*Casuarina* sp.	(19)
		F. oxysporum	Argentina	*Casuarina* sp.	(18)
		Fusarium sp.	Argentina	*Casuarina* sp.	(18, 19)
		Fusarium sp.	Argentina	*Populus* sp.	(17, 18, 19)
		R. santoroi	Argentina	*Populus* sp.	(2)
		Raffaelea sp.	Argentina	*Populus* sp.	(17, 19)
		Raffaelea sp.	Argentina	*Casuarina* sp.	(19)
		Other fungi	Argentina	*Populus* sp.	(17, 18, 19)
		Other fungi	Argentina	*Casuarina* sp.	(18, 19)
Platypus	*P. calamus*	*R. cyclorhipidii*	Japan	*Acer* sp.	(82)
		Other fungi	Japan	*Acer* sp.	(82)
	P. cylindrus	*Fusarium* sp.	Portugal	*Quercus* sp.	(12, 43)
		Fusarium sp.	Tunisia	*Quercus* sp.	(12)
		R. ambrosiae	Canada	*Quercus* sp.	(1)
		R. ambrosiae	England	*Quercus* sp.	(35)
		R. ambrosiae	UK	--	(39)
		R. ambrosiae	USA	*Quercus* sp.	(8)
		R. canadensis	Algeria	*Quercus* sp.	(4, 12)
		R. canadensis	Portugal	*Quercus* sp.	(47)
		R. montetyi	Algeria	*Quercus* sp.	(4, 11, 12)
		R. montetyi	Portugal	*Quercus* sp.	(12, 47)
		R. montetyi	Tunisia	*Quercus* sp.	(12)
		R. quercina	Portugal	*Quercus* sp.	(48)
		Raffaelea sp.	Portugal	*Quercus* sp.	(16, 44, 46)
		Other fungi	Algeria	*Quercus* sp.	(4, 11, 14)
		Other fungi	European country	*Ceratonia* sp.	(69)
		Other fungi	Greece	*Mussa* sp.	(86)
		Other fungi	Portugal	*Quercus* sp.	(12, 16, 45, 46, 49)
		Other fungi	Spain	*Quercus* sp.	(80)
		Other fungi	Tunisia	*Quercus* sp.	(14)
		Other fungi	USA	*Quercus* sp.	(8)
	P. externedentatus	*R. albimanens*	South Africa	--	(39)
		R. albimanens	South Africa	*Ficus* sp.	(70, 71, 83)
		R. hennebertii	South Africa	*Ficus* sp.	(70, 71, 83)
	P. flavicornis	*R. ambrosiae*	USA	*Quercus* sp.	(8)
	P. koryoensis	*R. quercus-mongolicae*	South Korea	*Quercus* sp.	(53, 54, 60, 61, 87)
		Other fungi	South Korea	--	(40)
		Other fungi	South Korea	*Quercus* sp.	(87, 94)
	P. oxyurus	*Graphium* sp.	France	*Quercus* sp.	(16)
	P. quercivorus	*Fusarium* sp.	Japan	*Quercus* sp.	(79)
		R. quercivora	Indonesia	*Castanopsis* sp.	(59)
		R. quercivora	Japan	*Castanea* sp.	(57)
		R. quercivora	Japan	*Pasania* sp.	(57)

Detailed data for each record can be found in Table 1S.

Los datos detallados de cada registro se pueden encontrar en la Tabla 1S.

Beetle genus	Beetle species	Fungal species	Country	Host plant	Reference
Platypus	*P. quercivorus*	*R. quercivora*	Japan	*Quercus* sp.	(28, 32, 43, 50, 56, 57, 59, 72, 84, 88, 93)
		R. quercivora	Taiwan	*Castanopsis* sp.	(59)
		R. quercivora	Thailand	*Podocarpus* sp.	(59)
		R. quercivora	Vietnam	*Lithocarpus* sp.	(59)
		R. quercivora	Vietnam	*Quercus* sp.	(59)
		Raffaelea sp.	Japan	*Quercus* sp.	(55)
		Other fungi	Japan	--	(25)
		Other fungi	Japan	*Castanopsis* sp.	(26, 27)
		Other fungi	Japan	*Quercus* sp.	(26, 27, 28, 55, 79)
	P. subgranosus	Other fungi	Australia	--	(7)
		Other fungi	Australia	*Nothofagus* sp.	(52)
		Other fungi	Tasmania	*Nothofagus* sp.	(51)
	P. solidus	Other fungi	India	*Quercus* sp.	(8)
	P. wilsoni	*R. canadensis*	Canada	*Pseudotsuga* sp.	(8)
		R. canadensis	Canada	*Tsuga* sp.	(37, 82)
		Other fungi	Canada	*Pseudotsuga* sp.	(8)
		Other fungi	Canada	--	(78)
	Platypus sp.	*Fusarium* sp.	New Guinea	*Theobroma* sp.	(81)
		Graphium sp.	New Zealand	*Nothofagus* sp.	(77)
		R. montetyi	France	*Quercus* sp.	(65)
		R. rapanae	South Africa	*Rapanea* sp.	(70, 71)
		Other fungi	India	--	(8)
		Other fungi	New Zealand	*Nothofagus* sp.	(66)

Detailed data for each record can be found in Table 1S.

Los datos detallados de cada registro se pueden encontrar en la Tabla 1S.

Some of these keywords were repeated throughout all the publications considered in this survey, thus underlying the importance of certain groups of words identified in this analysis. Fungi and Coleoptera appeared as prominent words in all these articles, which were our areas of interest in this study. The term Platypodidae was associated with an older taxonomic classification of this taxon, now placed at the rank of subfamily Platypodinae. The frequent usage of this keyword is probably attributed to the fact that it has been used for a long time. Another prominent word is Curculionidae, the family that includes (both) Platypodinae and Scolytinae.

Another keyword was ophiostomatoid, an artificial fungi group of Ascomycota which includes important tree pathogens that cause tree mortality and can develop a symbiotic relationship with EMP, as in the species of *Graphium* and *Raffaelea* (28, 39, 57). This group is also composed of many of the fungal genera analyzed in this study, categorized as '*Other fungi*', along with these two key genera that were our primary focus.

Co-authorship was the type of analysis. Countries were the units of analysis. Density view was selected.

La coautoría fue el tipo de análisis. Los países fueron las unidades de análisis. La visualización fue elegida por vista de densidad.

Figure 7. Map based on selected bibliographic data.
Figura 7. Mapa basado en datos bibliográficos seleccionados.

Co-occurrences were the type of analysis. Keywords were the units of analysis; the size of each word indicates frequency of occurrence and interaction with the different articles analyzed.

Las coocurrencias fueron el tipo de análisis. Las palabras clave fueron las unidades de análisis; el tamaño de cada palabra indica su frecuencia de aparición y su interacción con los diferentes artículos analizados.

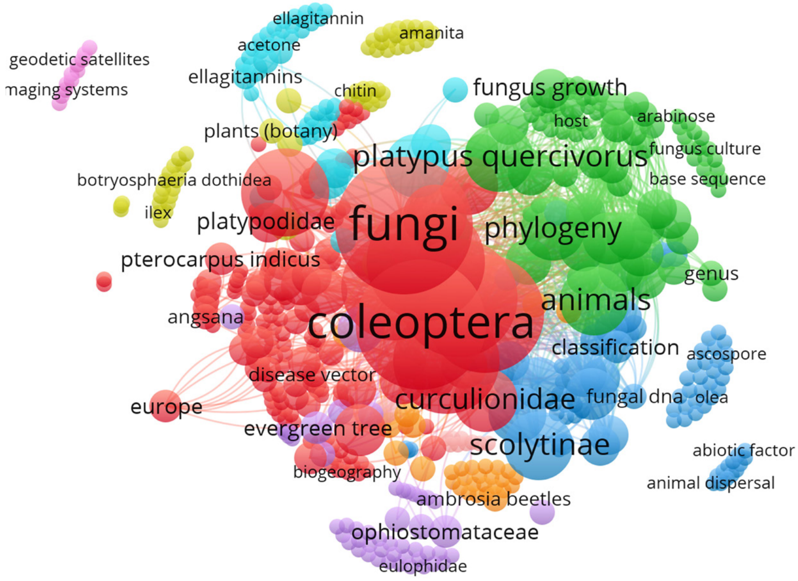


Figure 8. Map based on selected bibliographic data.
Figura 8. Mapa basado en datos bibliográficos seleccionados.

Discussion

In the present study, bibliometric information was used to analyze literature on fungi associated with three genera of Platypodinae, from the beginning of the nineteenth century to the present, to gain a clearer understanding of current research, trends and hotspots of these associations. More publications were found on Google Scholar than on Scopus or WoS. Accordingly, further analysis was performed using Google Scholar.

The first studies on *Platypus* and their associated fungi were published in 1945; however, before 2000, no publications were found on *Euplatypus* or *Megaplatypus* with their associated fungi. Since 2000, the number of publications has rapidly increased, especially since the 2010s. This could be linked an increasing interest in understanding the relationship between the dispersion of ambrosia beetles, including Platypodinae, and their impact on global economies, while also addressing the influence of international trade and climate change on these beetle-fungi interactions (36, 64, 76, 90). An increase in global temperature and the occurrence of extreme meteorological events might contribute to changing population outbreaks and propagating non-native ambrosia beetles outside their native range (76). Most fungal records correspond to *Raffaelea*, which has a worldwide distribution. *Raffaelea* is a crucial genus in most platypodine ambrosial associations, and a few of its species are regarded as important phytopathogens (20). *Raffaelea quercivora* plays a causal role in mass mortality syndrome in Japanese oaks (57); it has been described throughout Japan as associated with *P. quercivorus.* This beetle species is a prominent keyword due to its economic relevance in Japan and the substantial number of associated studies (57). The pathogenicity of *R. quercus-mongolicae* has not been fully confirmed (54); nevertheless, its association with *P. koryoensis* has been intensively studied in South Korea. Several other species of *Raffaele*a have been found to be associated with *P. cylindrus* (4, 11, 13, 45, 47, 48, 49).

Fusarium species, on the other hand, seem to be relevant for the establishment of forest pests (20). Reports of *Fusarium* concentrate on the Northern Hemisphere and are more common than those of *Graphium*. Note that the presence of this genus might be underestimated in diversity studies, especially when using culture-based methods that benefit the growth of more competitive taxa (42). Publications on fungi are found mostly in Argentina, Japan, South Korea, Portugal and the USA. Finally, *Graphium* species have been associated with mycangial platypodines and can also be present in galleries and male exoskeletons, as in the case of *M. mutatu*s-*G. basitruncatum*. It has been proposed that *G. basitruncatum* is one of the first colonizers of the host plant, particularly in newly excavated portions (20).

The almost skewed distribution of the publications analyzed shows that only those countries where EMP genera have been registered as forest pests have further studied their associated fungi. This distribution underlines the importance of these microorganisms at the time of pest settlement and the concentrated research efforts aimed at gaining a deeper understanding of these interactions for effective control *i.e.* as made for other biological models (73, 91).

In the co-occurrence network, which indicates collaboration between countries, it appears that there are limited collaborative relationships among these five countries. A relevant example is the promising and collaborative research program known as the 'Bark Beetle Mycobiome', dedicated to defining research priorities for the widespread insect-fungus symbiosis involving bark beetles. However, these programs are currently absent in the context of three genera of Platypodinae and of ambrosia beetles-fungi symbiosis. Initiating and strengthening these collaborations is essential to address knowledge gaps in this area.

Conclusion

This bibliometric analysis was successful in establishing the state-of-the-art publications on the relationship between EMP and fungi, indicating the most widely studied genera of beetles and fungi. The significance of ambrosia fungi as drivers of ecological interactions has been increasingly recognized. However, the present results suggest that ambrosia mycobiota is still underrepresented in research. Gaining thorough understanding of these interactions will shed light on the interconnectedness of species, contributing to our overall understanding of ecosystem dynamics and resilience.

Our analysis shows that Argentina, Japan, Portugal, South Korea and the USA (alphabetically ordered), among many other countries, have been conducting researches on fungal ambrosia, with limited collaboration between them. Despite successful collaborative initiatives internationally, there is a growing need for more effective partnerships to deepen the knowledge of South American ambrosia beetle-fungi symbiosis.

Supplemmentary material

https://docs.google.com/spreadsheets/d/1rwPDmqyY_Wo3aA0pOjdRNHybABWNSK0T/edit?usp=sharing&ouid=111310786017351827239&rtpof=true&sd=true

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Acknowledgements

This work was supported by the Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET PIP 0844) and Ministerio de Ciencia, Tecnología e Innovación (PICT-BID 2019-0100, PICT BID 2020-00513).

The authors thank Diego Higer for his advice on the use of the software, as well as his support in database accessibility. We also thank Mariana Valente for her invaluable assistance with images.