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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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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*, *Megaplatypu*s 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*, *Megaplatypu*s 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 XXX).

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.

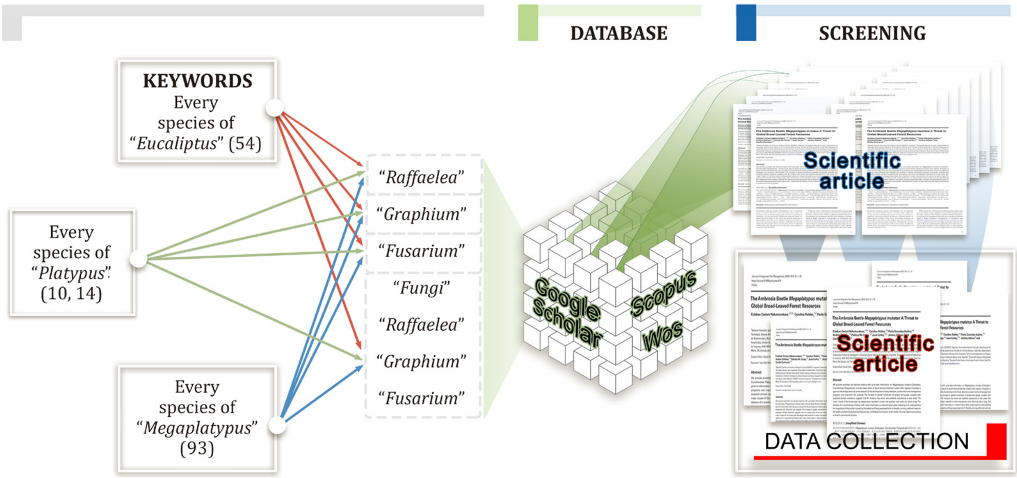


Figure 1. Workflow of search combinations in database search. Numbers in parentheses indicate the number of species within each genus.

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).

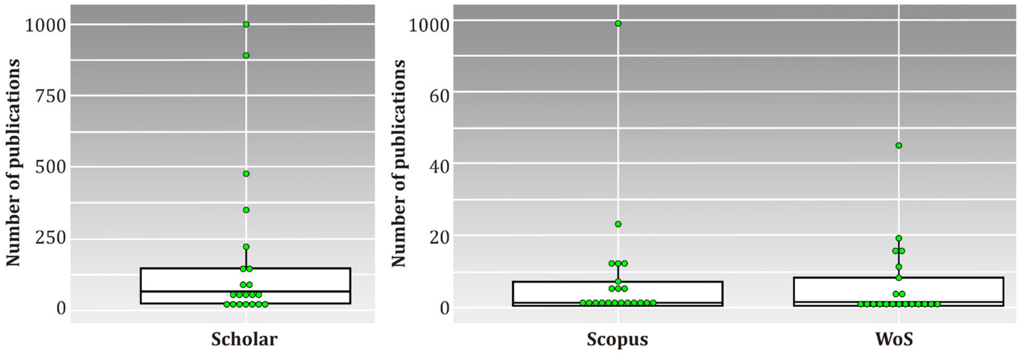
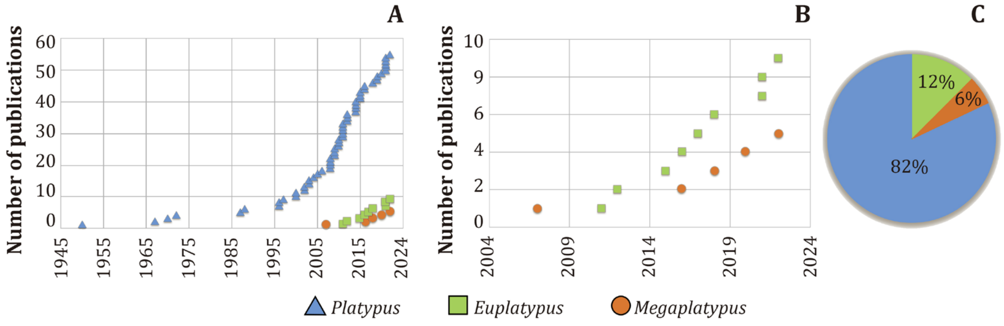


Figure 2. Publications shown for each search combination (figure 1, page XXX) in each search engine (Google Scholar, Scopus and WoS).

Figura 2. Número de publicaciones obtenidas para cada combinación de búsqueda (figura 1, pág. XXX) 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).

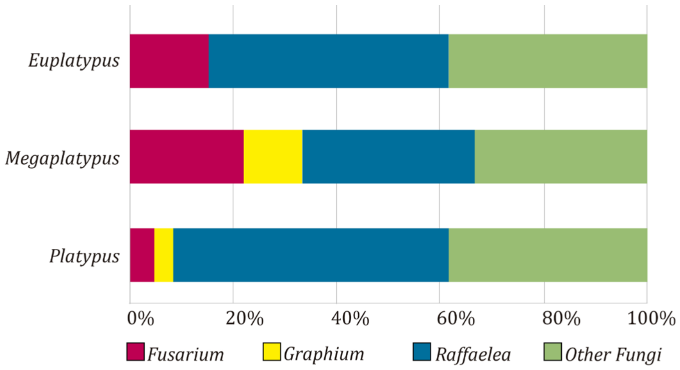


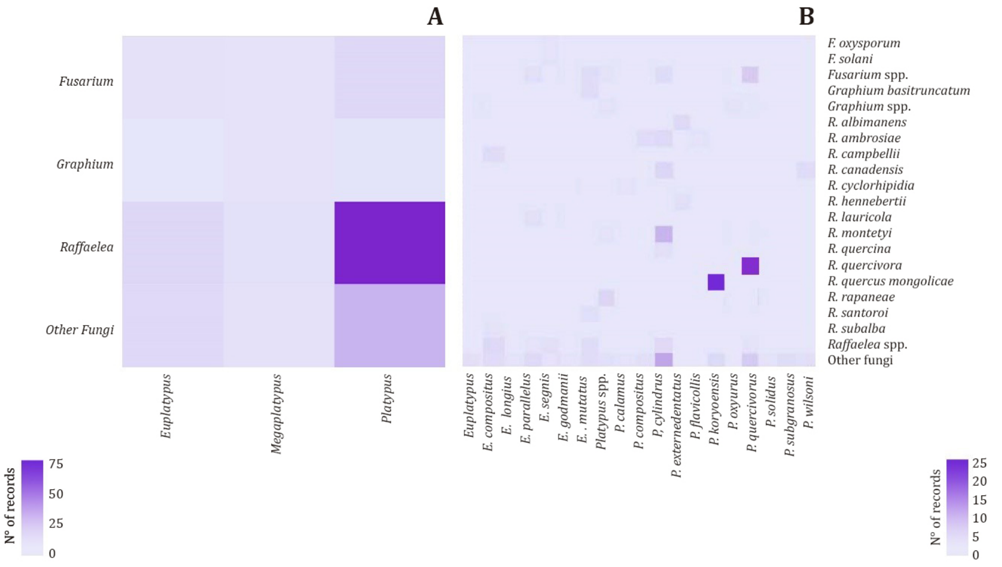
Figure 4. Percentage of publications for each beetle genus–fungal genus combination retrieved from Google Scholar.

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 XXX).

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.



Darker colors denote more publications in each combination.

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

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.

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 XXX).

A total of 23 plant genera were recorded as affected by the ambrosia beetle-fungi association (table 1, page XXX-XXX-XXX), 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 XXX).

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 XXX).

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.

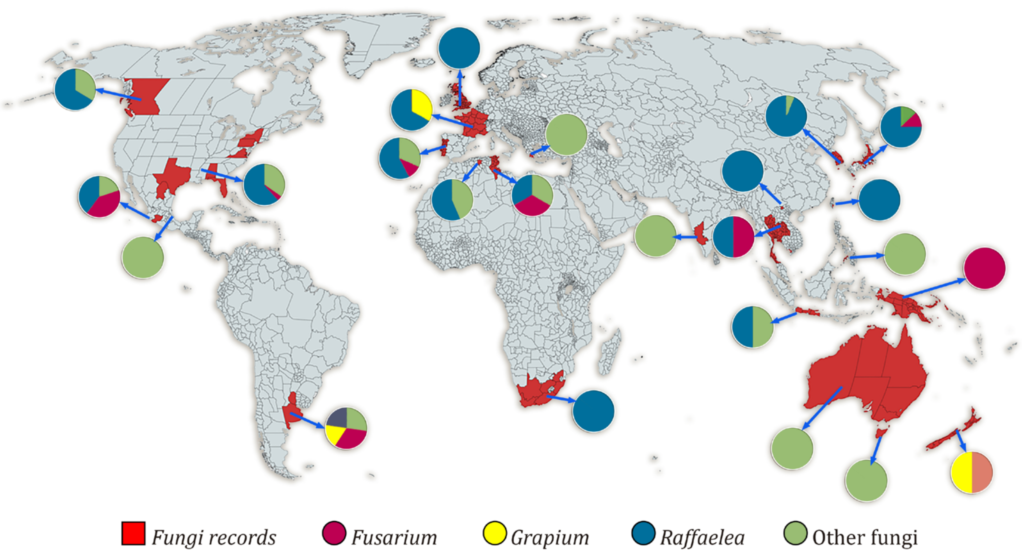


Figure 6. Map based on bibliographic data from selected publications.

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).

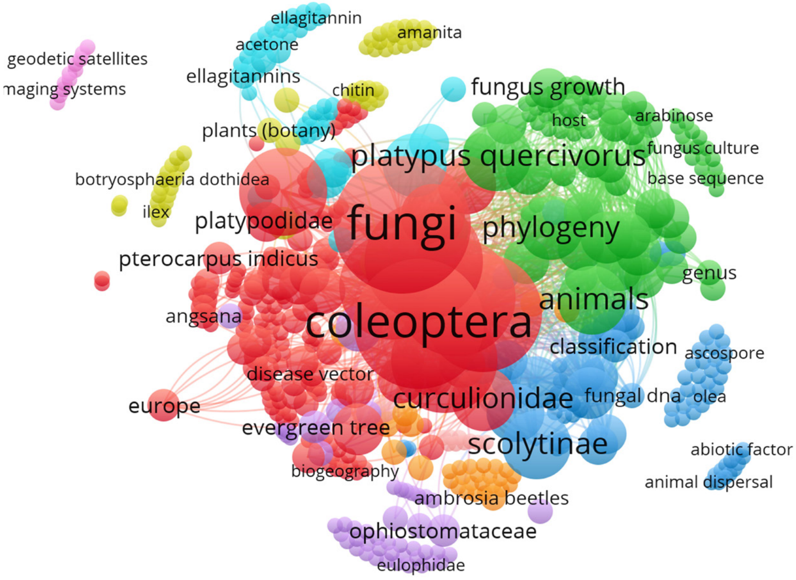


Figure 8. Map based on selected bibliographic data.

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

References

1. Alamouti, S. M.; Tsui, C. K.; Breuil, C. 2009. Multigene phylogeny of filamentous ambrosia fungi associated with ambrosia and bark beetles. Mycological research. 113(8): 822-835. https://doi.org/10.1016/j.mycres.2009.03.003
2. Alfaro, R.; Humble, L.; Gonzalez, P.; Villaverde, R.; Allegro, G. 2007. The threat of the ambrosia beetle *Megaplatypus mutatus* (Chapuis) (= *Platypus mutatus* Chapuis) to world poplar resources. Forestry. 80(4): 471-479. https://doi.org/10.1093/forestry/cpm029
3. Alvidrez-Villarreal, R.; Hernández-Castillo, F. D.; Garcia-Martínez, O.; Mendoza-Villarreal, R.; Rodríguez-Herrera, R.; Aguilar, C. N. 2012. Isolation and pathogenicity of fungi associated with the ambrosia borer (*Euplatypus segnis*) found injuring pecan *(Carya illinoensis*) wood. Agricultural Sciences. 3(3): 19041. https://doi.org/10.4236/as.2012.33048
4. Amoura, M.; Inácio, M. L.; Nóbrega, F.; Bonifacio, L.; Sousa, E.; Chakali, G. 2021. Fungi associated with *Platypus cylindrus* Fab. (Coleoptera: Curculionidae) from *Quercus suber* L. in North-Eastern Algeria. International Journal of Agricultural Policy and Research. 9(1): 1-8. https://doi.org/10.15739/IJAPR.21.001
5. Ángel-Restrepo, M.; Parra, P.; Ochoa-Ascencio, S.; Fernández-Pavía, S.; Vázquez-Marrufo, G.; Equihua-Martínez, A.; Barrientos-Priego, A.; Ploetz, P.; Konkol, J.; Saucedo-Carabez, J.; Gazis, R. 2022. First look into the ambrosia beetle–fungus symbiosis present in commercial avocado orchards in Michoacán, Mexico. Environmental Entomology. 51(2): 385-396. https://doi.org/10.1093/ee/nvab142
6. Araújo, J. P.; Li, Y.; Duong, T. A.; Smith, M. E.; Adams, S.; Hulcr, J. 2022. Four new species of *Harringtonia*: unravelling the laurel wilt fungal genus. Journal of Fungi. 8(6): 613. https://doi.org/10.3390/jof8060613
7. Bakshi, B. K. 1950. Fungi associated with ambrosia beetles in Great Britain. Transactions of the British Mycological Society. 33(1-2): 111-IN11. https://doi.org/10.1016/S0007-1536(50)80054-2
8. Batra, L. R. 1967. Ambrosia fungi: a taxonomic revision, and nutritional studies of some species. Mycologia. 59(6): 976-1017. https://doi.org/10.1080/00275514.1967.12018485
9. Beaver, R. A. 2013. The invasive Neotropical ambrosia beetle *Euplatypus parallelus* (Fabricius 1801) in the Oriental region and its pest status (Coleoptera: Curculionidae: Platypodinae). Entomologist's Monthly Magazine. 149(1): 143-154.
10. Beaver, R. A.; Liu, L. Y. 2013. A synopsis of the pin-hole borers of Thailand (Coleoptera: Curculionidae: Platypodinae). Zootaxa. 3646(4): 447-486. http://dx.doi.org/10.11646/zootaxa.3646.4.7
11. Belhoucine, L.; Bouhraoua, R. T.; Meijer, M.; Houbraken, J.; Harrak, M. J.; Samson, R. A.; Equihua-Martinez, A.; Pujade-Villar, J. 2011. Mycobiota associated with *Platypus cylindrus* (Coleoptera: Curculionidae, Platypodidae) in cork oak stands of north west Algeria, Africa. African Journal of Microbiology Research. 5(25): 4411-4423.
12. Bellahirech, A.; Inácio, M. L.; Bonifácio, L.; Nóbrega, F.; Sousa, E.; Ben Jamâa, M. L. 2014. Comparison of fungi associated with *Platypus cylindrus* F. (Coleoptera: Platypodidae) in Tunisian and Portuguese cork oak stands. IOBC/wprs Bull. 101: 149-156.
13. Bellahirech, A.; Inácio, M. L.; Ben Jamâa, M. L.; Nóbrega, F. 2018. Ophiostomatoid fungi associated with the ambrosia beetle *Platypus cylindrus* in cork oak forests in Tunisia. Tunisian Journal of Plant Protection. 13: 61-76.
14. Bellahirech, A.; Inácio, M. L.; Woodward, S.; Ben Jamâa, M. L.; Nóbrega, F. 2019. *Ophiostoma tsotsi* and *Ophiostoma quercus* associated with *Platypus cylindrus* F. (Coleoptera: Curculionidae) in cork oak stands in Tunisia. Forest Pathology. 49(1): 12482. https://doi.org/10.1111/efp.12482
15. Bumrungsri, S.; Beaver, R.; Phongpaichit, S.; Sittichaya, W. 2008. The infestation by an exotic ambrosia beetle, *Euplatypus parallelus* (F.) (Coleoptera: Curculionidae: Platypodinae) of Angsana trees (*Pterocarpus indicus* Willd.) in southern Thailand. Songklanakarin Journal of Science & Technology. 30(5): 579-582.
16. Cassier, P.; Lévieux, J.; Morelet, M.; Rougon, D. 1996. The mycangia of *Platypus cylindrus* Fab. and *P. oxyurus* Dufour (Coleoptera: Platypodidae). Structure and associated fungi. Journal of Insect Physiology. 42(2): 171-179. https://doi.org/10.1016/0022-1910(95)00056-9
17. Ceriani-Nakamurakare, E.; Slodowicz, M.; González-Audino, P.; Dolinko, A.; Carmaran, C. 2016. Mycobiota associated with the ambrosia beetle *Megaplatypus mutatus*: threat to poplar plantations. Forestry. 89(2): 191-200. https://doi.org/10.1093/forestry/cpw001
18. Ceriani-Nakamurakare, E.; Ramos, S.; Robles, C.; Novas, M. V.; D´Jonsiles, M. F.; González-Audino, P.; Carmarán, C. 2018. Metagenomic approach of associated fungi with *Megaplatypus mutatus* (Coleoptera: Platypodinae). Silva Fennica. 52(3): 9940. https://doi. org/10.14214/sf.9940
19. Ceriani-Nakamurakare, E.; Mc Cargo, P.; Gonzalez-Audino, P.; Ramos, S.; Carmarán, C. 2020. New insights into fungal diversity associated with *Megaplatypus mutatus*: gut mycobiota. Symbiosis. 81: 127-137. https://doi.org/10.1007/s13199-020-00687-8

20. Ceriani-Nakamurakare, E.; Robles, C.; González-Audino, P.; Dolinko, A.; Mc Cargo, P.; Corley, J.; Allison, J.; Carmarán, C. 2022. The ambrosia beetle *Megaplatypus mutatus*: a threat to global broad-leaved forest resources. Journal of Integrated Pest Management. 13(1): 21. https://doi.org/10.1093/jipm/pmac016
21. De Beer, Z. W.; Seifert, K. A.; Wingfield, M. J. 2013. A nomenclator for ophiostomatoid genera and species in the Ophiostomatales and Microascales. In: Seifert K. A.; De Beer, Z. W.; Wingfield, M. J. (Eds). The ophiostomatoid fungi: expanding frontiers. CBS-KNAW Fungal Biodiversity Center, Utrecht. 245-322.
22. De Beer, Z. W.; Procter, M.; Wingfield, M. J.; Marincowitz, S.; Duong, T. A. 2022. Generic boundaries in the Ophiostomatales reconsidered and revised. Studies in Mycology. 101(1): 57-120.
23. de Souza, T. D.; Pinto, A. A.; da Silva, L. F. V; Maciel, R. M. A.; Sosa-Gomez, D. R. 2023. Bibliometric analysis of global research on fungal *Metarhizium rileyi* based on Web of Science. Agronomy Journal. 115(1): 96-107. https://doi.org/10.1002/agj2.21203
24. Dreaden, T. J.; Davis, J. M.; De Beer, Z. W.; Ploetz, R. C.; Soltis, P. S.; Wingfield, M. J.; Smith, J. A. 2014. Phylogeny of ambrosia beetle symbionts in the genus *Raffaelea*. Fungal Biology. 118(12): 970-978. https://doi.org/10.1016/j.funbio.2014.09.001
25. Endoh, R.; Suzuki, M.; Benno, Y. 2008a. *Pichia rarassimilans* sp. nov., a novel yeast species isolated from body surface of the ambrosia beetle *Platypus quercivorus*. The Journal of General and Applied Microbiology. 54(3): 181-186. https://doi.org/10.2323/jgam.54.181
26. Endoh, R.; Suzuki, M.; Benno, Y. 2008b. *Ambrosiozyma kamigamensis* sp. nov. and *A. neoplatypodis* sp. nov., two new ascomycetous yeasts from ambrosia beetle galleries. Antonie van Leeuwenhoek. 94: 365-376. https://doi.org/10.1007/s10482-008-9253-z
27. Endoh, R.; Suzuki, M.; Benno, Y.; Futai, K. 2008c. *Candida kashinagacola* sp. nov., *C. pseudovanderkliftii* sp. nov. and *C. vanderkliftii* sp. nov., three new yeasts from ambrosia beetle-associated sources. Antonie van Leeuwenhoek. 94: 389-402. https://doi.org/10.1007/s10482-008-9256-9
28. Endoh, R.; Suzuki, M.; Okada, G.; Takeuchi, Y.; Futai, K. 2011. Fungus symbionts colonizing the galleries of the ambrosia beetle *Platypus quercivorus*. Microbial ecology. 62: 106-120. https://doi.org/10.1007/s00248-011-9838-3
29. EPPO/OEPP Pest Risk Analysis Reporting Service. 2004a. First report of *Platypus mutatus* in Italy: addition to the EPPO Alert List Nª 04 2004/061.
30. EPPO/OEPP Pest Risk Analysis Reporting Service. 2004b. New information on *Platypus mutatus*. 2004/166.
31. EPPO/OEPP Pest Risk Analysis Reporting Service. 2020. Update on the situation of *Megaplatypus mutatus* in Italy. 2020/218.
32. Esaki, K.; Kato, K.; Kamata, N. 2004. Stand-level distribution and movement of *Platypus quercivorus* adults and patterns of incidence of new infestation. Agricultural and Forest Entomology, 6(1): 71-82. https://doi.org/10.1111/j.1461-9563.2004.00206.x
33. Geib, S. M.; Scully, E. D.; Jimenez-Gasco, M. M.; Carlson, J. E.; Tien, M.; Hoover, K. 2012. Phylogenetic analysis of *Fusarium solani* associated with the Asian longhorned beetle, *Anoplophora glabripennis*. Insects. 3: 141-160. https://doi.org/10.3390/insects3010141
34. González-Audino, P.; Griffo, R.; Gatti, P.; Allegro, G.; Zerba, E. 2013. Pheromone detection of the introduced forest pest *Megaplatypus mutatus* (= *Platypus mutatus*) (Chapuis) (Platypodinae, Curculionidae) in Italy. Agroforestry systems. 87: 109-115. https://doi.org/10.1007/s10457-012-9527-3
35. Green, C. P.; Branch, N. P.; Coope, G. R.; Field, M. H.; Keen, D. H.; Wells, J. M.; Gleed-Owen, C. P. 2006. Marine Isotope Stage 9 environments of fluvial deposits at Hackney, north London, UK. Quaternary Science Reviews. 25(1-2): 89-113. https://doi.org/10.1016/j.quascirev.2004.10.011
36. Grégoire, J. C.; Raffa, K. F.; Lindgren, B. S. 2015. Economics and politics of bark beetles. In: Vega, F. E.; Hofstetter, R. W. (Eds.). Bark beetles: biology and ecology of native and invasive species. UK, London Elsevier Academic Press. 585-613.
37. Haack, R. A.; Cavey, J. F.; Hoebeke, E. R.; Law, K. 1996. *Anoplophora glabripennis*: a new tree-infesting exotic cerambycid invades New York. Newsletter of the Michigan Entomological Society. 41(2-3): 1-3.
38. Harrington, T. C.; Fraedrich, S. W.; Aghayeva, D. N. 2008. *Raffaelea lauricola*, a new ambrosia beetle symbiont and pathogen on the Lauraceae. Mycotaxon. 104: 399-404.
39. Harrington, T. C.; Aghayeva, D. N.; Fraedrich, S. W. 2010. New combinations in *Raffaelea, Ambrosiella*, and *Hyalorhinocladiella*, and four new species from the redbay ambrosia beetle, *Xyleborus glabratus*. Mycotaxon. 111: 337-361. https://doi.org/10.5248/111.337
40. Huang, Y. T.; Skelton, J.; Hulcr, J. 2019. Multiple evolutionary origins lead to diversity in the metabolic profiles of ambrosia fungi. Fungal Ecology. 38: 80-88. https://doi.org/10.1016/j.funeco.2018.03.006
41. Hulcr, J.; Dunn, R. 2011. The sudden emergence of pathogenicity in insect–fungus symbioses threatens naive forest ecosystems. Proceedings of the Royal Society B: Biological Sciences. 278(1720): 2866-2873. https://doi.org/10.1098/rspb.2011.1130
42. Hulcr, J.; Stelinski, L. L. 2017. The ambrosia symbiosis: from evolutionary ecology to practical management. Annual Review of Entomology. 62: 285-303. https://doi.org/10.1146/annurev-ento-031616-035105

43. Imai, K.; Mitsunaga, T.; Takemoto, H.; Yamada, T.; Ito, S. I.; Ohashi, H. 2009. Extractives of *Quercus crispula* sapwood infected by the pathogenic fungi *Raffaelea quercivora* I: comparison of sapwood extractives from noninfected and infected samples. Journal of wood science. 55: 126-132. https://doi.org/10.1007/s10086-008-1005-1
44. Inácio, M. L.; Henriques, J.; Lima, A.; Sousa, E. 2008. Fungi of *Raffaelea* genus (Ascomycota: Ophiostomatales) associated to *Platypus cylindrus* (Coleoptera: Platypodidae) in Portugal. Revista de Ciências Agrárias. 31(2): 96-104. https://doi.org/10.19084/rca.15606
45. Inácio, M. L.; Henriques, J.; Sousa, E. 2010. Mycobiota associated with *Platypus cylindrus* Fab. (Coleoptera: Platypodidae) on cork oak in Portugal. IOBC/wprs Bull. 57: 87-95.
46. Inácio, M. L.; Henriques, J.; Sousa, E. 2011. Contribution of symbiotic fungi to cork oak colonization by *Platypus cylindrus* (Coleoptera: Platypodidae). Silva Lusitana. 19: 89-99.
47. Inácio, M. L.; Henriques, J.; Lima, A.; Sousa, E. 2012. Ophiostomatoid fungi associated with cork oak mortality in Portugal. IOBC/wprs Bulletin. 76: 89-92.
48. Inácio, M. L.; Marcelino, J.; Lima, A.; Sousa, E.; Nóbrega, F. 2021. *Raffaelea quercina* sp. nov. associated with cork oak (*Quercus suber* L.) decline in Portugal. Forests. 12(4): 513. https://doi.org/10.3390/f12040513
49. Inácio, M. L.; Marcelino, J.; Lima, A.; Sousa, E.; Nóbrega, F. 2022. *Ceratocystiopsis quercina* sp. nov. associated with *Platypus cylindrus* on declining *Quercus suber* in Portugal. Biology. 11(5): 750. https://doi.org/10.3390/biology11050750
50. Johnson, B. A.; Tateishi, R.; Hoan, N. T. 2012. Satellite image pansharpening using a hybrid approach for object-based image analysis. ISPRS International Journal of Geo-Information. 1(3): 228-241. https://doi.org/10.3390/ijgi1030228
51. Kile, G. A.; Walker, J. 1987. *Chalara australis* sp nov (Hyphomycetes), a vascular pathogen of *Nothofagus cunninghamii* (Fagaceae) in Australia and its relationship to other *Chalara* species. Australian Journal of Botany. 35(1): 1-32. https://doi.org/10.1071/BT9870001
52. Kile, G. A.; Hall, M. F. 1988. Assessment of *Platypus subgranosis* as a vector of *Chalara australis*, causal agent of a vascular disease of *Nothofagus cunninghamii.* Zealand Journal of Forestry Science. 18(2): 166-86.
53. Kim, K. H.; Choi, Y. J.; Seo, S. T.; Shin, H. D. 2009. *Raffaelea quercus-mongolicae* sp. nov. associated with *Platypus koryoensi*s on oak in Korea. Mycotaxon. 110(1): 189-197. https://doi.org/10.5248/110.189
54. Kim, M. S.; Hohenlohe, P. A.; Kim, K. H.; Seo, S. T.; Klopfenstein, N. B. 2016. Genetic diversity and population structure of *Raffaelea quercus-mongolicae*, a fungus associated with oak mortality in South Korea. Forest pathology. 46(2): 164-167. https://doi.org/10.1111/efp.12263
55. Kinuura, H. 2002. Relative dominance of the mold fungus, *Raffaelea* sp., in the mycangium and proventriculus in relation to adult stages of the oak platypodid beetle, *Platypus quercivorus* (Coleoptera; Platypodidae). Journal of forest research. 7(1): 7-12. https://doi.org/10.1007/BF02762592
56. Komura, R.; Kamata, N.; Kubo, M.; Muramoto, K. I. 2005. Japanese oak wilt (JOW) using high spatial resolution satellite imagery. Proceedings IEEE International Conference Geoscience Remote Sensing, Seoul. https://doi.org/10.1109/IGARSS.2005.1525882
57. Kubono, T.; Ito, S. I. 2002. *Raffaelea quercivora* sp. nov. associated with mass mortality of Japanese oak, and the ambrosia beetle (*Platypus quercivorus*). Mycoscience. 43: 0255-0260. https://doi.org/10.1007/s102670200037
58. Kumar, R. V. 2021. Exploratory data analysis using R & RStudio. 1-23. Bhubaneswar, India: International Management Institute.
59. Kusumoto, D.; Masuya, H.; Hirao, T.; Goto, H.; Hamaguchi, K.; Chou, W. I.; Suasa-ard, W.; Buranapanichpan, S.; Uraichen, S.; Kern-asa, O.; Sanguansub, S.; Panmongkol, A.; Quang, T.; Kahono, S.; Julistiono, H.; Kamata, N. 2014. Discoloration induced by *Raffaelea quercivora* isolates in *Quercus serrata* logs and its relation to phylogeny: a comparison among isolates with and without the Japanese oak wilt incidence including outside of Japan. Journal of Forest Research. 19(4): 404-410. https://doi.org/10.1007/s10310-013-0420-3
60. Lee, D. H.; Son, S. Y.; Seo, S. T.; Lee, J. K. 2020. Investigation of the mating-type distribution of *Raffaelea quercus-mongolicae* in South Korea. Forest Pathology. 50(3): e12590. https://doi.org/10.1111/efp.12590
61. Lee, D. H.; Jung, J. M.; Seo, S. T. 2021. Population genetic structure of *Raffaelea quercus-mongolicae* indicates a recent fungal introduction event to Jeju Island from inland areas of South Korea. Plant Pathology. 70(8): 1871-1882. https://doi.org/10.1111/ppa.13427
62. Li, Y.; Huang, Y. T.; Kasson, M. T.; Macias, A. M.; Skelton, J.; Carlson, P. S.; Yin, M.; Hulcr, J. 2018. Specific and promiscuous ophiostomatalean fungi associated with Platypodinae ambrosia beetles in the southeastern United States. Fungal Ecology. 35: 42-50. https://doi.org/10.1016/j.funeco.2018.06.006
63. Lopez, A. L.; Pamunag, C. M.; Lozada, A. O.; Bagaforo, R. O. 2022. First report of the pinhole borer (*Euplatypus* sp.) to cause stem bleeding of rubber trees in the Philippines. Journal of Rubber Research. 25(2): 151-155. https://doi.org/10.1007/s42464-022-00165-4

64. Marini, L.; Haack, R. A.; Rabaglia, R. J.; Petrucco Toffolo, E.; Battisti, A.; Faccoli, M. 2011. Exploring associations between international trade and environmental factors with establishment patterns of exotic Scolytinae. Biological Invasions. 13: 2275-2288. https://doi.org/10.1007/s10530-011-0039-2

65. Matsuda, Y.; Kimura, K.; Ito, S. I. 2010. Genetic characterization of *Raffaelea quercivora* isolates collected from areas of oak wilt in Japan. Mycoscience. 51(4): 310-316. https://doi.org/10.1007/S10267-010-0040-0

66. McKenzie, E. H. C.; Buchanan, P. K.; Johnston, P. R. 2000. Checklist of fungi on *Nothofagus* species in New Zealand. New Zealand Journal of Botany. 38(4): 635-720. https://doi.org/10.1080/0028825X.2000.9512711

67. Menocal, O.; Kendra, P. E.; Montgomery, W. S.; Crane, J. H.; Carrillo, D. 2018. Vertical distribution and daily flight periodicity of ambrosia beetles (Coleoptera: Curculionidae) in Florida avocado orchards affected by laurel wilt. Journal of Economic Entomology. 111(3): 1190-1196. https://doi.org/10.1093/jee/toy044

68. Morales-Ramos, J. A.; Rojas, M. G.; Sittertz-Bhatkar, H.; Saldaña, G. 2000. Symbiotic relationship between *Hypothenemus hampei* (Coleoptera: Scolytidae) and *Fusarium solani* (Moniliales: Tuberculariaceae). Annals of the Entomological Society of America. 93: 541-547. https://doi.org/10.1603/0013-8746(2000)093[0541:SRBHHC]2.0.CO;2

69. Morales-Rodríguez, C.; Sferrazza, I.; Aleandri, M. P.; Dalla Valle, M.; Speranza, S.; Contarini, M.; Vannini, A. 2021. The fungal community associated with the ambrosia beetle *Xylosandrus compactus* invading the mediterranean maquis in central Italy reveals high biodiversity and suggests environmental acquisitions. Fungal biology. 125(1): 12-24. https://doi.org/10.1016/j.funbio.2020.09.008

70. Musvuugwa, T. 2014. Biodiversity and ecology of ophiostomatoid fungi associated with trees in the Cape Floristic Region of South Africa. Stellenbosch University, Ph.D.

71. Musvuugwa, T; De Beer, Z. W.; Duong, T. A.; Dreyer, L. L.; Oberlander, K. C.; Roets, F. 2015. New species of Ophiostomatales from Scolytinae and Platypodinae beetles in the Cape Floristic Region, including the discovery of the sexual state of *Raffaelea*. Antonie van Leeuwenhoek. 108: 933-950. https://doi.org/10.1007/s10482-015-0547-7

72. Nakajima, H.; Ishida, M. 2014. Decline of *Quercus crispula* in abandoned coppice forests caused by secondary succession and Japanese oak wilt disease: Stand dynamics over twenty years. Forest Ecology and Management. 334: 18-27. https://doi.org/10.1016/j.foreco.2014.08.021

73. Pelizza, S.; Mancini, M.; Russo, L.; Vianna, F.; Scorsetti, A. C. 2023. Control capacity of the LPSc 1067 strain of *Beauveria bassiana* (Ascomycota: Hypocreales) on different species of grasshoppers (Orthoptera: Acrididae: Melanoplinae), agricultural pests in Argentina. Revista de la Facultad de Ciencias Agrarias. Universidad Nacional de Cuyo. Mendoza. Argentina. 55(1): 98-103. DOI: https://doi.org/10.48162/rev.39.099

74. Peña, J. E; Weihman, S. W.; McLean, S.; Cave, R. D.; Carrillo, D.; Duncan, R. E.; Krauth, S.; Thomas, M.; Lu, S.; Kendra, P. E.; Roda, A. L. 2015. Predators and parasitoids associated with Scolytinae in *Persea* species (Laurales: Lauraceae) and other Lauraceae in Florida and Taiwan. Florida Entomologist. 98(3): 903-910. https://doi.org/10.1653/024.098.0314

75. Ploetz, R. C.; Konkol, J. L.; Narvaez, T.; Duncan, R. E.; Saucedo, R. J.; Mantilla, J.; Campbell, A.; Carrillo, D.; Kendra, P. E. 2017. Presence and prevalence of *Raffaelea lauricola*, cause of laurel wilt, in different species of ambrosia beetle in Florida, USA. Journal of Economic Entomology. 110(2): 347-354. https://doi.org/10.1093/jee/tow292

76. Pureswaran, D. S.; Meurisse, N.; Rassati, D.; Liebhold, A. M.; Faccoli, M. 2022. Climate change and invasions by nonnative bark and ambrosia beetles. In: Hostetter, R. W.; Gandhi, K. (Eds.) Bark beetle management, ecology and climate change. USA, New York Academic Press. 3-30. https://doi.org/10.1016/B978-0-12-822145-7.00002-7

77. Ridley, G. S.; Bain, J.; Bulman, L. S.; Dick, M. A.; Kay, M. K. 2000. Threats to New Zealand's indigenous forests from exotic pathogens and pests. Department of Conservation, Wellington, Science for Conservation. 142. 67.

78. Roeper, R. A. 1972. Biology of symbiotic fungi associated with ambrosia beetles of western United States. Oregon State University, Ph.D. 145 p.

79. Qi, H. Y.; Wang, J. G.; Endoh, R., Takeuchi, Y.; Tarno, H.; Futai, K. 2011. Pathogenicity of microorganisms isolated from the oak platypodid, *Platypus quercivorus* (Murayama) (Coleoptera: Platypodidae). Applied entomology and zoology. 46: 201-210. https://doi.org/10.1007/s13355-011-0032-3

80. Sánchez, M. E.; Venegas, J.; Romero, M. A.; Phillips, A. J.; Trapero, A. 2003. *Botryosphaeria* and related taxa causing oak canker in southwestern Spain. Plant disease. 87(12): 1515-1521. https://doi.org/10.1094/PDIS.2003.87.12.1515

81. Sanderson, F. R.; King, F. Y.; Pheng, Y. C.; Ho, O. K.; Anuar, S. 1997. A *Fusarium* wilt (*Fusarium oxysporum*) of angsana (*Pterocarpus indicus*) in Singapore: I. Epidemiology and identification of the causal organism. Arboricultural Journal. 21(3): 187-204. https://doi. org/10.1080/03071375.1997.9747165

82. Saragih, S. A.; Kusumoto, D.; Takemoto, S.; Torii, M.; Kamata, N. 2021. Virulence of fungi isolated from ambrosia beetles to *Acer amoenum* branches. Plant Disease. 105(10): 3087-3091. https://doi.org/10.1094/PDIS-11-20-2543-R

83. Scott, D. B.; Du Toit, J. W. 1970. Three new *Raffaelea* species. Transactions of the British Mycological Society. 55(2): 181-IN1.

84. Seo, M. Y.; Matsuda, Y.; Nakashima, C.; Ito, S. I. 2012. Taxonomic reevaluation of *Raffaelea quercivora* isolates collected from mass mortality of oak trees in Japan. Mycoscience. 53(3): 211-219. https://doi.org/10.1007/S10267-011-0154-Z

85. Simmons, D.; De Beer, Z.; Huang, Y.; Bateman, C.; Campbell, A.; Dreaden, T. J.; Li, Y.; Ploetz, R.; Black, A.; Li, H.; Chen, C.; Wingfied, M.; Hulcr, J. 2016. New *Raffaelea* species (Ophiostomatales) from the USA and Taiwan associated with ambrosia beetles and plant hosts. IMA fungus. 7: 265-273. https://doi.org/10.5598/imafungus.2016.07.02.06

86. Soulioti, N.; Tsopelas, P.; Woodward, S. 2015. *Platypus cylindrus*, a vector of *Ceratocystis platani* in *Platanus orientalis* stands in Greece. Forest pathology. 45(5): 367-372. https://doi.org/10.1111/efp.12176

87. Suh, D. Y.; Hyun, M. W.; Kim, S. H.; Seo, S. T.; Kim, K. H. 2011. Filamentous fungi isolated from *Platypus koryoensis*, the insect vector of oak wilt disease in Korea. Mycobiology. 39(4): 313-316. https://doi.org/10.5941/MYCO.2011.39.4.313

88. Takahashi, Y. S.; Matsushita, N.; Hogetsu, T. 2015. Genotype distribution of *Raffaelea quercivora* in the oak galleries and its composition in the mycangia of *Platypus quercivorus*. Forest Pathology. 45(2): 149-154. https://doi.org/ 10.1111/efp.12148

89. Tarno, H.; Septia, E. D.; Aini, L. Q. 2016. Microbial community associated with ambrosia beetle, *Euplatypus parallelus* on sonokembang, *Pterocarpus indicus* in Malang. Agrivita Journal of Agricultural Science. 38(3): 312-320.

90. Urvois, T.; Auger-Rozenberg, M. A.; Roques, A.; Rossi, J. P.; Kerdelhue, C. 2021. Climate change impact on the potential geographical distribution of two invading *Xylosandrus* ambrosia beetles. Scientific Reports. 11(1): 1339. https://doi.org/10.1038/s41598-020-80157-9

91. Vianna, F.; Russo, L.; Troncozo, I.; Ferreri, N.; de Abajo, J. M.; Scorsetti, A. C.; Pelizza, S. 2023. Susceptibility of Rhyzopertha dominica(Coleoptera: Bostrichidae) and *Sitophilus oryzae* (Coleoptera: Curculionidae) to the fungal entomopathogen *Beauveria bassiana* (Balsamo-Crivelli) Vuillemin s.l. (Hypocreales: Clavicipitaceae). Revista de la Facultad de Ciencias Agrarias. Universidad Nacional de Cuyo. Mendoza. Argentina. 55(2): 76-84. DOI: https://doi.org/10.48162/rev.39.110

92. VOSviewer version 1.6.17. 2023. Centre for Science and Technology Studies, Leiden University, The Netherlands. https://www.vosviewer.com (Accessed June 2023).

93. Yamada, T.; Ichihara, Y.; Hori, K. 2003. Defense responses of oak trees against the fungus *Raffaelea quercivora* vectored by the ambrosia beetle *Platypus quercivorus*. Proceedings IUFRO Kanazawa Forest insect population dynamics and host influences. Kanazawa University, Kanazawa. 132-135 p.

94. Yun, Y. H.; Suh, D. Y.; Yoo, H. D.; Oh, M. H.; Kim, S. H. 2015. Yeast associated with the ambrosia beetle, *Platypus koryoensis*, the pest of oak trees in Korea. Mycobiology. 43(4): 458-466. https://doi.org/10.5941/MYCO.2015.43.4.458

95. Zanuncio, J. C.; Sossai, M. F.; Couto, L.; Pinto, R. 2002. Occurrence of *Euplatypus parallelus*, *Euplatypus* sp. (col.: Euplatypodidae) and *Xyleborus affinis* (col.: Scolytidae) in *Pinus* sp. in Ribas do Rio Pardo, Mato Grosso do Sul, Brazil. Revista Árvore. 26: 387-389. https://doi.org/10.1590/ S0100-67622002000300015

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