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A review of research trends on *Nattrassia mangiferae* from 1966-2022: A bibliometric approach

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In recent years, *Nattrassia mangiferae* has received tremendous attention as a destructive plant pathogen that may potentially infect humans and animals. The pathogen was isolated from 61 species belonging to 47 genera and 30 family plants but was most frequently isolated from Cactaceae, Rosaceae, Euphorbiaceae, Anacardiaceae, and Rutaceae hosts. To systematically and comprehensively describe the progress, trends, and hotspots of *N. mangiferae* research, the 376 related publications from 1966 to 2022 were collected from the Scopus database. The bibliometric characteristics including publication output, countries/region of focus, author's productivity, most prolific authors, authorship pattern, citation frequency, institutes, most prolific journals, and research focus were evaluated by using Excel 2013 and VOSviewer. Out of 376 original articles, there are 139 plant and 237 human studies. The leading countries based on the number of publications were the United States, the United Kingdom, and Brazil. A sharp increase in the number of studies related to the pathogenicity of *N. mangiferae* during 2018 to 2021 was observed, coinciding with an increase in the number of short reports and outbreak reports worldwide. The journal and subject categories with the most significant publications are Plant Disease and Medical Mycology, respectively. The most common document types were article, note, review, and letter. *N. mangiferae* is a thermophilic fungus, and warming temperatures may weaken trees and affect their susceptibility to this pathogen. The increase in reports of the pathogenicity of this pathogen on various plants and humans from 70 different countries in recent years shows the importance of this pathogen as a sever threat to the world. Our bibliometric analysis reveals the current research hotspots and topic trends on *N. mangiferae*, thus offering potential clues for further examination.

Key words: *Neoscytalidium dimidiatum*, plant pathogen, Onychomycosis, VOSviewer, Iran.

INTRODUCTION

The genus *Nattrassia* is a member of the Botryosphaeriaceae family (Dothideomycetes, Pezizomycotina, Ascomycota) that produces multiple morphologically distinct anamorphs (synanamorphs). The synanamorph of this genus is *Neoscytalidium* that contains four species, including *Neoscytalidium*

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dimidiatum, *Neoscytalidium novaehollandiae*, *Neoscytalidium oculus*, and *Neoscytalidium orchidacearum* (Crous et al., 2006; Pavlic et al., 2008; Huang et al., 2016; Calvillo-Medina et al., 2019). This genus may potentially infect plants (Türkölmez et al., 2019b; Goudarzi and Moslehi, 2020; Taguiam et al., 2021), humans, and animals (Bakhshizadeh et al., 2014; Dionne et al., 2015). The distribution of this genus has extended to all continents. Neoscytalidium genus can influence the different parts of plants by causing diseases that show various symptoms on aerial and underground parts of hosts, including shoot blight canker and gummosis (Polizzi et al., 2009), dieback (Ray et al., 2010), collar and root rot (Machado et al., 2012), brown spot (Lan et al., 2012), death of graft (Chen et al., 2013), internal black rot (Ezea et al., 2013), shoot and needle blight (Türkölmez et al., 2019a), tuber rot (Derviş et al., 2020a), root and stem rot (Oksal and Ozer, 2021; Kuruppu et al., 2021), stem-end rot (Li et al., 2021), sooty canker (Yeganeh and Mohammadi, 2022), and leaf scorch (Güney et al., 2022) (Table 1). Members in the genus *Neoscytalidium* have been reported as pathogenic agents on various crops and trees, such as almond (*Prunus dulcis*), *Avicennia marina* Forssk., baobab (*Adansonia gibbosa*), bardi bush (*Acacia synchronica*), blue grevillea (*Grevillia agrifolia*), rattlepod (*Crotalaria medicaginea*), olive (*Olea europaea* L.), etc. (Table 1), causing economic yield losses (Pavlic et al., 2008; Ray et al., 2010; Sakalidis et al., 2011; Rahmani, 2018; Chakusary et al., 2019; Sabernasab et al., 2019; Derviş et al., 2019; Mello et al., 2019; Türkölmez et al., 2019; Brito et al., 2020; Alananbeh et al., 2020; Oksal and Ozer, 2021; Kuruppu et al., 2021; Oren et al., 2022; Yeganeh and Mohammadi, 2022; Güney et al., 2022). Though, they have also been reported as opportunistic human pathogens causing chronic superficial infections of skin, nails, and nose, cutaneous, invasive cutaneous, deep cutaneous infection, onychomycosis, dermatomycosis, fingernail onychomycosis, superficial black onychomycosis, rhinosinusitis, brain abscess, and pulmonary disease (Bakhshizadeh et al., 2014; Dionne et al., 2015; Yang et al., 2019; Jo et al., 2020; González Cortés et al., 2021; Raiesi et al., 2022). Despite the issues in its identification, e.g., by using morphological and molecular techniques, the number of first-case and outbreak reports is increasing, revealing the virulence of the organism, which has already been detected in 70 countries.

Neoscytalidium spp. produces two different asexual states; arthric and pycnidia synanamorphs (Pavlic et al., 2008; Phillips et al., 2013). While Nattrass (1933) first described the pycnidial synanamorph as *Hendersonula toruloidea*, the production of two asexual morphs has led to some confusion in the taxonomy of this species (Crous et al., 2006). Other arthric and pycnidial existing morphs for *H. toruloidea* were *Torula dimidiate* (arthric morph), *Scytalidium dimidiatum* (arthric morph), and *Fusicoccum dimidiatum* (pycnidial morph) (Penzig, 1882; Sutton and Dyko, 1989; Farr et al., 2005). Crous et al. (2006), based on a DNA phylogeny of the family Botryosphaeriaceae revealed that the genus *Scytalidium* was polyphyletic, and the new genus *Neoscytalidium* was introduced to accommodate *Fusicoccum*-like with arthric morph (Crous et al., 2006).

To my knowledge, only a few bibliometric studies on plant disease have been done recently (Mayuri and Dayanithi, 2020; Avwerosuo 2021). Due to the increasing reports of pathogenicity in humans and plants and the associated public health concerns, no review has been done about this pathogen, and bibliometric analysis is still missing. In this regard, bibliometric analysis constitutes a systematic tool for monitoring this pathogen, offering veterans and new scientists an overview of the scientific panorama concerning this emerging pathogen. In this contribution, a bibliometric analysis of the studies on *Nattrassia mangiferae* published in the timespan from 1966 to 2022 is presented.

MATERIALS AND METHODS

Scopus (http://www.scopus.com), the most extensive database with abstracts and citations, journals, books, conference proceedings, and peer-reviewed literature, was chosen as the data source for the period 1966-2022 (Elsevier, 2017, 2019). To identify publications, the following keywords were used in the combined fields of title, abstract and keywords (per publication): "*Hendersonula toruloidea*" OR "*Nattrassia mangiferae*" OR "*Scytalidium dimidiatum*" OR "*Scytalidium hyalinum*" OR "*Neoscytalidium dimidiatum*" OR "*Neoscytalidium novahollandiae*" OR "*Fusicoccum dimidiatum*" OR "*Neoscytalidium hyalinum*" OR "*Torula dimidiata*" OR "*Neoscytalidium orchidacearum*" OR "*Neoscytalidium oculus*". The downloaded search results contained full literature data such as document type (research articles, reviews, letters, book chapters, and books), abstract, keywords, author, year of publication, references, title, citations, and funding agency. All the retrieved documents were downloaded in the format of BibTeX, for easy recognition by VOSviewer (Version 1.6.18; 2020; Leiden University, Leiden, the Netherlands) (van Eck and Waltman, 2010) for further citation analysis. Then, the VOSviewer visualization software was used for citation analysis by co-occurrence and clusters of related publications, author collaboration (co-authorship), co-citation, country input, research hotspot, and frontier trend. Default parameter values of the VOSviewer were usually used in the analysis. Each term was represented by a label and a circle whose diameter and label size were directly proportional to their frequency (to avoid overlapping labels, only a subset of all labels is displayed in the maps). The colors in the network visualization represented clusters of similar terms as calculated by the program. The distance between the terms indicated the strength of the relationships.

RESULTS

Articles distributions by publication years

From 1966 to 2022, the total number of published manuscripts in Scopus was 376. Between 1966 and 1983

Table 1. Hosts, country and symptoms caused by *Neoscytalidium* species in the worlds.

Species	Name of host	Species Plant	Family	Country	Symptoms	Author
Neoscytalidium dimidiatum	olive	*Olea europaea* L.	Oleaceae	Turkey	Canker and leaf scorch	Güney et al. (2022)
Neoscytalidium dimidiatum	Common fig	*Ficus carica*	Moraceae	Turkey	dieback and canker	Güney et al. (2022)
Neoscytalidium dimidiatum	Pitahaya	*Hylocereus polyrhizus*	Cactaceae	Southern Thailand	Stem Canker	Dy et al. (2022)
Neoscytalidium dimidiatum	Grapevine	*Vitis vinifera*	Vitaceae	Iran	trunk disease	Nourian et al. (2021)(Moghadam et al., 2022)
Neoscytalidium dimidiatum	Apple	*Malus domestica*	Rosaceae	Iran	canker	Nourian et al. (2021)
Neoscytalidium dimidiatum	Apple	*Malus domestica*	Rosaceae	Turkey	branch dieback and canker	Ören et al. (2022)
Neoscytalidium dimidiatum	Turkish oregano	*Origanum onites*	Lamiaceae	Turkey	leaf blight	Alkan et al. (2022)
Neoscytalidium dimidiatum	Royal poinciana	*Delonix regia*	Fabaceae	United Arab Emirates	stem canker	El-Tarabily et al. (2021)
Neoscytalidium dimidiatum	Grapevine	*Vitis vinifera*	Vitaceae	Algeria	trunk diseases	Arkam et al. (2021)
Neoscytalidium dimidiatum	yam	*Dioscorea rotundata*	Dioscoreaceae	Colombia	dry rot disease	Arrieta-Guerra et al. (2021)
Neoscytalidium dimidiatum	Lemon balm	*Melissa officinalis*	Lamiaceae	Turkey	blight	Özer et al. (2022)
Neoscytalidium dimidiatum	Dragon Fruit	*Hylocereus undatus*	Cactaceae	Thailand	Stem Brown Spot	Ratanaprom et al. (2021)
Neoscytalidium dimidiatum	lavender	*Lavandula angustifolia*	Lamiaceae	Turkey	foliar and stem blight	Güney et al. (2021)
Neoscytalidium hyalinum	Grapevine	*Vitis vinifera*	Vitaceae	Iran	trunk diseases	Bahmani et al. (2021)
Neoscytalidium dimidiatum	Dragon fruit	*Selenicereus* spp.	Cactaceae	Philippines	stem and fruit disease	Taguiam et al. (2021)
Neoscytalidium dimidiatum	Pitaya	*Hylocereus* spp.	Cactaceae	China	fruit canker	Wang et al. (2021)
Neoscytalidium dimidiatum	Sweet potato	*Ipomoea batatas*	Convolvulaceae	Brazil	root and stem rot	de Mello et al. (2021)
Neoscytalidium dimidiatum	Pineapple	*Ananas comosus*	Bromeliaceae	Malaysia	Stem End Rot	Kuruppu et al. (2021)
Neoscytalidium dimidiatum	Sisal	*Agave sisalana*	Asparagaceae	China	Black Spot	Xie et al. (2021)
Neoscytalidium dimidiatum	Fig	*Ficus carica*	Moraceae	USA	Dieback	Gusella et al. (2021)
Neoscytalidium dimidiatum	Almond	*Prunus dulcis*	Rosaceae	USA	Canker	Holland et al. (2021)
Neoscytalidium dimidiatum	Guava	*Psidium guajava*	Myrtaceae	Malaysia	Fruit Rot	Ismail et al. (2021)
Neoscytalidium dimidiatum	Neem	*Azadirachta indica*	Meliaceae	Iran	Trunk disease	Ghasemi-Sardareh and Mohammadi (2020)
Neoscytalidium hyalinum	Citrus	*Citrus* spp.	Rutaceae	Iran	Trunk Disease	Esparham et al. (2020)
Neoscytalidium dimidiatum	Cassava	*Manihot esculenta*	Euphorbiaceae	Brazil	black root rot and stem cutting dry rot	Brito et al. (2020)
Neoscytalidium dimidia	potato	*Solanum tuberosum*	Solanaceae	Turkey	tuber rot	Derviş et al. (2020)
Neoscytalidium dimidiatum	apricot	*Prunus armeniaca*	Rosaceae	Turkey	shoot blight, dieback and canker	Oksal et al. (2020)
Neoscytalidium dimidiatum	Pitahaya	*Hylocereus* spp.	Cactaceae	USA	Fruit Canker	Hong et al. (2020)
Neoscytalidium dimidiatum	snake plant	*Sansevieria trifasciata*	*Asparagaceae*	Brazil	leaf blight	Monteles et al. (2020)
Neoscytalidium dimidiatum	pitaya	*Hylocereus polyrhizus*	Cactaceae	China	Canker	Xu et al. (2020)
Neoscytalidium dimidiatum	Cattleya × hybrid	*Cattleya* spp.	Orchidaceae	Taiwan	leaf blight	Chang et al. (2020)
Neoscytalidium dimidiatum	Citrus	*Citrus* spp.	Rutaceae	Jordan	Shoot Blight	Alananbeh et al. (2020)
Neoscytalidium dimidiatum	Royal Poinciana	*Delonix regia*	Fabaceae	United Arab Emirates	Stem Canker	Al Raish et al. (2020)
Neoscytalidium dimidiatum	mangrove	Avicennia marina *Rhizophora mucronata*	Acanthaceae Rhizophoraceae	Iran	dieback	Goudarzi and Moslehi (2020)

Table 1. Contd.

Neoscytalidium dimidiatum	Grapevine	*Vitis vinifera*	Vitaceae	Turkey	canker and dieback	Oksal et al. (2019)
Neoscytalidium dimidiatum	Persian oak	*Querqus brantii*	Fagaceae	Iran	decline	Alidadi et al. (2019)
Neoscytalidium dimidiatum	Pines	*Pinus* spp.	Pinaceae	Turkey	Shoot and Needle Blight	Türkölmez et al. (2019a)
Neoscytalidium hyalinum	cactus prickly pear	*Nopalea cochenillifera*	Cactaceae	Brazil	spot	Feijo et al. (2019)
Neoscytalidium dimidiatum	Walnut	*Juglans regia*	Juglandaceae	Turkey	Black Canker and Root Rot	Dervis et al. (2019)
Neoscytalidium dimidiatum	Willow	*Salix* spp.	Salicaceae	Turkey	Dieback, Shoot Blight, and Branch Canker	Türkölmez et al. (2019b)
Neoscytalidium dimidiatum	Pistachio	*Pistacia vera*	Anacardiaceae	Turkey	Canker, Shoot Blight, and Root Rot	Dervis et al. (2019)
Neoscytalidium dimidiatum	Tomatoe	*Solarium lycopersicum*	Solanaceae	Turkey	Shoot blight	Türkölmez et al. (2019c)
Neoscytalidium hyalinum	Malabar plum	*Syzygium cumini*	Myrtaceae	Iran	Trunk Disease	Panahandeh et al. (2019)
Neoscytalidium hyalinum	Melon	*Cucumis melo*	Cucurbitaceae	Iran	Fruit rot	Mirtalebi et al. (2019)
Neoscytalidium dimidiatum	Sweet Potato	*Ipomoea batatas*	Convolvulaceae	Brazil	Root Rot	Mello et al. (2019)
Neoscytalidium novaehollandiae	Persian oak	*Quercus brantii*	Fagaceae	Iran	dieback	Sabernasab et al. (2019)
Neoscytalidium hyalinum	cassava	*Manihot esculenta*	Euphorbiaceae	-	black and dry root rot	Hohenfeld et al. (2018)
Neoscytalidium dimidiatum	Almond	*Prunus dulcis*	Rosaceae	USA	Canker, Shoot Blight and Fruit Rot	Nouri et al. (2018)
Neoscytalidium hyalinum	cashew	*Anacardium occidentale*	Anacardiaceae	Brazil	dieback and stem and branch canker	Coutinho et al. (2018)
Neoscytalidium hyalinum	mango	*Mangifera indica*				
Neoscytalidium dimidiatum	Egyptian Ficus trees	*Ficus carica*	Moraceae	Egypt	canker	Al-Bedak et al. (2018)
Neoscytalidium orchidacearum	cattleya orchid	*Cattleya lueddemanniana* var. *lueddemanniana*	Orchidaceae	Thailand	Leaf spot	Suwannarach et al. (2018)
Neoscytalidium dimidiatum	Snake plant	*Sansevieria trifasciata*	*Asparagaceae*	Malaysia	leaf blight	Kee et al. (2017)
Neoscytalidium hyalinum	elm	*Ulmus* spp.	Ulmaceae	Iran	decline	Hashemi et al. (2017)
Nattrasia mangiferae	Cassava	*Manihot esculenta*	Euphorbiaceae	West Africa	ROOT ROT	Zinsou et al. (2017
Neoscytalidium dimidiatum	Pitaya	*Hylocereus* spp.	Cactaceae	Costa Rica	stem canker	Retana et al. (2017)
Neoscytalidium dimidiatum	Lesser Yam	*Dioscorea esculenta*	Dioscoreaceae	China	Dieback	Lin et al. (2017)
Neoscytalidium hyalinum	Citrus	*Citrus* spp.	Rutaceae	USA	Branch Canker	Mayorquin et al. (2016)
Neoscytalidium hyalinum	willow and poplar	*Salix* and *Populus*	Salicaceae	Iran	internal wood lesions and decline	Hashemi and Mohammadi (2016)
Neoscytalidium hyalinum	Grapevine	*Vitis vinifera*	Vitaceae	Brazil	Dieback	Correia et al. (2016)
Neoscytalidium dimidiatum	pitahaya	*Hylocereus* spp.	Cactaceae	China	Fruit internal brown rot	Yi et al. (2015)
Neoscytalidium hyalinum	Physic Nut	*Jatropha curcas*	Euphorbiaceae	Brazil	collar and root rot	Machado et al. (2014)
Neoscytalidium dimidiatum	mango	*Mangifera indica*	Anacardiaceae	Thailand	dieback	Trakunyingcharoen et al. (2014)
Neoscytalidium dimidiatum	Citrus	*Citrus* spp.	Rutaceae	Oman	Root Diseases	Al-Sadi et al. (2014)
Neoscytalidium dimidiatum	Dragon Fruit	*Hylocereus polyrhizus*	Cactaceae	Malaysia	Stem Canker	Mohd et al. (2013)
Neoscytalidium dimidiatum	Grapevine	*Vitis vinifera*	Vitaceae	USA	Wood Canker	Rolshausen et al. (2013)
Neoscytalidium dimidiatum	Pitahaya	*Hylocereus undatus*	Cactaceae	Israel	Internal Black Rot	Ezra et al. (2013)

Table 1. Contd.

Neoscytalidium dimidiatum	Physic Nut	*Jatropha curcas*	Euphorbiaceae	Brazil	Collar and Root Rot	Machado et al. (2012)
Nattrassia mangiferae	Mango	*Mangifera indica*	Anacardiaceae	Pakistan	Decline	Anwar et al. (2012)
Neoscytalidium dimidiatum	Pitaya	*Hylocereus undatus* and *H. polyrhizus*	Cactaceae	Taiwan	Stem Canker	Chuang et al. (2012)
Neoscytalidium dimidiatum	mangoe	*Mangifera indica*	Anacardiaceae	Australia	dieback and stem end rot	Sakalidis et al. (2011)
Neoscytalidium dimidiatum	Citrus	*Citrus* spp.	Rutaceae	Italy	Sooty canke	Polizzi et al. (2011)
Neoscytalidium dimidiatum	Mango	*Mangifera indica*	Anacardiaceae	Australia	Dieback	Ray et al. (2010)
Neoscytalidium novaehollandiae	Fig	*Ficus carica*	Moraceae			
Nattrassia mangiferae	Black locust	*Robinia pseudoacacia*	Fabaceae	Iran	dieback	Jamali and Banihashemi (2010)
Nattrassia mangiferae	Sycamore Maple	*Acer pseudoplatanus*	Aceraceae	Iran	dieback	Jamali and Banihashemi (2010)
Nattrassia mangiferae	Loquat	*Eriobotrya japonica*	Rosaceae	Iran	dieback	Jamali and Banihashemi (2010)
Nattrassia mangiferae	bull bay	*Magnolia grandiflora*	Magnoliaceae	Iran	dieback	Jamali and Banihashemi (2010)
Scytalidium dimidiatum	Banyan	*Ficus benghalensis*	Moraceae	Sudan	dieback	Anonymous (2005)
Hendersonula toruloidea	date palm	*Phoenix dactylifera*	Arecaceae	Iraq	decline	Juber et al. (2005)
Nattrassia mangiferae	cassava	*Manihot esculenta*	Euphorbiaceae	Benin	root and stem rot	Msikita et al. (2005)
Nattrassia mangiferae	Fig and Guava	*Ficus religiosa* and *Psidium guajava*	Moraceae and Myrtaceae	Iran	die-back and trunk cankers	Mirzâee et al. (2002)
Scytalidium dimidiatum	Siris tree	*Albizia lebbeck*	Fabaceae	Oman	dieback	Elshafie and Ba-Omar (2002)
Hendersonula toruloidea	Strawberry tree	*Arbutus unedo*	Ericaceae	Europe	Foliar	Tsahouridou and Thanassoulopoulos (2000)
Nattrassia mangiferae	cassava	*Manihot esculenta*	Euphorbiaceae	West Africa	root and stem rot	Msikita et al. (1998)
Hendersonula toruloidea	Eucalyptus	*Eucalyptus* spp.	Myrtaceae	Iran	-	Baban et al. (1995)
Hendersonula toruloidea	Apricot	*Prunus armeniaca*	Rosaceae	Israel	gummosis	Rotem et al. (1995)
Nattrassia mangiferae	rubber tree	*Hevea brasiliensis*	Euphorbiaceae	Srilanka	Foot canker and sudden wilt	Jayasinghe and Silva (1994)
Nattrassia mangiferae	Eucalyptus	*Eucalyptus* spp.	Myrtaceae	North-America	Dieback	Mathero and Sigler (1994)
Nattrassia toruloidea	Grapevine	*Vitis vinifera*	Vitaceae	Italy	Death	Granata and Sidoti (1991)

Source: Own authorship

(17 years), the publication number per year was less than 5. The number of publications showed an increasing trend from 1984 (Figure 1) onwards, and the highest number of documents were published in 2021 (n=32). From 1966 onward, the average number of publications per year was 6.6,

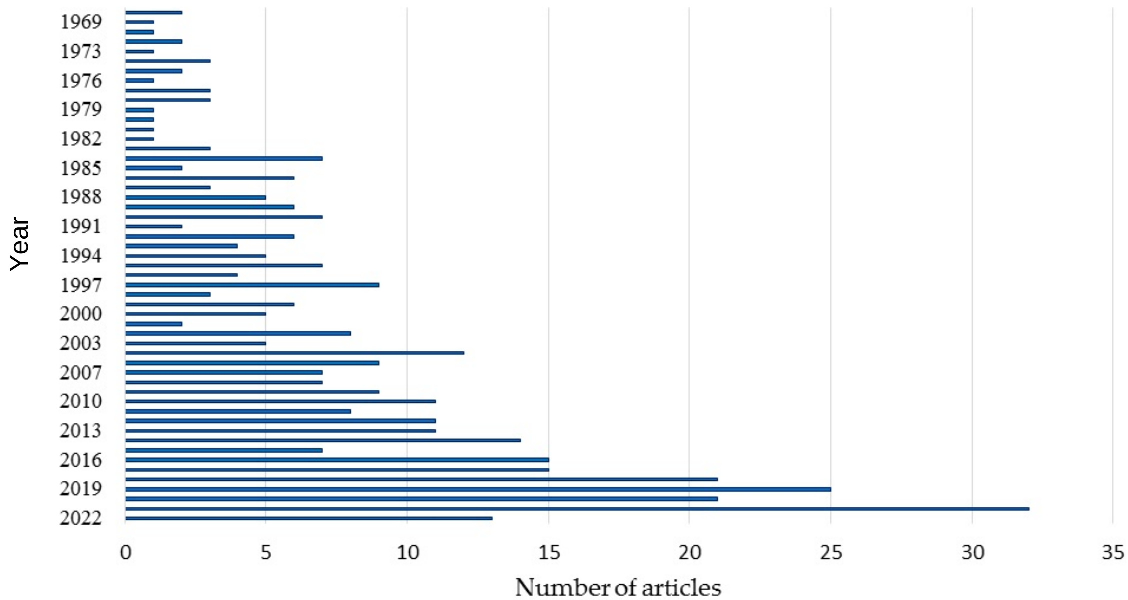

Figure 1. Annual growth of publications in focus area of *Nattrassia mangiferae* (1966-2022).
Source: Own authorship

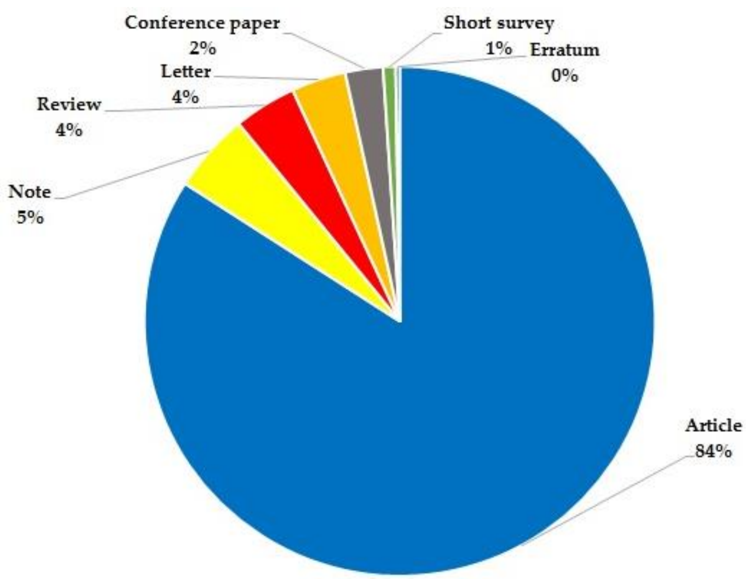

Figure 2. Document type of the publication about *Nattrassia mangiferae* from the Scopus.
Source: Own authorship

ranging from 0 (in 1967, 1968, 1971, 2006) to 32 (in 2021). Fifty-six percent of the articles were published between 2009 and 2022.

Document types and language of publication

The majority of articles retrieved were research articles (316; 84.04%) followed by notes (19; 5.03%), reviews (15; 3.98%), letters (13; 3.45%), conference papers (9; 2.39%), and short survey (3; 0.79%) (Figure 2). The first article titled "microbial rotting of stored yams (*Dioscorea* species) in Nigeria" (Okafor, 1966) was published in Experimental Agriculture (2:179-182). The first report of the pathogenicity of this species in humans was made by Gentles and Evans (1970) as "infection of the feet and

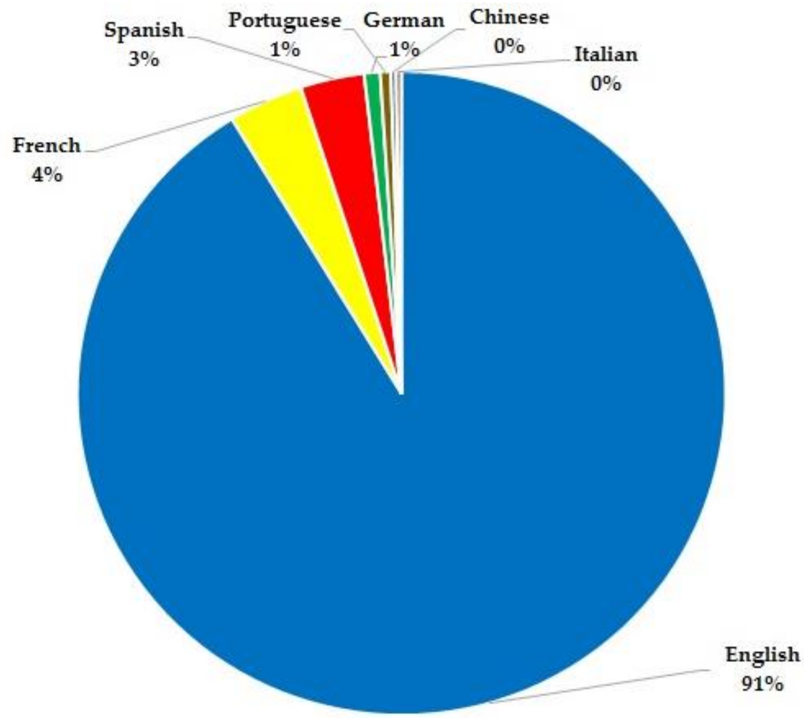

Figure 3. Language of the publication about *Nattrassia mangiferae* from the Scopus.
Source: Own authorship

nails with *H. toruloidea*". Almost all of the articles were published in English (343; 91.22%); others were published in French (14; 3.72%), Spanish (12; 3.19%), German (3; 0.79%), Portuguese (2; 0.53%), Chinese (1; 0.26%), and Italian (1; 0.26%) (Figure 3). Most of the published documents were in the form of original research articles, and English was the most common language used (Khan et al., 2020).

Journal analysis

The studies were published in 60 different journals, with the large majority belonging to the subject areas of medicine (208; 41.76%), agriculture and biological science (139; 27.91%), immunology and microbiology (49; 9.83%), biochemistry, genetics and molecular biology (37; 7.42%), environmental science (16; 3.21%), and veterinary (16; 3.21%) (Figure 4). Thirty two percent of the articles were published in one of these eight journals: Plant Disease (n=29), Medical Mycology (n=25), Mycoses (n=16), British Journal of Dermatology (n=13), Mycopathologia (n=13), Journal of Clinical Microbiology (n=10), Journal of Plant Pathology (8), and Journal de Mycologie Medicale (n=7) (Figure 5). The maximum number of articles was published in the Plant Disease followed by Medical Mycology (Figure 5). Among 10 journals, 7 of them belonged to medicine, and the rest are 3 related to plant diseases. The most cited article in the Plant Disease was by Chen et al. (2014) and their study reported *N. dimidiatum* as the cause of cankers and blights of English walnut in California.

Citation analysis

It is understood that highly cited articles have a significant impact on the concerned subject worldwide. The citation analysis of retrieved documents showed 3798 citations with an average of 10.10 citations per document. The most cited (240 times) article was published in 1989 titled "Onychomycosis, tinea pedis and tinea manuum caused by non-dermatophytic filamentous fungi nicht-dermatophyten-fadenpilze als erreger von onychomykosen, tinea pedis und tinea manuum" in the journal Mycoses. Three of the most cited articles were research articles. These articles discussed the diagnosis, epidemiology, clinical manifestations, and therapy of infections caused by this fungus.

Country, author, and institution analysis

The selected group of studies included 160 unique authors representing 70 countries across six continents. The five countries that contributed the most significant

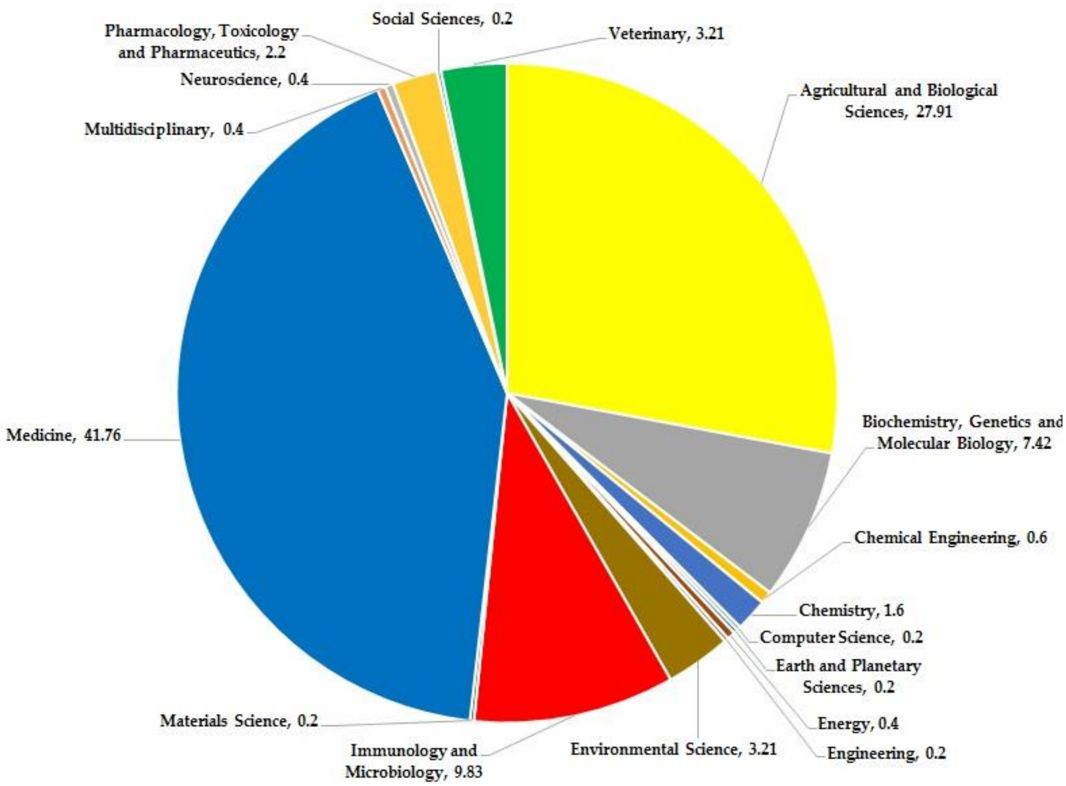

Figure 4. A. Pie-chart depicting the subject areas of research of the documents retrieved in the study.
Source: Own authorship

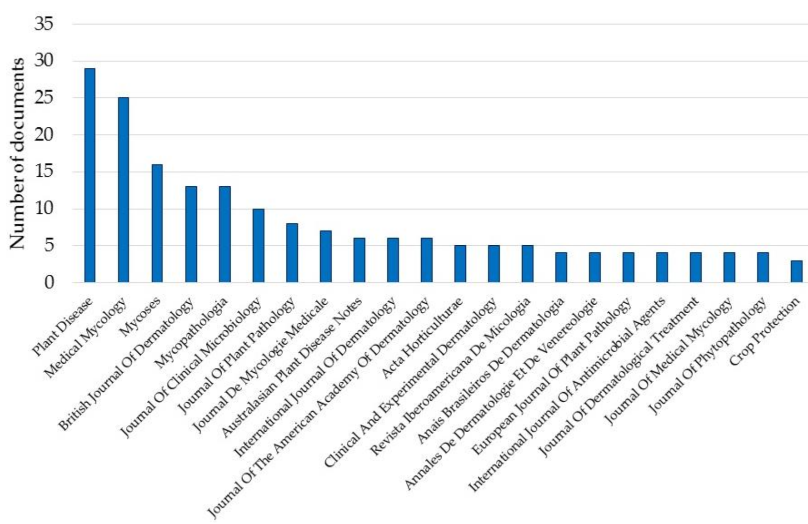

Figure 5. Evolution of number of publications related to *Nattrassia mangiferae* between 1996 and 2022.
Source: Own authorship

number of authors were the United States (50 articles), the United Kingdom (39 articles), Brazil (32 articles), France (25 articles), and Iran (25 articles), which took up 45.47% of the total (Figure 6). The identification of the most frequent authors helps to identify potential mentors and reviewers. A total of 160 authors were involved in publications retrieved during the defined period; 3 contributed more than ten manuscripts. In Table 2, we

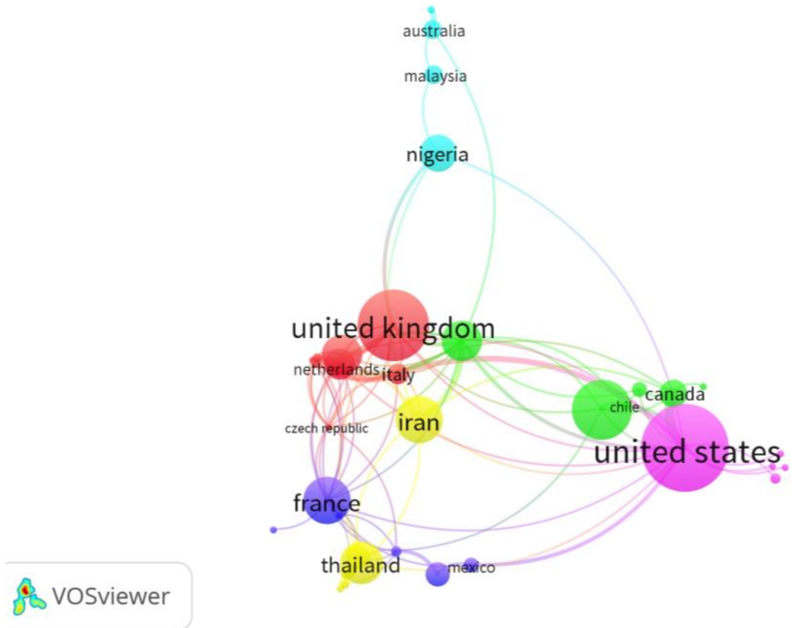

Figure 6. The network map of co-authorship based on affiliation of authors belonging to different countries.
Source: Own authorship

recorded top ten most productive and most cited authors, along with the institutions and countries they belonged. The authors listed came from Thailand, the United Kingdom, India, Nigeria, Turkey, and Spain. Four scholars appeared in both most productive and the most cited list: Moore MK (12 papers, 380 cites), Gugnani HC (11 articles, 206 cites), Hay RJ (7 articles, 332 cites), and Guarro J (6 articles, 166 cites). The leading organizations were the St John's Institute of Dermatology, UK, Mahidol University, Thailand, and the Mardin Artuklu University, Turkey, with 13, 12, and 11 publications.

Article title text mining

A text analysis of the words in the title and abstract of all publications (n=376) identified 2855 words (305 meet the threshold), after excluding words that carry very little information, which was ordered by frequency and displayed in a word cloud map. Figures 7 and 8 show the research-topic map of *N. mangiferae* studies between 1966 and 2022. Frequent terms were mapped into five clusters (Figure 7). Here, it is clear the particular interest in mycoses (onychomycosis, dermatophyte) caused by *N. mangiferae*. *N. mangiferae* has been reported as human pathogen causing chronic superficial infections of the skin, nails, and nose, onychomycosis, dermatomycosis, and pulmonary disease. Cluster 1 (red colored; n=86 terms) had keywords such as onychomycosis (highest with 103 occurrences), female, aged, middle-aged, dermatophyte, major clinical study, *Trichophyton rubrum*, tinea pedis, and skin disease. The second cluster (green color, n=83 terms) with a research theme highlighting isolation and purification, fungus identification, pathogenicity, phylogeny, plant disease, and classification. The third cluster (blue cluster, n = 60 terms) included humans, mycosis, antifungal agent, amphotericin b, itraconazole, and voriconazole. The fourth cluster (yellow color, n=42 terms) included human, male, adult, dermatomycoses, food dermatoses, nail diseases, and mitosporic fungi. The fifth cluster (violet color, n=32 terms) included nonhuman, controlled study, antifungal agents, *in vitro* study, and drug efficacy.

Bibliometric analysis of co-authorship

Authors from 70 countries showing at least two documents and having a minimum of 4 citations each were selected. Forty-six met the threshold, and these formed 6 clusters. The United States had the highest number of documents (n=49); 1737 citations with a total link strength of 139. The main collaborating partners of the United States were Canada and Italy. The United Kingdom, with 39 documents and 1314 citations, was in second place. The link strength for the UK was 18. The main collaborators of the UK were India, Nigeria and Spain. Brazil was at third place with 32 documents, having 451 citations, and eight total link strengths. Of the 851 organizations that were involved in research,

Table 2. Top 10 most productive and most cited authors.

Rank	Author (Most prolific)	Paper No. (Times cited)	Institution/Country	Author (Most cited)	Times cited (Paper No.)	Institution/Country
1	Bunyaratavej S	12 (77)	Mahidol Univ/Thailand	Moore MK	380 (12)	St John's Institute of Dermatology/UK
2	Moore MK	12 (380)	St John's Institute of Dermatology/UK	Hay RJ	332 (7)	St Thomas' Hospital/UK
3	Gugnani HC	11 (206)	Delhi Univ /India	Michailides TJ	268 (5)	California-Davis Univ /USA
4	Leeyaphan C	11 (53)	Mahidol Univ/Thailand	Gupta AK	238 (4)	Toronto Univ / Canada
5	Oyeka CA	10 (154)	Nnamdi Azikiwe Univ/ Nigeria	Sigler L	206 (4)	Alberta Univ /Canada
6	Matthapan L	8 (53)	Mahidol Univ/Thailand	Gugnani HC	206 (11)	Delhi Univ / India
7	Özer G	8 (10)	Bolu Abant Izzet Baysal Univ/Turkey	Martin JP	203 (4)	California Univ /USA
8	Hay RJ	7 (332)	St Thomas' Hospital/UK	Clayton YM	202 (5)	St Thomas's Hospitals/ UK
9	Derviş S	7 (16)	Mardin Artuklu Univ/Turkey	Lacroix C	172 (5)	Laboratoire de Mycologie-Parasitologie/France
10	Guarro J	6 (166)	Rovira i Virgili Univ/Spain	Guarro J	166 (6)	Rovira i Virgili Univ/ Spain

Source: Own authorship

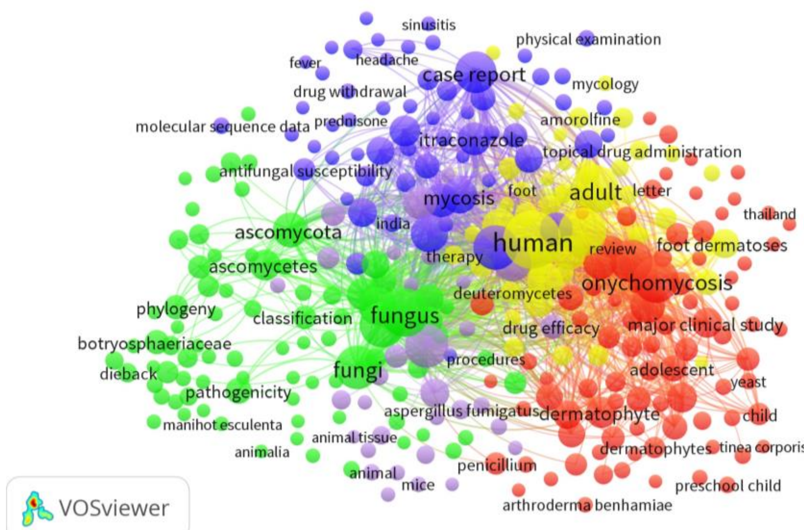

Figure 7. Network visualization based on co-occurrence of keywords. Each node represents a keyword. The size of the node represents the co-occurrence between keywords. Each of the five clusters represents a particular theme. Nodes in a cluster together have a common theme and their relationships with other nodes are represented by links.
Source: Own authorship

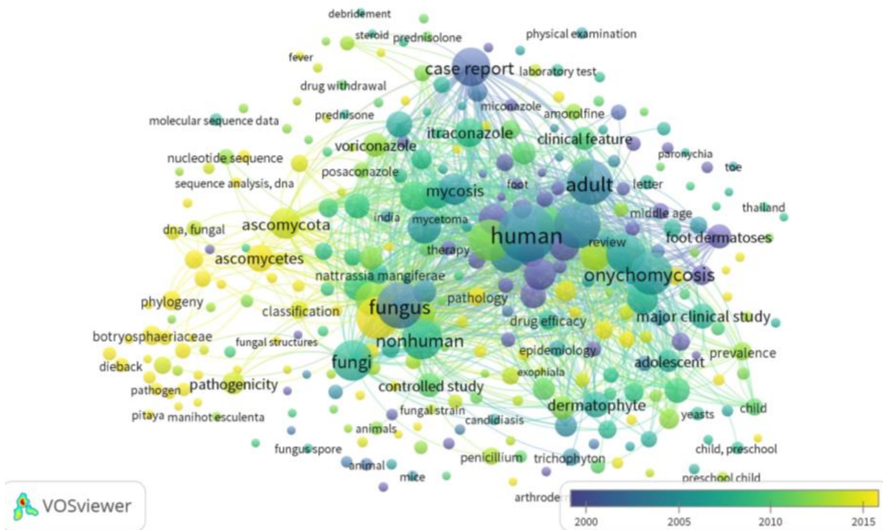

Figure 8. Overlay visualization of the research-topic map of studies related to *Nattrassia mangiferae* between 1966 and 2022. The minimum number of occurrences of a keyword is 5.
Source: Own authorship

collaborations were seen between 3 (with a minimum threshold of three documents and three citations).

DISCUSSION

Bibliometric analysis is a valuable tool for tracing the intellectual structure of a specific field of research. It allows a more structured literature review, including information and detection patterns (Vogel and Güttel, 2013). In this study, we utilized bibliometrics information visualization to analyze the literature set of *N. mangiferae* from 1966 to 2022 to gain a general view of the current research status, hot spots, and trends. Out of 376 published articles, 237 articles belonged to the subject area of medicine (237; 63.03%), and 139 articles were in the field of agriculture and biological science (139; 36.96%). Today, reports of the pathogenicity of this species on plants and humans are increasing.

Sabernasab et al. (2019) reported that minimum, optimum and maximum temperatures for growth of the *N. mangiferae* were, respectively, 10, 35, and 40°C. Similarly, Jamali and Banihashemi (2010) reported that the optimum temperature for growth of *N. mangiferae* was 35°C. Also, many researchers have shown that *N. mangiferae* could progressively grow and make symptoms in host plants in high temperatures and low relative humidity (Elshafie and Ba-Omar, 2002; Hassan et al., 2011; Mayorquin et al., 2016). Calavan and Wallace (1954) reported that *N. mangiferae* is aggressive on drought-stressed hosts. Drought stress leads to the reduced mechanical strength of the bark-wood bonds, and may result in bark cracks that can be invaded by *N. mangiferae* (Bettucci et al., 1999; Sabernasab et al., 2019). During the past decade, warming temperatures occurred in the world. This climate change may predispose trees to infection by this thermophilic fungus. *N. mangiferae* represent some of the most critical threats to urban and forest health where climate change is occurring. This study shows that the pathogen was isolated from 61 species belonging to 47 genera and 30 families of plants but was most frequently isolated from Cactaceae, Rosaceae, Euphorbiaceae, Anacardiaceae, and Rutaceae hosts. The pathogen produces high populations of black powdery spores under the bark of trees that are easily transmitted by wind and insects (Sabernasab et al., 2019), infecting other susceptible, injured, or weak hosts. Also, the broad host range of this pathogen and the high populations of black powdery spores can be a threat to human health, especially in people with defective immune systems. Among the top 10 most co-cited references from 1966 to 2022, seven of them concern onychomycosis, infection of the feet and nails, and superficial fungal infections caused by *H. toruloidea*, and then the rest of three papers are revisions of *Hendersonula* and its pathogenicity on citrus. Overlay visualization of the research-topic map of studies related to *N. mangiferae* between 1966 and 2022 shows how the research topics moved from case report/foot dermatoses/dermatomycosis/hand dermatoses/ ketoconazole/miconazole/griseofulvin/clotrimazole (end of 2000), passing by human/male/adult/onychomycosis/ nonhuman (beginning of 2015), to plant disease/ pathogenicity/classification/phylogeny/sequence analysis (end of 2022) (Figure 8). Future studies should be focused on control measures for future outbreaks of *N.*

mangiferae. Based on our results, the importance of this field is the interest of some countries like the USA, UK, Brazil, France, and Iran. The most productive organizations were the St John's Institute of Dermatology, UK, Mahidol University, Thailand, and the Mardin Artuklu University, Turkey. The most frequent author's keywords are *N. dimidiatum*, onychomycosis, *S. dimidiatum*, *N. mangiferae*, dermatophytes, epidemiology, and dermatomycosis, which are all related to the pathogenicity of this fungus in humans. Foot and nail infection are one of the first diseases caused by *N. mangiferae*. After that, various diseases caused by this species have been reported in humans. Considering the optimal growth temperature of this pathogen, which is 37°C, and the growth potential in the human body, more investigation is required to characterize factors promoting diseases caused by this fungus. This can notify the strategies to prevent and manage diseases caused by this pathogen in woody plants, crops, and humans throughout the world.

Conclusion

In recent years, *N. mangiferae* has received tremendous attention as a destructive plant pathogen that may potentially infect humans, and animals. Based on 376 documents retrieved from the Scopus database, a bibliometric analysis of the *N. mangiferae* was carried out to fully understand the most productive countries, publications, journals, authors, institutions, and research categories, as well as research hotspots and future research directions. These results are helpful to researchers to analyze the existing publications, thereby helping them improve their research direction and keep up with the research frontier. It must be pointed out that due to the incomplete search items, some irrelevant articles may be collected, while some relevant articles may have been missed. Also, self-citation removing and non-English publications are not considered in this study, which will lead to an incomplete analysis. In future research, these deficiencies will be corrected to obtain more detailed and accurate research conclusions.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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