

Dactylopius opuntiae Cockrell (Hemiptera: Dactylopiidae), an emerging threat for *Opuntia* spp: a bibliometric analysis

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Abstract. *Dactylopius opuntiae* Cockerell (Hemiptera: Dactylopiidae) is a worldwide successful biological control agent for some invasive *Opuntia* Mill. (Caryophyllales: Cactaceae) species, and a primary pest where this species is commercially cultivated, which has renewed its scientific interest. Therefore, this research characterized regularities of the scientific production and identified emerging research trends on *D. opuntiae*, using one-dimensional and multidimensional bibliometric indicators. The search and retrieve of metadata from nine scientific publications databases (Biological Abstracts, Cab abstracts, Crossref, Google Academic, Dimensions, Microsoft Academic Search, Science Citation Index Expanded, Scopus, and Zoological Record) was condensed into a 193 documents collection, spanning from 1848 to 2021 using the Zotero[®] bibliographic reference manager. Publish or Perish[®] and Excel[®] were used to generate one-dimensional indicators and VOSviewer[®] for multi-dimensional indicators. Eighty percent of the publications on *D. opuntiae* were registered in the last 20 years, which denotes the specie's recently acquired importance. The addressed topics in the two assessed periods showed drastic changes, since, while in the first period (1848-2000) these were directed, particularly, to its applications as a biological control agent for various *Opuntia* species; during the next period (2001-2021), they focused on generating strategies for its eradication and control. A high number of non-peer-reviewed publications were not included in our studies, such as serials, books, theses, and conference proceedings. Despite the recent interest in *D. opuntiae* and the growing number of scientific documents, no previous publications were found that address this issue. Finally, the research allowed for the identification of emerging research trends and showed their locations and who makes up the clusters or research groups, and the addressed topics, which could facilitate collaboration networks establishment and contribute to the scientific development of *D. opuntiae*.

Keywords: *Scientific production evaluation; Metric studies of the information; Co-word analysis; Emerging research trends; Co-atorship network.*

Introduction

The cactus pear, *Opuntia* Mill. (Caryophyllales: Cactaceae) is a controversial plant, generating contrasting opinions, it is either loved or hated (Shackleton, 2012); this divergence, between its benefits and damages, has caused a conflict of interest regarding the way it is used and managed (Novoa *et al.*, 2015). It is native to North America, particularly in central and southern Mexico (Griffith, 2004) and southwestern South America (Majure *et al.*, 2012) from where it has successively been introduced to Europe, Africa, Asia, and Oceania (Ciriminna *et al.*, 2017). Recently, the interest in it has renewed worldwide because of the nutraceutical properties of its fruits and “nopalitos” (young edible cladodes) (Stintzing *et al.*, 2001; Feugang *et al.*, 2006; Jimenez- Aguilar *et al.*, 2014; Rbia and Smiti, 2019); for this reason, it is used in the pharmaceutical, cosmetic and food industries (Ciriminna *et al.*, 2019

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It is also important for its ecosystem services (Nefzaoui, 2018), for its use in animal nutrition (Flores-Hernández et al., 2017; Rocha et al., 2021) and as a food substrate for *Dactylopius coccus* Costa (Hemiptera: Dactylopiidae) rearing, in carminic acid production (Mendez-Gallegos et al., 2003), as well as its emerging potential uses (López-García et al., 2017; Ramírez-Arpide et al., 2018; Torres-Acosta and Diaz-Cruz, 2020). Also, derived from its adaptation to different agroclimatic conditions, easy reproduction, water efficiency, and absence of natural enemies (Novoa et al., 2019), it is currently cultivated in over 30 countries (Ochoa and Barbera, 2017), occupying an approximate 2.6 million ha area (Nefzaoui, 2018). However, its permanence and expansion are threatened by the recent invasion of *Dactylopius opuntiae* Cockerell (Hemiptera: Dactylopiidae), a native species to Mexico, as well as its hosts (De Lotto, 1974; Griffith, 2004; Carneiro-Leão et al., 2017) and considered the most aggressive and destructive (Paterson et al., 2011) of the 11 *Dactylopius* species (Ramírez-Cruz et al., 2020), putting several important production areas at risk. According to Mazzeo et al. (2019), *D. opuntiae* is distributed in at least 20 countries; recently, it has been registered in Lebanon (Moussa et al., 2017), Cyprus (Ülgentürk and Hocaali, 2019), Jordan (Bader and Abu-Alloush, 2019), Namibia (Paterson et al., 2019), Syria (Bufaur and Bohamdan, 2020), and Algeria (El Bouhissi et al., 2022) which shows its rapid dispersion, whether induced or natural and its wide distribution.

D. opuntiae expansion to new areas, the severity of its damage, and its economic impact generated great scientific interest worldwide, due to the threat it represents for all those regions where *Opuntia* spp. are present, whether wild or cultivated. Despite the increasing scientific production related to *D. opuntiae* and the recent publication of two reviews (Torres and Giorgi, 2018; Mazzeo et al., 2019), which offer a broad panorama of the state-of-the-art, and according to the available literature, the systematic study of bibliometric research has received little attention, since research using bibliometric analysis techniques and instruments have not been approached as with other phytosanitary scientific disciplines (Hernández-Rosas et al., 2020; Orjuela et al., 2020; Stopar et al., 2020; Raparelli and Lolletti, 2020). Currently, some tools facilitate the information search and confirm its relevance, one of these tools is bibliometrics, which includes a series of statistical tools, which allow analyzing a text's impact, as well as facilitating search-related texts (Jiménez et al., 2020). These also allow to save time in the analysis of a discipline and accelerate the learning and research process (Vargas-Hernández and González, 2015). The bibliometric analysis allows for the measurement of quantitative and qualitative aspects of the literature in a scientific field (Gálvez, 2016) with the potential to be extended to almost all scientific disciplines (Fuentes et al., 2019) and is especially useful when dealing with large amounts of information (Daim et al., 2006).

Given the increasing number of scientific publications and considering that, to our knowledge, no evidence was found from bibliometric studies on the state of the research on *D. opuntiae*, a systematization of this scientific knowledge generated is required, which allows researchers to have timely and reliable information obtained through techniques and tools such as bibliometrics. Therefore, this research analyzes the scientific production of *D. opuntiae* published in articles, reviews, and scientific notes, from documents published between 1848 and 2021, to define the area's development its trends, as well as to facilitate insights, decision-making, reorientation or research focus, promote synergies and establish links between institutions, research centers, academic bodies and researchers, aspects not considered in previous theoretical reviews.

Material and Methods

Information sources

The databases used to identify and extract information on *D. opuntiae* included: Biological Abstracts, Cab Abstracts, Crossref, Google Scholar, Dimensions, Microsoft Academic Search, Science Citation Index Expanded, Scopus, and Zoological Record, all via their web pages.

Information search and retrieval strategy

The terms used for the search and extraction of scientific documents published in peer-reviewed journals and included in the databases were: "*Dactylopius opuntiae*" and "wild cochineal". This search involved both terms in the title, keywords, and abstracts. These were reviewed to determine if the depth with which they dealt the subject in them was sufficient to be included in the database used to collect all the records. Among the recovered documents, some publications on *D. tomentosus* were found, as a synonym of *D. opuntiae* derived from a confusion in the taxon identification, given that in previous articles by Cockerell (1929). In this research, the decision was made to use the documents on *D. tomentosus* when the host was *Cylindropuntia* spp., taking the research by Mathenge et al. (2009) as an indicator. It should be noted that reports, book chapters, books, and thesis are not included in this research, because these types of documents are not reviewed by academic peers and are poorly disseminated. In whose formats numerous research related to the subject is published, such is the case of three documents of great importance for the development of scientific research on this species: Cockerell (1896), Hunter et al. (1912), and Mann (1969).

The records of the extracted documents were systematized in a collection, using the Zotero® bibliographic reference manager. Likewise, six descriptors representing six research topics were added, according to the topics addressed on *D. opuntiae*: 1) Biocontrol, for research on its use as a biological control agent, 2) Biology, for the documents that cover aspects related to the bioecology and habits of the insect, 3) Characterization, for research that include aspects on identification and morphological aspects, 4) Impact, for research that addresses the social and economic impact derived from the pest damage, 5) Occurrence, documents on lists, distribution, and new records, and 6) Control, for research on the different management and control practices, to group the research theme developed on *D. opuntiae*. Two time periods were defined: a) the first period, between 1848 and 2000; b) a second period, from 2001 to August 2021, to analyze with greater precision the trend and themes addressed by the researchers.

Content analysis and scientific mapping

Using a database, created in the Zotero® bibliographic reference manager, the scientific documents were analyzed by one-dimensional bibliometric indicators (van Raan, 1993): growth of the literature by research topics, publication journals, co-authorship index, highest production authors, and most cited documents. Multidimensional indicators were also generated (Sanz and Martín, 1997): collaboration networks between authors with two or more published articles, and a research themes and trends map, through the co-occurrence of authors' keywords and the six general themes described above. To develop and obtain the one-dimensional indicators, the computer software, Microsoft® Excel and Publish or Perish® (Harzing, 2007) were used, and for the multidimensional VOSviewer® (van Eck and Waltman, 2010), which uses a visualization method of similarities, an alternative for multidimensional scaling (van Eck and Waltman, 2007). VOSviewer allows the creation and view of maps from bibliographic records obtained in commercial databases, as well as those expressly created to allow the records to be exported in Research Information Systems (RIS) format. These maps show networks of documents and scientific journals, researchers, institutions, countries, and/or related keywords. The elements

that make up these networks can be co-authorship, co-occurrence, joint citation, or bibliographic coupling (van Eck and Waltman, 2010).

Results and discussion

Growth of the literature by research topics

In the created databases, 193 articles on *D. opuntiae* were identified over the assessed periods and published in various scientific journals and bulletins. During the first period, despite considering a higher number of years, about 150 years, only 63 documents were identified (32.64% of the total), with 67 thematic mentions, because four of the documents address topics included in two categories (Table 1).

Table 1. Number of documents and main topics on *Dactylopius opuntiae* from 1848 to 2000.

Año	Biocontrol	Biology	Characterization	Impacts	Occurrence	Control	Total
1848						1	1
1921-1930	5				1	1	7
1931-1940	7				3		10
1941-1950	8					4	12
1951-1960	2					1	3
1961-1970	2	1					3
1971-1980	2	1	1		2	2	8
1981-1990	3	3	1			1	8
1991-2000	8	2	1		2	2	15
Total	37	7	3	0	8	12	67
% 1848-2000	58.73	11.11	4.76	0	12.7	19.05	
% Total	19.17	3.63	1.55	0.00	4.15	6.22	

At this stage of the analysis, 37 articles (58.73%) focused on using *D. opuntiae* as a “biological control agent” (Biocontrol, in Table 1) of some *Opuntia* species in various countries (India, South Africa, Australia, and the United States of America). On them, the species were considered invasive weeds or undesirable plants; or were themed on the eradication of species for cultivation for *D. coccus* breeding, for human or animal consumption, or out-of-control ornamental plants, resulting in an important problem of interest. The period where the highest number of publications were recorded was between 1921 to 1960 with 20 documents; the oldest article found on this topic was written by Hamlin (1924). At the same time, the most prolific author was Franklin William Pettey with six documents including one on the control of spineless cactus pear in South Africa (Pettey, 1950). Also, outstanding in this period, is the work by Cockerell in 1929, considered to be the first publication where the taxon is referred to for the first time (Table 1). In this period important works were published, such as those of Simmonds and Bennett (1966), Moran and Zimmermann (1991), Zimmermann and Moran (1991), and Volchansky *et al.* (1999).

Other outstanding topics, although with less production, seven articles (11.11%) focused on aspects of “habits and biology” (Biology, in Table 1), among which are: Nur, (1982); Moran *et al.* (1987), Wang and Nobel (1995), and Volchansky *et al.* (1999); and as well as its “presence or new records” with eight documents (12.7%) (Occurrence, in Table 1), among which are: Donkin (1977) and Middleton (1999). Similarly, 12 articles (19.05%), aimed at generating knowledge about “management and eradication strategies” (Control, in Table 1) were published with greater frequency, among which the first document identified “biological control” (Biocontrol in Table 1)

stands out (Guérin–Méneville, 1848), and the works of Annecke *et al.* (1976), Moran and Hoffmann (1987), and Pretorius and Van Ark (1992). A special mention on this topic was two pioneering documents on the biological control of *D. opuntiae*, on *Exochomus flavipes* (Geyer, 1947a, b). Three articles (4.76%) were identified (De Lotto, 1974; MacGregor and Sampedro; 1983; and Pérez and Kosztarab, 1992) where important aspects relating to the “morphological and taxonomic characterization” are addressed, as well as their identification (Characterization, in Table 1). It is to be noted that during this period no studies aimed at quantifying or determining the “socioeconomic impacts” (Impacts in Table 1) derived from *D. opuntiae* attack were founded.

It is important to observe that even though *D. opuntiae* is a species native to North America, mainly the southern USA and northern Mexico, the Mexican scientists' low contribution during this stage is notable, even though it was registered as a pest in 1939 by Coronado (1939) and later also by García (1965). However, it is not indicative that research on this insect was not carried out, but rather, that this could be associated with the fact that the related publications on the subject were restricted to projects on final degree, serial magazines, communications to congresses, or published in brochures, restricted distribution guides and manuals but not in peer-reviewed journals. Another important aspect was related to the scarce institutional support and the public policies of not encouraging researchers to publish in high visibility journals. Finally, another influencing factor was the low associativity that allowed the formation of academic networks.

For the second period (2001-2021), the number of documents doubled, 130 articles were published, 67.35% of the total registered, with 134 thematic mentions because four documents were categorized into two topics (Table 2). At this study interval, the trend of the addressed topics drastically changed, since the documents researched the “control and management” of the insect (Control, in Table 2) were prioritized, with 84 (63.16 % in the period and 42.49% of the total). Therefore, if the 6.22% published in the first period is added, it yields that 50% of the articles studied deal with *D. opuntiae* control as an *Opuntia* pest. This denotes the status of the primary pest of this insect in various regions of the world, particularly in the Mediterranean basin, where this cactus is appreciated for commercial or subsistence purposes, and where *D. opuntiae* is an important phytosanitary risk (Table 2). It is important to highlight that as of 2018, the studies rapidly increased, especially by 2019 and 2020 with 15 and 12 documents, respectively; although by 2021, according to the shown trend, these averages could be exceeded, given that by July 2021, ten documents have been published. Among the published documents on this topic are: Vasconcelos *et al.* (2009), Vanegas-Rico *et al.* (2016) Torres and Giorgi (2018), and Santos *et al.* (2019); and among the most recent: Barreto-García *et al.* (2020) and Gonçalves *et al.* (2020). Due to the number of identified documents (15), corresponding to 11.54% of the period, it is followed in decreasing order by studies aimed at registering the “presence or occurrence” of this insect invading new areas (Occurrence, in Table 2); among the documents that address this issue are Chávez-Moreno *et al.* (2009; 2011), Spodek *et al.* (2014), and Bouharroud *et al.* (2016). Likewise, 13 registered documents addressed aspects of the “biology and reproductive parameters” (Biology, in Table 2); this has allowed having more and better information to facilitate their containment or eradication. Among the most representative documents are: De Souza and Hoffmann (2015), Rule and Hoffmann (2018), and Monteiro *et al.* (2019). During the second phase, research aimed at the use of *D. opuntiae* as a “biological control agent” (Biocontrol, in Table 2), also continued to appear in new areas where some *Opuntia* species have been accidentally or fortuitously introduced, such as Kenya, Namibia, New South Wales, Zimbabwe, and South Africa, among others. On this subject, among the eight identified documents, the following stand out: Tiago *et al.* (2016), Rule and Hoffmann (2018), Shaw *et al.* (2018), and Mazzeo *et al.* (2019). Another important topic corresponds to aspects related to its chromatographic and molecular characterization, thus

simplifying its identification and the species separation, through its chromatographic profile and 'symbionts' presence; among the nine identified documents are Chávez-Moreno *et al.* (2010), Ramírez-Puebla *et al.* (2010), Serrano *et al.* (2013), and Vera-Ponce de León *et al.* (2016; 2017) (Characterization, in Table 2). Finally, during this period, seven studies were recorded, aimed at quantifying the "social and economic impact" (Impacts, in Table 2), derived from its trophic activity, mainly taking place in Brazil; among the documents related to this topic are Almeida *et al.* (2011; 2019), Serrano-Montes *et al.* (2018), and Witt *et al.* (2020).

Table 2. Number of documents and main topics on *Dactylopius opuntiae*, during the 2001-2021 period.

Año	Biocontrol	Biology	Chracterization	Impacts	Occurrence	Control	Total
2001					1		1
2002		1					1
2004					1	1	2
2006		2			1		3
2008					1	1	2
2009		3			1	4	8
2010		1	2			3	6
2011				1	1	6	8
2012						2	2
2013	1		2			4	7
2014				1	2	2	5
2015		1			1	3	5
2016	1		1		1	6	9
2017			1		1	4	6
2018	2	3		2	1	9	17
2019	2	1		1	2	15	21
2020	2		1	2	1	12	18
2021		1	2			10	13
Total	8	13	9	7	15	82	134
% 2001-21	6.15	10.00	6.92	5.38	11.54	63.08	
% Total	4.15	6.74	4.66	3.63	7.77	42.49	

This remarkable growth of scientific production on *D. opuntiae*, during this second stage, could be associated with two important situations: the dispersion of *Cactoblastis cactorum* Berg. (Pyralidae: Lepidoptera) in the Caribbean and the southern USA and the concern about its imminent invasion of Mexico, the center of origin and dispersion of important *Opuntia* species, which drew attention due to its phytosanitary aspects. The other important conjunctural aspect was the wide diffusion and promotion of the cactus pear worldwide by different organizations such as the Food and Agriculture Organization (FAO), which enhanced its dispersion and massive establishment in different regions. This reflected is in a notable increase in scientific publications related to the comprehensive use of cactus pear and its co-products (Table 3) (Bravo-Vinaja and Méndez-Gallegos, 2016).

Table 3. Journals in which 50% of articles on *Dactylopius opuntiae* were published during the 1848-2021 period.

Journal title	Database and impact (2020)	Thematic category, Position and Quartile (Q)	Nº of articles	% of articles
Biocontrol Science and Technology	SCIE [†] , JIF 1.665	Entomology, 49/102 (Q2)	8	4.15
Farming in South Africa	NA	Active 1927-1972	8	4.15
Acta Horticulturae	SCOPUS, CS 0.5	Horticulture, 76/86 (Q4)	6	3.11
Engenharia Ambiental: Pesquisa e Tecnologia	NA	Environment	5	2.59
International Journal of Tropical Insect Science	SCIE, JIF 0.774	Entomology, 80/102 (Q4)	5	2.59
Journal of the Entomological Society of Southern Africa	NA	Active: 1935-2005	5	2.59
Acta Zoológica Mexicana	CRMICYT, 48.31 NC	Biology and Chemistry	4	2.07
Biocontrol	SCIE, JIF 3.571	Entomology, 12/102 (Q1)	4	2.07
Biological Control	SCIE, JIF 3.687	Entomology, 10/102 (Q1)	4	2.07
EPPO Bulletin	SCOPUS, CS 1.5	Horticulture, 46/86 (Q2)	4	2.07
Phytoparasitica	SCIE, JIF 1.439	Entomology, 53/102 (Q3)	4	2.07
Agriculture, Ecosystems & Environment	SCIE, JIF 5.567	Agriculture, Multidisciplinary, 1/58 (Q1)	3	1.55
Environmental Entomology	SCIE, JIF 2.377	Entomology, 27/102 (Q2)	3	1.55
Journal of Applied Ecology	SCIE, JIF 6.528	Biodiversity Conservation, 4/60 (Q1)	3	1.55
Neotropical Entomology	SCIE JIF 1.434	Entomology 54/102 (Q3)	3	1.55
Pesquisa Agropecuaria Pernambucana	NA	Agronomy	3	1.55
Revista Chapingo Serie Zonas Áridas	CRMICYT, 55.18 IC	Biotechnology & Agriculture	3	1.55
Southwestern Entomologist	SCIE, JIF 0.511	Entomology, 95/102 (Q4)	3	1.55
African Entomology	SCIE, JIF 1.188	Entomology, 65/102 (Q3)	2	1.04
Archives of Phytopathology and Plant Protection	ESCI, NA	Horticulture	2	1.04
Bulletin (Union of South Africa. Dept. Agri. Tech. Serv.)	NA	Active: 1921-1958	2	1.04

Bulletin de la Societe Entomologique de France	NA	Entomology	2	1.04
Bulletin of Entomological Research	SCIE JIF 1.75	Entomology 43/102 (Q2)	2	1.04
Ecological Entomology	SCIE JIF 2.465	Entomology 25/102 (Q1)	2	1.04
Journal of Agricultural Science	SCIE JIF 1.476	Agriculture, Multidisciplinary, 28/58 (Q2)	2	1.04
Journal of Economic Entomology	SCIE JIF 2.381	Entomology 26/102 (Q2)	2	1.04
Journal of Pest Science	SCIE JIF 5.918	Entomology 2/102 (Q1)	2	1.04
Revista Brasileira de Gestao Ambiental e Sustentabilidade	NA	Exact and earth sciences	2	1.04
28 (23.33%) journals			98	50.78

†Abbreviations: CS = CiteScore, CRMICYT = Classification System of Mexican Journals of Science and Technology, ESCI = Emerging Sources Citation Index, IC = International Competence, JIF = Journal Impact Factor, NA = Not Available, NC = National Competence, SCIE = Science Citation Index Expanded.

92 (76.67%) journals published the remaining 95 (49.22%) studied documents. Of the total studied journals not included in Table 3, 32 are indexed in the SCIE, one in the SSCI, and one in the A&HCI; three journals in the ESCI, and six articles were published in the same number of predatory journals, 11 journals are not currently published. In the detailed analysis of the 120 journals used for the document's dissemination, it was found that 50 journals are indexed in the SCIE, SSCI, and A&HCI of the Web of Science, which together published 92 (47.67%) of the assessed documents. It should be clarified, that most of these journals are also indexed in Scopus, but three journals are indexed in Scopus and not in SCIE; three journals are indexed in the ESCI, and 41 are indexed in other databases such as Zoological Record, Biological Abstracts, Cab Abstracts, Academic Google, CrossRef; likewise, 15 journals are no longer published, and six journals (Agricultural Science Research Journals, Asian Journal of Advances in Agricultural Research, Journal of Advanced Research in Dynamical and Control Systems, Journal of Bio Innovation, Journal of Critical Reviews, and Journal of Innovative Technology and Education) are considered predatory publisher journals, according to the sites <https://predatoryjournals.com/journals/> and <https://beallist.net/>. It is important to mention that 80 of the assessed journals publishing language is English, 19 Spanish, 13 Portuguese, five French, two German, and one Hebrew. It should be noted that most of the journals that publish in Spanish also do so in English, and most of the journals in Portuguese also do so in Spanish and English. Seventy-five (62.5%) journals do not publish in large editorial groups, but rather on administrative platforms such as the Open Journal System (OJS) or normal web pages. Out of the total 23 countries, the documents from Brazil, Mexico, South Africa, and the United States have the most publishing bodies publishing articles on *D. opuntiae* with 17, 10, 9, and 9 each; however, Israel, Lebanon, Jordan, Morocco, and Turkey, among other countries, have at least one locally edited journal that published an article on the species, which may be an indicator of the importance of studying *D. opuntiae* in the Middle East. For their part, large editorial groups published 45 (37.5%) of the journals, in which 80 (41.51%) articles were published. Among the publishing groups that publish the most journals were Springer (7), Elsevier (6), Oxford (5), Cambridge (4), and Wiley (4).

Co-authorship index

The average number of authors who participated in the creation of the documents, known as the co-authorship index (CI), consistently increased throughout the study period: from 1848 to 1950 it was 1; from 1951 to 2000 was 2.12; from 2001 to 2010 was 3.96, and between 2011 and 2021 it rose to 4.72; the global average CI was 3.61, which indicates an increasing collaboration to publish, especially in the last decade.

Authors with the highest production

It is noted that the authors with the highest production of *D. opuntiae* are from Brazil (5), South Africa (4), Morocco (4), Mexico (3), and Lebanon (1), highlighting those who have recently published, such as Rachid Bouharroud, Mohamed Sbaghi, and Mohamed El Aalaoui, from Morocco, El Mustapha Bouhssini from Lebanon, Antonio Félix da Costa, from Brazil, and Esteban Rodríguez-Leyva, from Mexico (Table 4), which indicates the current research importance on the subject in these countries. Three authors who in the recent past have been decisive in the advancement of the research on *D. opuntiae* stand out in the list, such as John H. Hoffmann, Vincent Cliff Moran, and Helmuth G. Zimmermann, all three from institutions established in South Africa. The expertise of most of the authors is related to biological control, integrated pest management, health, and plant protection, only two authors slightly differ in their expertise, such as Carlos Henrique de Brito, a specialist in biodiversity monitoring, and Edson Batista Lopes, agronomy specialist, both from Brazil; the authors with the highest number of citations are from South Africa: Moran (5146), Hoffman (4987), and Zimmermann (1011); from Lebanon Mustapha Bouhssini (1786); from Morocco, Mohamed Sbaghi (1577); from Mexico, José R. Lomelí-Flores (937) and Esteban Rodríguez-Leyva (815), from Brazil Patricia Vieira Tiago (348) (Table 4).

Table 4. Authors with six or more published articles on *Dactylopius opuntiae* during the 1848 - 2021 period.

Author	Nº of docs.	Nº of received citations ^{†§}	Work institution	Skills or expertise
Bouharroud, Rachid	15	300 (RG [‡])	Inst Nat Res Agron (Morocco)	Integrated Pest Management
Sbaghi, Mohamed	15	1577 (RG)	Inst Nat Res Agron (Morocco)	Plant bio-defenses
El Bouhssini, Mustapha	14	1786 (RG)	ICARDA (Lebanon)	Integrated pest management
da Costa, Antonio Félix	11	188 (Scopus)	Inst Agron Pernambuco (Brazil)	Plant health
El Aalaoui, Mohamed	11	77 (GS)	Inst Nat Res Agron (Morocco)	Biological control
Rodríguez-Leyva, Esteban	11	815 (GS)	Colegio de Postgraduados (Mexico)	Biological control
Hoffmann, John H.	10	4987(GS)	Univ of Cape Town (South Africa)	Biological control

Lomelí-Flores, José Refugio	10	937 (GS)	Colegio de Postgraduados (Mexico)	Biological control
Moran, Vincent Cliff	10	5146 (GS)	Univ of Cape Town (South Africa)	Biological control
Zimmermann, Helmuth G.	10	1011 (SCOPUS)	Agric Res C-Plant Health and Prot, Queenswood (South Africa)	Plant Health and Protection
Hilali, Lahoucine	9	125 (SCOPUS)	Faculté des Sciences et Techniques Settat (Morocco)	Biological control
Vanegas-Rico, Juan Manuel	9	216 (GS)	Colegio de Postgraduados (Mexico)	Integrated Pest Management
Vieira Tiago, Patricia	7	348 (RG)	Fed Univ of Pernambuco (Brazil)	Biological control
Pettey, Franklin Williams	7	NA	South Africa Dept of Agriculture	Biological control
da Silva, Deise Maria Passos	6	73 (SCOPUS)	Inst Agron Pernambuco (Brazil)	Plant health
de Brito, Carlos Henrique	6	241 (RG)	Univ Fed de Paraiba (Brazil)	Biodiversity monitoring
Lopes, Edson Batista	6	82 (RG)	EMBRAPA (Brazil)	Agronomy

[†]The received citations correspond to the total publications of each author present in the indicated database on September 7, 2021, not only those that deal with *D. opuntiae*.

[‡]Abbreviations: RG = Research Gate, GS = Google Scholar.

[§]The preference for listing the source of citations to authors was in the order: GS, RG, and SCOPUS.

Collaboration networks between authors

With the RIS file of the records concentrated in Zotero and the normalized authors' file, and using VOSviewer, with the *LingLog Modularity* normalization method, through the weight visualization in the links, a collaboration map between authors was obtained (showing the age or timeliness of the research networks) with two or more publications. Twenty-two clusters were obtained, with 11 co-authorship networks, seven of which are made up of Brazilian authors, two of Mexican authors, one of South African, and one Moroccan author, mainly; the rest (11) of the clusters are made up of a single author. The Brazilian research networks were made up of three groups of six to 16 authors, two of four and two with three authors. The largest cluster, had 16 authors including Antonio F. da Costa, Patricia Vieira Tiago, and Neiva Tinti de Oliveira, which is linked to a cluster made up of 11 researchers, among which stand out: Deise Maria Passos da Silva, Hiram Marinho Falcao, and Djalma dos Santos Cordeiro; this group relates in turn, with the cluster formed by six members, among whom are: Raquel María da Silva and Cristina María de Souza-Motta, these three groups are located on the right in the map (Figure 1). Regarding the current research state,

the yellow and orange coloration of the map indicates that they developed between 2010 and 2021. The remaining groups of Brazilian researchers, who have emerged in the last decade, include, among others: CH de Brito and IC of Albuquerque; MAC de Silva, CAT Gava; JAS Neto and Hermes Alves de Almeida; and JB Torres and JA Giorgi. Of the two groups with Mexican majority, four researchers stand out, three from the Colegio de Postgraduados: Esteban Rodríguez Leyva, J. Refugio Lomelí-Flores, Juan Manuel Vanegas-Rico, and Ana Lilia Viguera Guzmán from the Universidad de Guadalajara. The other group is made up of seven researchers, including Esperanza Martínez-Romero, Mónica T. Rosenblueth L., and Carla K. Chávez-Moreno, who carried out their research between 2010 and 2020. The South African group that has published research from 1970 to 2000, is made up of eight authors, including the classics: Helmuth G. Zimmermann, Vincent Cliff Moran, and John H. Hoffmann. Finally, in the group that has developed its research in recent years, the following stand out: Rachid Bouharroud, Mohamed Sbaghi, Mohamed el-Aalaoui, from Morocco, and el-Mustapha Bouhssini, from Lebanon (Figure 1). Among the single-author clusters, the following stand out: Franklin W. Pettey, Monique Sheelagh Jacquard Simmonds, and Theodore Dru Alison Cockerell.

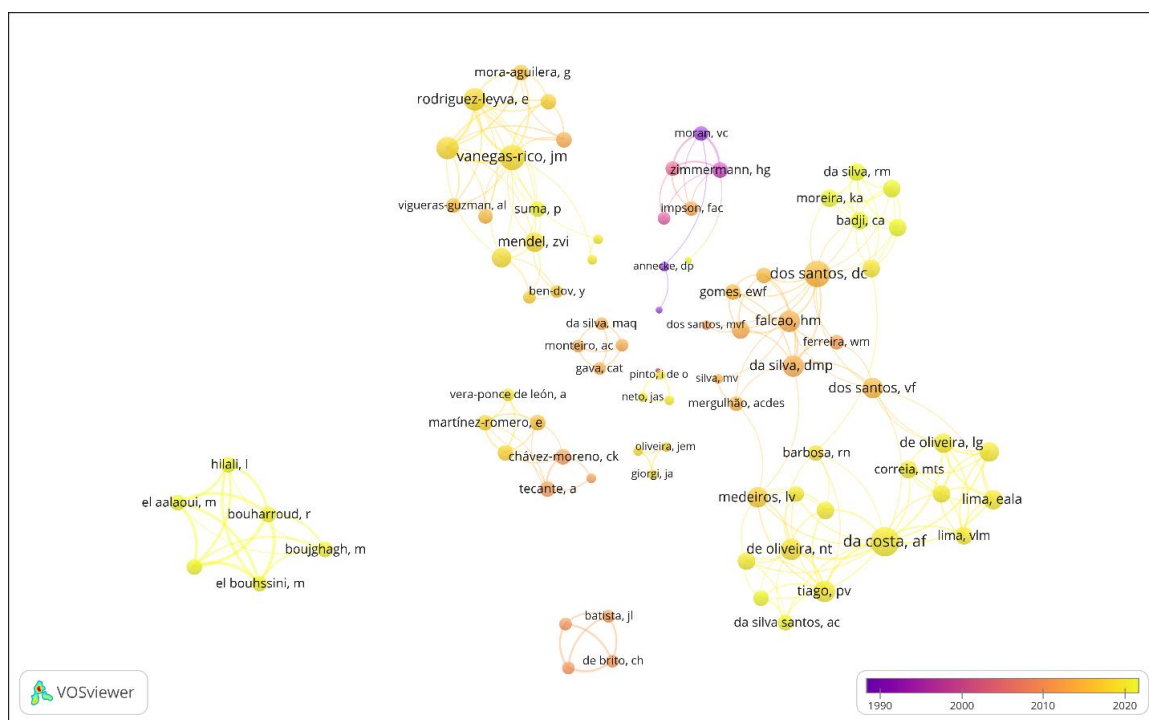


Figure 1. Collaboration networks between authors with two or more published articles on *Dactylopus opuntiae*, during the 1848 – 2021 period.

Most cited articles

The most cited articles were arranged in the six themes in which the articles were categorized; this provides a better perspective on the most cited articles than if only the ones with the most citations were identified. In the same way, the most recent articles were evaluated, which has a disadvantage because of the smaller citation window. For their part, the oldest ones also have disadvantages, because they are not indexed in the most popular databases for citations and abstracts. The citations were obtained from Google Scholar on September 7, 2021. Among the 11 most cited documents on the “biological control agents” topic (Biocontrol, Table 5), the following stand out: Pettey (1948) with 131 citations, and the documents by Moran and Zimmermann, (1984) with 107 citations; Simmonds and Bennett, (1966) with 97 citations, and Moran and Zimmermann, (1991) with 87 citations. It is to be noted that one of the first documents published on the subject, *Biological Control of the Prickly Pear*, does not have many citations (12) despite being published

in the Science journal (Cockerell, 1929), possibly because it was indirectly cited by been mentioned as the descriptor of the species in multiple research on *D. opuntiae*; it also stands out with 27 citations, the most cited document published in this century by Shaw *et al.* (2018) where *D. opuntiae* is mentioned as an important biological control agent.

Table 5. Most cited articles, ordered by topic and number of citations on *Dactylopius opuntiae*, during the 1848-2021 period, according to Google Scholar (GS).

Topic	Document	Citations [†] GS
Biocontrol	(Pettey, 1948)	131
Biocontrol	(Annecke and Moran, 1978)	129
Biocontrol	(Moran and Zimmermann, 1984)	107
Biocontrol	(Simmonds and Bennett, 1966)	94
Biocontrol	(Moran and Zimmermann, 1991)	87
Biocontrol	(Zimmermann and Moran, 1991)	80
Biocontrol	(Volchansky <i>et al.</i> , 1999)	67
Biocontrol	(Dodd, 1936)	42
Biocontrol	(Shaw <i>et al.</i> , 2018)	27
Biocontrol	(Cockerell, 1929)	14
Biocontrol/ Biología	(Goeden <i>et al.</i> , 1967)	80
Biology	(Hoffmann <i>et al.</i> , 2002)	46
Biology	(Flores-Hernández <i>et al.</i> , 2006)	41
Biology	(Monteiro <i>et al.</i> , 2019)	15
Characterization	(de Lotto, 1974)	112
Characterization	(Ramírez-Puebla <i>et al.</i> , 2010)	54
Characterization	(Vera-Ponce de León <i>et al.</i> , 2016)	23
Characterization	(Vera-Ponce de León <i>et al.</i> , 2017)	18
Control	(Vanegas-Rico <i>et al.</i> , 2010)	80
Control	(Santos <i>et al.</i> , 2016)	32
Control	(Geyer, 1947 a,b)	27
Control	(Santos <i>et al.</i> , 2016)	26
Control	(Cruz-Rodríguez <i>et al.</i> , 2016)	24
Control	(Falcão <i>et al.</i> , 2013)	20
Control	(Vanegas-Rico <i>et al.</i> , 2016)	18
Control	(Mazzeo <i>et al.</i> , 2019)	16
Control	(El Aalaoui <i>et al.</i> , 2019)	11
Control	(Guérin–Méneville, 1848)	2
Impact	(Almeida <i>et al.</i> , 2011)	17
Impact	(Witt <i>et al.</i> , 2020)	2
Occurrence	(Donkin, 1977)	201
Occurrence	(Chávez-Moreno <i>et al.</i> , 2009)	79

Occurrence	(Middleton, 1999)	70
Occurrence	(Miller, 1996)	54
Occurrence	(Portillo and Viguera, 2006)	41
Occurrence	(Spodek <i>et al.</i> , 2014)	32
Occurrence	(Bouharroud <i>et al.</i> , 2016)	29
Occurrence	(Chávez-Moreno <i>et al.</i> , 2011)	28
Occurrence	(Flores <i>et al.</i> , 2013)	24

†Citations updated on September 7, 2021.

Regarding the topic “biology” of the specie, the following stand out: Hoffmann *et al.*, (2002) with 46 citations, Flores-Hernández *et al.* (2006) with 41 citations. On the topic “identification and characterization” (Characterization, in Table 5), the most cited articles were De Lotto (1974) with 112 citations and Ramírez-Puebla *et al.* (2010) with 54. The published research on management and control practices that have received the most citations (80), is from Vanegas-Rico *et al.* (2010). Also noteworthy are the recent works by Santos *et al.* (2019) with 26 citations; by Mazzeo *et al.* (2019) with 16 citations; and by El Aalaoui *et al.* (2019) with 11 citations. Special mention is deserved by the work of Guérin-Méneville (1848), which was the first published document identified in this area, and has only two citations. Regarding the papers on the “social and economic impacts” topic (Impacts in Table 5), the work by Almeida *et al.* (2011) has 17 citations. The document with the highest number of citations (201) of all the assessed documents was: Donkin (1977), this document was classified as part of the “presence and occurrence” topic (Occurrence, in Table 5), and the second document with the most citations (79) was Chávez-Moreno *et al.* (2009). For its part, the most recent article with a significant number of citations (29) was that by Bouharroud *et al.* (2016).

Themes map and research trends

A network map of co-words was created, which was made with the keywords or concepts assigned by the authors of the documents and the classification made by the authors of this research; for this, the VOSviewer was used, applying the “strength of association” normalization method (Figure 2). The map shows the actuality of the trend of the investigations visualized by coloring nodes that represents the keywords or related concepts, according to the proximity between them; the closer they are, the greater their thematic relationship or affinity. In purple, the themes associated with *D. opuntiae* as a biological control agent are observed, published between 1970 and 1990, and carried out in South Africa, Australia, and India, as examples of this are the research by Pettey (1948), Annecke and Moran (1978), Moran and Zimmermann (1984), and Moran and Zimmermann (1991). The concepts related to management and control practices of *D. opuntiae* are grouped on the left side of the map, in orange and yellow color, which indicates that most of them were published between 2000 and 2021. These themes relate to Brazil, Mexico, Morocco, and Spain. The main themes include the use of entomopathogenic fungi (Santos *et al.*, 2016; Ramírez-Sánchez *et al.*, 2019), the use of natural enemies (Bouharroud *et al.*, 2019; El Aalaoui *et al.*, 2021), alternative methods such as simulated rain (Moran *et al.*, 1987), alternative products to chemical products such as botanical extracts (Viguera *et al.*, 2009), usage of bioinsecticides (Hernández-Pérez *et al.*, 2019), biodegradable products (Borges *et al.*, 2013), edible vegetable oils (Cuevas-Salgado *et al.*, 2015); and recycled vegetable oils (Torres-Gabriola and Cuevas-Salgado, 2019), among others.

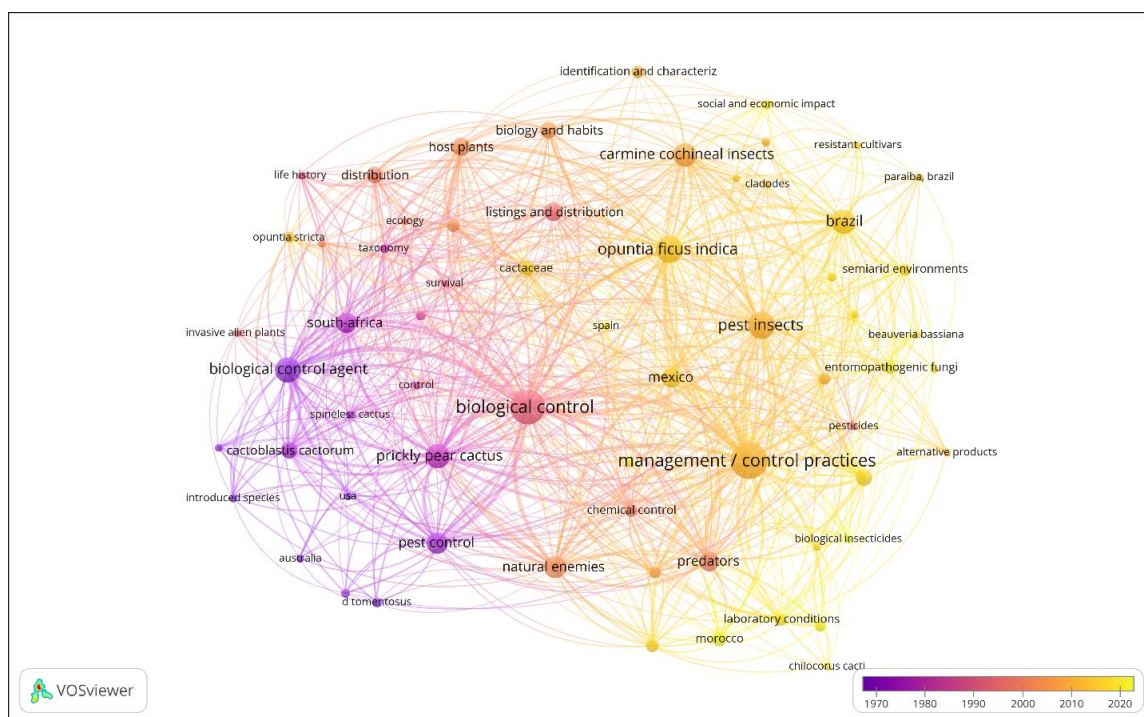


Figure 2. Network map (overlay option) of co-words on *Dactylopius opuntiae* (1848-2021) from the keywords of the authors and the terms assigned by the authors of this document, showing the temporality of the research topics.

The 23 documents on the species listing and distribution were published throughout the study period; for this reason, they are displayed in the middle of the map, in pink; among the research are by Donkin (1977), Chávez-Moreno *et al.* (2009), and Miller (1996); the oldest recorded work: (Lizer 1922) and the three most recent identified works: Ülgentürk and Hocaalı (2019); Bader and Abu-Alloush (2019); and Bufaur and Bohamdan (2020). The 20 papers on the biology and habits of the species were mainly published between 1999 and 2010, among them the following stand out: Volchansky *et al.* (1999) and Flores-Hernández *et al.* (2006). Some documents were also published in the last century such as: Nur (1982) and Wang and Nobel (1995), among the most recent works are: Palafox-Luna *et al.* (2018), López-Rodríguez *et al.* (2018), and Musengi *et al.* (2021). The vast majority of the documents on the identification and characterization (the term is located in the upper part of Figure 2) of the species were published in the last decade of this century, among which are: Ramírez-Puebla *et al.* (2010) and Vera-Ponce de León *et al.* (2016); at the same time, tree papers from the last century stand out, the multi-cited De Lotto (1974), MacGregor and Sampedro (1983), and Pérez and Kosztarab (1992). The category with the fewest published documents (social and economic impact) is associated with Brazil in the upper part of the map in yellow, which indicates that all the articles were published in the 2010-2020 decade, among the most representative works are Almeida *et al.* (2011) and Dantas *et al.* (2020). At the center of the map in Figure 2, the term “biological control” appears, which was the most frequent descriptor in the analyzed documents, as it appears in this position it indicates that it is used both by the research addressing the use of *D. opuntiae* as a control agent for *Opuntia* as a weed, as well as those articles on the different biological methods used to control *D. opuntiae* expansion as a pest in *Opuntia*. The pink color indicates that most of the documents were published in this period, although publications appear throughout the study period.

Conclusion

According to this search carried out in the different databases, 193 documents were identified and extracted, ranging from 1848 to 2021 related to *D. opuntiae*. During the 1848-2000 period only

20% of the total documents were published, while from 2001 to 2021 most publications were registered (80 %), which denotes the acquired importance of the species during the last two decades. Similarly, the topics addressed in each of the periods showed drastic changes, since in the first assessed period they particularly focused on studies of its use as a biological control agent for *Opuntia*, while during the following period, they focused on generating information on combat measures. The countries where the highest number of publications were generated were: Morocco, Brazil, South Africa, and Mexico. Bouharroud, R. and Sbaghi, M. were the authors with the highest number of published documents, while the authors with the highest number of citations were V. C. Moran and J. H. Hoffman. The most cited article was Spanish Red: An Ethnogeographical Study of Cochineal and the *Opuntia* Cactus, written by Donkin in 1977. It was possible to identify 11 co-authorship networks, from which, seven are made up of Brazilian authors, two by Mexican authors, and one by Moroccan authors. The network that has remained for the longest period is that from South Africa since it has consistently been publishing together since 1970. The term with the highest frequency found was “biological control”, associated with the use of *D. opuntiae* in the eradication of some cacti considered as weeds and the use of natural enemies and microorganisms as a control strategy for *D. opuntiae*. Finally, taking into account that *D. opuntiae* has been registered in at least 30 of the 64 countries in which *Opuntia* is present and that during the last five years it has spread to seven new ones; it could be considered an emerging pest where the species is found either wild or cultivated.

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Not applicable

Statement of ethics

Not applicable

Consent to publication

Not applicable

Data availability

The datasets in XLSX format generated and/or analyzed during the current study are available in the Zenodo repository, Colegio de Postgraduados Campus San Luis Potosí Community, DOI: <https://doi.org/10.5281/zenodo.5636337>.

The dataset of all articles in RIS format used during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests

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Author contributions

Santiago de Jesús Méndez-Gallegos participated in the conceptualization of the project, made the investigation for the background of the manuscript, wrote part of the original draft, reviewed and edited all versions of the manuscript, and executed a part of the project administration.

Angel Bravo-Vinaja participated in the conceptualization of the project, applied the bibliometric methodology, used software for generating the science maps, validated and curated the metadata

information, made the formal analysis of the bibliometric indicators, managed the information resources, curated the Zotero database, wrote part of the original draft, reviewed and edited the manuscript, made the visualization maps, and executed a part of the project administration.

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