

EMERGING TRENDS IN SCIENTIFIC RESEARCH ON *Dactylopius coccus* Costa (HEMIPTERA: DACTYLOPIIDAE), CARMINIC ACID AND ITS DERIVATIVES: A BIBLIOMETRIC ANALYSIS

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ABSTRACT

The objective of study was to identify the emerging topics of scientific production published in mainstream journals, their visibility and synergies through an approach of unidimensional and multidimensional bibliometric indicators (BIs) on *Dactylopius coccus*, carminic acid (CA) and its derivatives, from 1980 to 2019. The BIs were obtained with the information software programs Excel[®], *bibliometrix*, and VOSviewer. During the period of study, an increase was seen in the publications where scientific articles in English predominate, concentrated in two journals: Food Chemistry and Journal of Raman Spectroscopy. I. Karapanagiotis was the author with the highest productivity; the authors with greatest influence in the generation of new knowledge were M. Leona (576 citations) and F. Casadio (568 citations), both from the United States of America (USA). The main research was focused on the identification, characterization and analysis of CA with different techniques. Other emerging and innovating topics that stand out were the application of CA in solar cells, and its therapeutic properties as antioxidant and for cancer prevention. Some of the recurring topics are related to biological aspects of the insect, the secondary effects associated with the consumption or exposure to CA, its use as dye of natural or animal fibers, and its applications as a food additive.

Keywords: bibliometrics, cochineal, evaluation of scientific production, text mining, research trends, VOSviewer.

INTRODUCTION

The cochineal *Dactylopius coccus* Costa (Hemiptera: Dactylopiidae) is an insect of great social and economic importance (Méndez-Gallegos *et al.*, 2010; Cooksey, 2019) in several countries, among which Peru, Chile, Spain and Mexico stand out. Its importance consists in that a natural dye (González *et al.*, 2002; Borges *et al.*, 2012) and the main coloring compound, carminic acid (CA) (Miller *et al.*, 2017), are obtained from the dry bodies of the females. Carminic acid, constituted by a glucose unit linked to hydroxyanthraquinone (Lancaster *et al.*, 1996), is biosynthesized by the insect with defense purposes (Dettner, 2014) and it is present in variable proportions in all the *Dactylopius* species (Chávez-Moreno *et al.*, 2010).

Both CA and its derivatives (lacquer, carmine, extract, among others) have multiple applications, and are of great industrial interest (Borges *et al.*, 2012; Müller-Maatsch and Gras, 2016; Cooksey, 2019). Their use has been favored by technical and regulatory restrictions on some synthetic colors with collateral effects on health. Likewise, CA and its derivatives are appreciated for their high stability with heat, light and oxygen (Dufossé,

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2014), for their new potential applications at the global scale (Velho *et al.*, 2017; Sánchez-García *et al.*, 2018; Roslan *et al.*, 2018), and for their antioxidant properties and absence of mutagenic activity (Li *et al.*, 2009), among others.

In addition, there is the identification and characterization of the main allergen (Ohgiya *et al.*, 2009), which allowed the use of CA with lower risk to health, a greater efficiency in the extraction methods that reduces the adverse reactions from the presence of residues and impurities (Schmidt-Jacobsen and Frandsen, 2011; Borges *et al.*, 2012) and the development of simpler and faster methods to detect contaminants (Nakayama *et al.*, 2015). These aspects eased their authorization by the principal food and health regulating agencies, such as the US Food and Drug Administration (FDA) and the European Union (Dufossé, 2014; EFSA, 2015; Müller-Maatsch and Gras, 2016; Miller *et al.*, 2017).

Therefore, there is a great research effort by businesses, manufacturers of food additives, research centers and universities, as well as groups of researchers, which has been reflected in scientific articles, theses and patents. Scientific publications make the dissemination of information easier and foster the emergence of new knowledge, a growth in science and scientific progress (Bordons, 2004). Their quantitative analysis provides a view of the complex process of scientific communication, since it allows examining their behavior in a specific field of science. Bibliometrics, defined by Groos and Pritchard (1969) as the application of mathematical methods to books and other means of communication, offers a set of methods and measures to study the structure and process of said academic communication (Borgman and Furner, 2002).

A way of applying bibliometrics is the use of scientometric indicators, defined by van Raan (1993) as quantitative measurements based on data from published material, particularly serialized literature, called bibliometric indicators (BIs). Among these, three types are differentiated: size and characteristics of scientific production, impact from it and structural characteristics of science. Likewise, van Raan (1993) distinguished two methodological types of indicators: unidimensional or scalar, and bi-dimensional or relational. Sanz-Casado and Martín-Moreno (1997) also called the latter multidimensional, to include the indicators of more than two dimensions.

The scalar or one-dimension technique is based on direct counting (occurrences) of specific bibliographic elements from publications and patents. Meanwhile, the relational technique indicators are built from co-occurrences of specific items that show the joint relationships and interactions that can be represented through “bibliometric maps” (Tijssen and Van Raan, 1994). Between the unidimensional BIs, the following stand out: growth of the scientific production, its ageing and obsolescence, and the dispersion of the literature (Bradford, 1934); also, the collaboration in publications, whether between authors (co-authorship indices), institutions and countries, linguistic capacity or language of publication and documental typology. Lastly, the number of citations received by the authors, measured by the H index (Hirsch, 2005) and the main journals for publication, characteristic determined by indices such as the impact factor (JIF) (Garfield, 2006) or the CiteScore (Ziljstra and McCollough, 2016).

The multidimensional indicators allow analyzing a multifaceted phenomenon such as scientific production in greater detail. These indicators are based on data matrices, where each of the components represents the co-occurrence of common variables between two objects; they can represent authors, institutions, journals or research topics, while the variables can be co-authorship, citations, or joint appearance of descriptors or keywords (Lascurain-Sánchez, 2006). This type of BIs also includes two important aspects: the analysis of joint words or co-occurrence of words, that is, the use of groups of words with simultaneous appearance in many documents, whether in controlled language or free text. The co-occurrence analysis allows identifying key terms and associating the documents by the degree of co-occurrence of the terms to produce the map of a specialty of science (Spinak, 1996). Meanwhile, text mining, understood as data mining applied to texts in natural language (Leopold *et al.*, 2004), is an inter-disciplinary field that combines linguistics, informatics and statistics techniques, to recover and extract information from the digital text in an efficient manner through information tools (Bergman *et al.*, 2013). Informatics tools and software are used in bibliometric analyses, both proprietary and of open code, such as VOSviewer (van Eck and Waltman, 2010) and *bibliometrix* (Aria and Cuccurullo, 2017), which allow processing large amounts of bibliographic information. These software programs were used in this study with the objective of characterizing the scientific production about *Dactylopius coccus*, CA and its derivatives, with the aim of identifying the scientific research trends in mainstream journals, during the 1980 to 2019 period.

METHODOLOGY

Search strategy

A search strategy was established to identify in the databases indexed by the mainstream journals (Salager-Zeyer, 2015), Science Citation Index Expanded (SCIE) and Social Sciences Citation Index (SSCI) from Clarivate Analytics. Specifically in the fields: title, abstract and keywords from the bibliographic records of documents related with *Dactylopius coccus*, carminic acid and derivatives. The expression of the strategy that is shown next was executed in the option “advanced search”:

TS=((cochineal NOT “*Dactylopius opuntiae*”) OR cochénille OR “carminic acid” OR “carminic acid” OR “carmine E-120” OR “CI 75470” OR “Natural red 4” OR “*Dactylopius coccus*” OR (“Carmine acid” NOT “Indigo carmine”) OR (“*Dactylopius coccus*” AND “*Dactylopius opuntiae*”))

To identify the documents that included the theme or words in the titles, those that contained them in the abstract and the keywords were separated from the documents, with the following search expression:

TS=((cochineal NOT “*Dactylopius opuntiae*”) OR cochénille OR “carminic acid” OR “carminic acid” OR “carmine E-120” OR “CI 75470” OR “Natural red 4” OR “*Dactylopius coccus*” OR (“Carmine acid” NOT “Indigo carmine”) OR (“*Dactylopius*

coccus” AND “*Dactylopius opuntiae*”)) NOT TI=((Cochineal NOT “*Dactylopius opuntiae*”) OR Cochenille OR “Carminic acid” OR “Carminc acid” OR “Carmine E-120” OR “CI 75470” OR “Natural red 4” OR “*Dactylopius coccus*” OR (“Carmine acid” NOT “Indigo carmine”) OR (“*Dactylopius coccus*” AND “*Dactylopius opuntiae*”))

This separation allowed identifying with greater certainty the documents that address the theme, from those that deal with it in a secondary or partial way. The results were used for the elaboration of the indicators “Documental typology” and “Authors with highest production”.

In both cases, the records obtained until May 21, 2020, were reclassified by year of publication (1980-2019) and by documental typology (articles, *in extenso* articles from congresses, review articles, early access, letters and scientific notes). The identification of documents with the use of these criteria is important, because when the search of the terms is restricted only in the document’s title, it is ensured that in fact they address the research topics of interest. Meanwhile, the search that includes the terms in the abstract and keywords, which in most cases do not repeat the concepts already expressed in the title, addresses the theme in a secondary way, incidental or related to other related topics.

Statistical processing

A total of 617 bibliographic records were obtained in the databases consulted, which were exported in RIS format to process them with Zotero. Later, they were reclassified in Excel[®] to generate the following unidimensional bibliographic indicators (BIs): Growth of scientific production, Document typology, Journals of publication, Index of co-authorship, and Production by countries. Likewise, the complete bibliographic records with the citations included were exported as “text without format” to the *bibliometrix* software, where the unidimensional BI, Concentration and dispersion of literature, was generated by application of the Bradford Law (1934). Also with *bibliometrix*, the following multidimensional BIs were obtained: Authors with highest production by country and their relation with the research topics, through the keywords assigned by the database (Keyword Plus); Authors with highest production through time; Thematic evolution of the research, according to the words contained in the title of the documents; and, Authors with highest production and their relationship with the Research topics by countries. Finally, the complete records and cited references were imported from the VOSviewer software, after their export from SCIE and SSCI in the file format “text without format” to generate the unidimensional BI: Authors with highest production, and the multidimensional BIs: Citation relationships between journals; Joint citations relationships between journals; Collaboration networks between authors; Collaboration network between countries; and Thematic evolution of the research according to the words of the title of the documents (Table 1).

Table 1. Unidimensional and multidimensional bibliometric indicators (BIs) used to describe regularities and to identify trends in scientific information on *Dactylopius coccus*, carminic acid (CA) and its derivatives, in mainstream journals (1980-2019).

Unidimensional BIs	Multidimensional BIs
Growth of scientific production	Citation relationships between journals
Document typology	Joint citations relationships between journals
Publishing languages	Collaboration networks between authors
Publishing journals	Authors with the highest production by country and their relationship with the research topics according to the terms of “Keyword Plus”
Concentration and dispersion of literature	Authors with the greatest production, through time
Co-authorship index	Collaboration network between countries
Authors with greater production	Identification of research topics through a network map of the co-occurrence of words or descriptors based on text data (title and abstract)
Most cited authors	
Production and impact of documents by country	Thematic evolution of the research according to the words of the title of the documents

Elaboration of network maps

The procedures of bibliometric analysis to create and to visualize the maps mentioned (Table 1) were carried out with the VOSviewer software. This software allows creating and visualizing maps from bibliographic records obtained in databases such as SCIE, SSCI, Scopus, Dimensions, CrossRef and PubMed. These maps recreate networks of interactions and interrelations of scientific documents and publications, researchers, institutions, countries or keywords related with a specific research topic. The connection of elements that make up these networks can happen by co-authorship, co-occurrence, citation, joint citation, or bibliographic coupling (van Eck and Waltman, 2010).

VOSviewer uses visual representation by similarity (Visualization of Similarities–VOS), a method proposed by van Ech and Waltman (2007) as an alternative to the multidimensional scale to visualize similarities between objects. VOSviewer uses by allocation the normalization method called Association Force (AF) to create clusters. It also offers the possibility of obtaining them with the LinLong Fractionalization and Modularity methods (Noack, 2007) and without normalizing, as described by van Eck and Waltman (2010).

Text mining

The text mining function was used in the VOSviewer software to generate a map of research topics and to compare it with the analysis of concurrent words obtained with the keywords. This analysis, despite it representing the most objective option, is criticized because it considers only the keywords from authors, which in many cases are limited by journals to five and without repeating the words contained in the document’s title; this is why the keywords or descriptors do not reliably represent the topics addressed. Another

important criticism refers to the possible inconsistencies or omissions in the selection of terms by professional indexers who work in the different databases, which is called the “indexer effect” (Spinak, 1996).

The functionality of text mining by VOSviewer allows the creation of term maps from a set of documents, such as the title and abstract. A term map is a bi-dimensional map in which they are located in a way that the distance between two terms can be interpreted as a relationship between them; in general, the smaller the distance between two terms, the stronger their relationship and this is determined in function of the coincidences found in the documents analyzed (van Eck and Waltman, 2011).

Lastly, VOSviewer allows the creation of thesauruses of terms to normalize authors and words or else to eliminate them so that they do not appear in the maps. Three thesauruses were created to normalize authors, author keywords and Keyword Plus, and for words obtained from the documents’ titles and abstracts.

RESULTS AND DISCUSSION

Growth in scientific production

In the 40 years that the study period covered, a constant growth in scientific production was observed, as demonstrated by the trend line ($R^2 = 0.7599$). During the first third of the study period (1980 to 1993), less than 10 documents were published per year, while from 1994 to 2004 an increase was found to an average of 10 to 20 documents published per year, and from 2005 to date, in most years between 20 and 50 documents per year were published (Figure 1).

Document typology

Regarding the type of documents, a high predominance of research articles was observed, with 95.3%, followed by review articles with 3.08%. The full congress articles, counted also as research articles, contributed with 5.19% of the total; meanwhile, the pre-printed (early access documents), letters, and notes had a participation lower than 1% (Table 2). The documents whose research topics were found in the title represented more than a third (37%), while around 63% were located in abstract and keywords.

Publishing language

The English language predominated in the documents published with 92.7%, followed by Japanese (1.62%), French and German (1.14%). The documents published in Spanish, Portuguese, Mandarin, Hungarian and Polish contributed average values below 1% (Table 3). These results show that mainstream journals publish in English in this area of science, despite the Latin American origin of the insect.

Publishing journals

The results obtained showed that there is a high concentration of the documents published in a small number of journals. It was found that only 73 journals (20%) published 50%

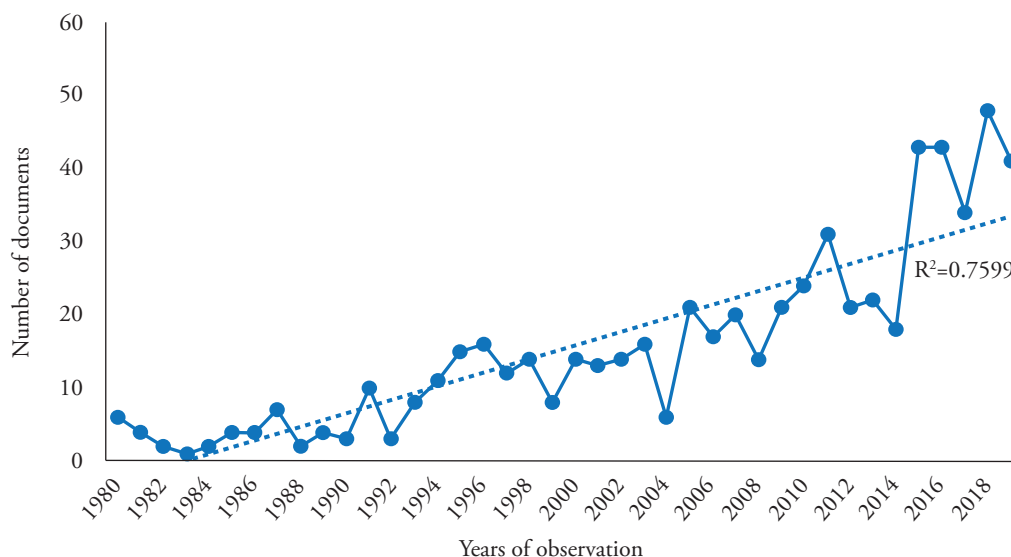


Figure 1. Behavior of the publications (1980–2019) on *Dactylopius coccus*, carminic acid (CA) and its derivatives, in mainstream journals.

of the total documents; the other 50% of the publications were distributed in 289 (80%) journals. It should be emphasized that 61% (223) of the journals published only one document. Table 4 lists the 20 journals, a 5.95% of the 336 titles recorded, where a fourth of the documents (25.77%) related to the topic evaluated was published.

Only two journals published more than 15 documents related with the topic, Food Chemistry and Journal of Raman Spectroscopy (16). Most of the journals that published more about the topic are among the best positioned according to the JIF obtained in 2019 in their JCR categories; 15 of the 25 titles included in Table 4 are positioned in the first quartile; four journals in the second quartile; one in the third quartile; and two in the fourth quartile. *Agrociencia*, the only Latin American journal that appears among those

Table 2. Document types on *Dactylopius coccus*, carminic acid (CA) and its derivatives, published in mainstream journals (1980-2019).

Document types	Detected in the title	Detected in abstracts and keywords	Total	%
Research articles	217	371	588	95.30
*Full conference articles	5	27	32	5.19
Review Articles	3	16	19	3.08
Early access articles	1	0	1	0.16
Letters	6	0	6	0.97
Research notes	1	3	4	0.64
Total	233 (228)	417 (389)	640 (617)	

*Full congress articles are also classified as research articles.

Table 3. Publishing languages of documents related to *Dactylopius coccus*, carminic acid (CA) and its derivatives published in mainstream journals (1980-2020).

Language	Documents	%
English	572	92.70
Japanese	10	1.62
French	7	1.14
German	7	1.14
Spanish	6	0.97
Portuguese	5	0.81
Mandarin Chinese	3	0.49
Russian	3	0.49
Hungarian	2	0.32
Polish	2	0.32
Total	617	100

Table 4. Mainstream journals (top 20) with more documents published on *Dactylopius coccus*, carminic acid (CA) and its derivatives (1980-2019).

Journal	# of docs.	% of docs.	2019 JIF	JCR category	Position / JCR category	JCR category quartile
Food Chemistry	16	2.63	6.309	Food science and technology	6/139	1
Journal of Raman Spectroscopy	16	2.47	2.000	Spectroscopy	19/42	2
Analytical and Bioanalytical Chemistry	12	1.86	3.637	Analytic chemistry	18/86	1
Talanta	12	1.86	5.339	Analytic chemistry	11/86	1
Dyes and Pigments	11	1.70	4.613	Materials Sciences, Textiles	1/24	1
Journal of Chromatography A	9	1.39	4.049	Biochemical Research Methods	13/77	1
Heritage Science	8	1.24	1.902	Spectroscopy	21/42	2
Analytica Chimica Acta	7	1.08	5.977	Analytic chemistry	10/86	1
Journal of Agricultural and Food Chemistry	7	1.08	4.192	Multidisciplinary Agriculture	4/58	1
Journal of Cultural Heritage	7	1.08	2.553	Spectroscopy	14/42	2
Agrociencia	6	0.93	0.346	Multidisciplinary Agriculture	51/58	4
Coloration Technology	6	0.93	1.500	Materials Sciences, Textiles	9/24	2
Journal of The Food Hygienic Society of Japan	6	0.93	0.371*	Food science and technology	nd	nd
Microchemical Journal	6	0.93	3.594	Analytic chemistry	19/86	1
Spectrochimica Acta part A-Molecular and Biomolecular Spectroscopy	6	0.93	3.232	Spectroscopy	7/42	1
Analyst	5	0.77	3.978	Analytic chemistry	15/86	1

Table 4. Continuation.

Journal	# of docs.	% of docs.	2019 JIF	JCR category	Position / JCR category	JCR category quartile
Food Additives and Contaminants Part A-Chemistry Analysis Control Exposure Risk Assessment	5	0.77	2.340	Food science and technology	60/139	2
Food and Chemical Toxicology	5	0.77	4.679	Food science and technology	14/139	1
Journal of Liquid Chromatography & Related Technologies	5	0.77	0.992	Analytic chemistry	75/86	4
Allergy	4	0.62	8.706	Allergies	2/28	1
316 journals with 4 or fewer publications.	458	72.02				
Total: 336	617	100				

*The JIF of this journal corresponds to the year 2011, last year when it was included in the JCR.

that publish about the topic is located in the fourth quartile. From the 20 journals in the list, eight are categorized in Analytic Chemistry and five in Spectroscopy. According to the JCR categories, from the 336 mainstream journals that published the 617 documents, 136 (40.48%) are categorized in Analytic Chemistry, 89 (26.49%) in Food Science and Technology, 66 (19.64%) in Applied Chemistry, and 53 (15.47%) in Spectroscopy. However, it should be considered that some journals can be included in one or more categories (Table 4).

To visualize the impact in the topic of study, it is necessary to identify the journals with the highest number of citations in the 617 documents analyzed. Among the 10 journals whose documents received more citations, until May 21, 2020, the ones with topics focused on spectroscopy and chromatography stand out, such as Journal of Raman Spectroscopy and Journal of Chromatography (Table 5).

Concentration and dispersion of the literature

When applying the Bradford Law (Bradford, 1934), or Bradford's mathematical model, three groups of journals were identified where the documents that address the theme of study were concentrated and dispersed. The first group included 32 journals that published 207 documents (33.55%) and 20 journals from this group are listed in Table 4; the second group considered 101 journals that published 207 documents (33.55%); and a third group of 203 journals published 203 documents (32.9%).

Citation relationships between journals

The relationships (by citations) between journals in study are presented in a map of visual representation of similarities, obtained with the bibliographic data from the 617

Table 5. Mainstream journals (top ten) with the most citations in the 617 documents analyzed, on *Dactylopius coccus*, carminic acid (CA) and its derivatives (1980-2019).

Journal	Documents	Citations	% of total citations (11430)
Journal of Raman Spectroscopy	16	735	6.43
Journal of Chromatography A	9	507	4.46
Analytical and Bioanalytical Chemistry	12	364	3.18
Dyes and Pigments	11	288	2.52
Talanta	12	285	2.49
Food Chemistry	16	260	2.27
International Journal of Food Science and Technology	2	241	2.1
Analytical Chemistry	4	233	2.03
Analytica Chimica Acta	7	225	1.97
Journal of Agricultural and Food Chemistry	7	224	1.96

documents analyzed in VOSviewer (Figure 2). The journals with at least two documents published and with at least 10 citations were identified in it; the map was visualized with the option *citations*. In the map it stands out that the journals are related through citations, according to the topics addressed.

With the Ling/Log Modularity normalization method, 105 journals grouped into six clusters were identified. Cluster one (red) concentrated 33 journals, whose main topic is food chemistry, where Food Chemistry and Journal of Agricultural of Food Chemistry stood out. Cluster two (green) included 21 journals that publish about aspects of analytic chemistry, chromatography, and conservation and cultural heritage, where the following

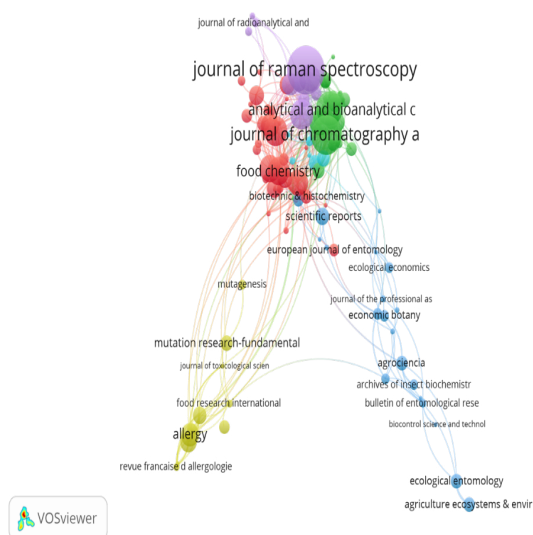


Figure 2. Map of citation relationships between mainstream journals that published on *Dactylopius coccus*, carminic acid (CA) and its derivatives (1980-2019).

journals stood out: *Journal of Chromatography*, *Química Analítica y Bioanalítica*, *Chimica Analytica Acta* and *Journal of Cultural Heritage*. Cluster three (blue) showed a clear specialization in aspects related with the insect's biology, such as entomology, ecology and botany, and 20 journals were grouped, where *Scientific Reports*, *Ecological Entomology*, *Agriculture Ecosystems and Environment*, and *Agrociencia* stood out. The journals from cluster four (yellow), including 14 of them, stood out in the map (the same as cluster three) which, when separating it from the rest, grouped the journals that address topics related with allergies, where *Allergy* and *Journal of Allergy* stood out. Cluster five (purple) considered 11 journals which mainly publish aspects of spectroscopy, on the identification and characterization of natural dyes; in addition, this cluster maintained a close relationship with the journals from cluster two; the most outstanding journals from this group were *Journal of Raman Spectroscopy* and *Dyes and Pigments*. Lastly, cluster six (aquamarine) grouped six journals that were focused on textiles, fibers and their coloring, where the journals *Textile Research Journal* and *Coloration Technology* stood out.

Co-citations relationships between journals

The index of co-citations (Small, 1973), applied to the journals identifies those in which their documents have a double citation relationship in the documents evaluated, compared to the simple citations that show the relationships of journals in which the documents are published. Co-citations allow identifying more clearly the research topics where journals are specialized, and with that, to identify the research aspects that are most researched in a broad topic as in this study.

In the joint citations map, only 99 journals were considered which had 30 citations in the date when data were taken. The total strength of the links of “co-citations” between one source and another was calculated; the results showed the influence of some journals that are not included in the main current. Such is the case of *Acta Horticulturae* grouped in the red cluster and the books “*Artist's pigments, a handbook for their history and characteristics*” and “*National Gallery Technical Bulletin*” (green cluster) (Figure 3).

In general, the co-citations map obtained showed a similar behavior to the citation map, forming six clusters. However, it is worth to highlight two important aspects: first, the disappearance of the cluster that groups the journals on entomology, ecology and botany, which could be related to the fact that only journals with 30 citations or more were analyzed. However, this would indicate that the topic is cited less than those that do appear (blue cluster, Figure 3). The second aspect, specialization visualized through a marked separation from the cluster that groups the journals about allergies, and to a lesser extent journals about chemistry and food science and technology, are cited more between them than with the other clusters.

Collaboration between authors

The collaboration in the publication of documents can be present in different modalities, such as authors, institutions and countries. The following six indicators show different facets of such a collaboration.

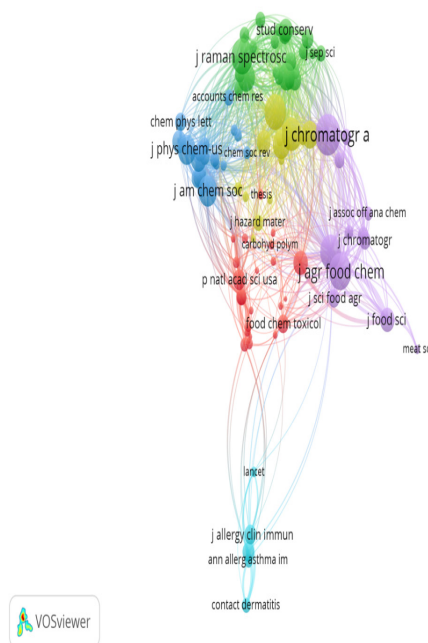


Figure 3. Map of co-citation relationships between mainstream journals related with *Dactylopius coccus*, carminic acid (CA) and its derivatives (1980-2019).

Co-authorship index

The co-authorship index is the mean value of the number of authors that participate in the creation of a scientific document (Vinkler, 1993); in this study the average was 4.17 authors by document. This value indicates a high collaboration to publish; however, this does not hold as a general rule, since the index found for the decade of the 1980s was 2.89, although during the ten most recent years it increased to 4.68. This shows that the index had a constantly increasing trend through time. The values of the co-authorship index found for the decades 1990–1999 (3.59) and 2000–2009 (3.75) are similar to the behavior reported in Mexico for the Consultative, Scientific and Technological Forum (2006) during the 1990–2004 period, with an average index of 3.96 for agricultural sciences.

Authors with highest production

The three authors with highest scientific production about *Dactylopius coccus*, CA and its derivatives were: Ioannis Karapanagiotis from the Ecclesiastic University Academia from Salonica, Greece, whose main topics are analysis through chromatograph techniques of the cultural heritage and the identification of natural pigments in textiles; Masoud

Salavati-Niasari from the Kashan University in Iran, with his research about nanomaterial nanotechnology and about the synthesis of silver nanoparticles from the cochineal dye; and Celina Llanderal-Cázares, from Colegio de Postgraduados in Mexico, with her studies related to the physiology of insects, particularly about breeding of *Dactylopius coccus* and propagation with commercial purposes (Table 6).

It should be clarified that the columns “Docs. title” and “Docs. r kw” marked in Table 6 included the number of documents in which the concepts considered in the search strategy were identified in title, abstract and keywords; and others, in the abstracts and keywords of documents analyzed. The colors assigned highlight the section of bibliographic record where those concepts were found, according to the search strategy. It was seen that 12

Table 6. Authors with the highest production related to *Dactylopius coccus*, carminic acid (CA) and its derivatives, in mainstream journals (1980-2019).

Author (H index)	Docs.	Citations	Docs. title	Docs. r kw	Institution	Research topics
Karapanagiotis, Ioannis (SCI 25, S 26, GS 29)*	17	475	2	15	Univ. Eccl. Acad. Thessaloniki (Greece)	Cultural heritage, Polymers.
Salavati-Niasari, Masoud (SCI 81, S 85, GS 92)	10	298	4	6	Kashan Univ. (Iran)	Nanotechnology, Nanomaterials
Llanderal-Cázares, Celina (SCI 8, S 9, GS 12)	9	52	9	0	ColPos (Mexico)	Cochineal, insect physiology.
Navalon, Alberto (SCI 37, S 39, GS 43)	8	281	2	6	Univ. Granada (Spain)	Analytic chemistry
Goudarzi, Mojgan (SCI, 11, GS 14)	8	205	3	5	Kashan Univ. (Iran)	Nanotechnology, Photocatalysis
Sugimoto, Naoki (SCI 17, S 18)	8	60	5	3	Nat. Inst. Health Sci. (Japan)	Cochineal, dye, chromatography, food additives.
Leona, Marco (SCI 22, S 24, GS 28)	7	576	0	7	Met. Museum of Art (USA)	Conservation of artistic works, SERS
Vilchez, José Luis (SCI 38, S 38, GS 56)	7	262	2	5	Univ. Granada (Spain)	Analytic chemistry, Spectrometry.
Jarosz, Maciej (SCI 24, S 23)	7	208	2	5	Warsaw Univ. Technol (Poland)	Identification of dyes (spectrometric techniques)
Zimmermann, Helmuth G. (SCI 14, S 18, GS 36)	7	191	0	7	Plant Protect Res. Institute (South Africa)	Biologic control
López-Martínez, Leticia (SCI 12, S 15)	7	81	5	2	Univ. Guanajuato (Mexico)	Analytical Chemistry, nuclear sciences.
Casadio, Francesca (SCI 22, S 25, GS 31)	6	568	0	6	School of the Art Institute of Chicago (USA)	Conservation of artistic works, SERS.
Mousavi-Kamazani, Mehedi (SCI 13, S 16, GS 19)	6	259	1	5	Islamic Azad Univ. (Irán)	Nanotechnology solar cells, photocatalysis
Chryssoulakis, Yannis (SCI 13, S 14, GS 15)	6	255	0	6	Natl. Tech. Univ. Athens (Greece)	Archaeometry, Textiles, DAD, Art, HPLC
Valianou, Lemonia (SCI 5, S 9, GS 10)	6	240	1	5	Natl. Tech. Univ. Athens (Greece)	Cultural heritage, polymers

Table 6. Continuation.

Author (H index)	Docs.	Citations	Docs. title	Docs. r kw	Institution	Research topics
Martínez-Romero, Esperanza (SCI 47, S 56, GS 74)	6	85	3	3	UNAM (Mexico)	Genomics
Rosenblueth, Monica (SCI 14, S 15, GS 19)	6	85	3	3	UNAM (Mexico)	Molecular biology
López-De-Alba, PL (SCI 13, S 15, GS 19)	6	71	4	2	Univ. Guanajuato (Mexico)	Analytical Chemistry, Nuclear Sciences
Akiyama, Hiroshi (SCI 30, S 35)	6	54	5	1	Nat. Inst. of Health Sci. (Japan)	Allergy, food chemistry
Safapour, Siyamak (SCI 9, S 11, GS 12)	6	43	4	2	Tabriz Islamic Art Univ. (Iran)	Textiles and fibers
Total documents	149		55	94		

Docs. title: documents with search terms found in the title. Docs. r kw: documents with search concepts found in the abstract and keywords.

*(SCI: Science Citation Index Expanded, S: Scopus, GS: Google scholar).

out of the 20 most productive authors published documents that addressed the topics of carminic acid and *Dactylopius coccus* in a secondary manner, since, in most of the studies, the information search concepts on the topic were found in the abstract or in the keywords. These studies were directed in particular to the analysis (with spectral analysis techniques such as SERS and HPCL) of various types of natural dyes, among which the one produced by *Dactylopius coccus* is found. Other topics also stood out, such as the use of dye from *Dactylopius coccus* in the synthesis of silver nanoparticles, and the identification of dyes in textile works and in works of art, considered cultural heritage. Among those authors, the following stood out: Karapanagiotis, from Greece; Salavati-Niasari and Goudarzi, from Iran; Navalón from Spain; and Marco Leona, from USA. On the contrary, only six of the authors with highest number of publications included in the title of the documents the search words of the study topic; this means that *Dactylopius coccus*, CA and its derivatives represent the main topic addressed in those documents, among which the ones that stand out are food chemistry, dyes in textiles, crops and production, as well as physiological aspects.

The authors with the highest number of publications were Llanderal-Cázares, from Mexico; Sugimoto, from Japan; and López-Martínez and López de Alba, from Mexico. The authors who published about the topic and addressed it both in a primary and secondary manner were Esperanza Martínez-Romero and Mónica Rosenblueth, both from UNAM in Mexico. The three authors with the highest H index in the SCIE were: Masoud Salavati-Niasari, from Kashan University from Iran (SCI 81), Esperanza Martínez Romero, from UNAM, Mexico (SCI 47) and José Luis Vílchez, from Universidad de Granada, Spain (SCI 38) (Table 6).

Most cited authors

The authors with highest influence (200 citations or more) in the generation of new knowledge in this area were: Marco Leona (576), Richard P. Van Duyne (533), Francesca Casadio (568) and John R. Lombardi (287), all of them from USA; Ioannis Karapanagiotis (475), Yannis Chryssoulakis (255) and LEMONIA Valianou (240), from Greece; Masoud Salavati-Niasari (298), Mehedi Mousavi-Kamazani (259) and Mojgan Goudarzi (205), from Iran; Alberto Navalón (281), José Luis Vílchez (262) and Domingo Concepción (200), from Spain; and Maciej Jarosz, from Poland (Tables 6 and 7).

All of the authors with 200 citations or more published on *Dactylopius coccus*, CA and its derivatives in a secondary manner; that is, their studies included other different objects of study (Table 6). The publications were focused on the spectral analysis (with different techniques such as SERS and HPLC, among others) to identify natural dyes, about textiles and works of art (paintings), or else nanotechnology.

Network of authors' collaboration

The collaboration between authors has increased with time, as the co-authorship indices shown in the different periods of study have reflected. Most of the collaborations are concentrated between authors of the same country. This is confirmed with the 22 collaboration networks identified through VOSviewer, from those researchers that published four or more documents. It is important to highlight that the visualization gives more weight to the number of citations of the authors. Because of their magnitude, the networks led by Marco Leona stand out, who collaborates with Francesca Casadio, Richard Van Duyne and María Vega Cañamares, who in turn collaborates with Concepción Domingo and Santiago Sánchez Cortés. For his part, Ioannis Karapanagiotis collaborates with Yannis Chryssoulakis, LEMONIA Valianou, S. Danila and C. Panayiotu. The network by Masoud Salavati-Niasari is complemented by Mehedi Mousavi-Kamazani and Mojgan Goudarzi.

The following networks also stand out: Alberto Navalón with José Luis Vílchez; Helmuth Zimmermann with Cliff Moran, John H. Hoffman and C.W. Mathenege; Celina Llanderal-Cázares with A. Ramírez-Cruz, Sandra Caselín-Castro and S. de Jesús Méndez-

Table 7. Most cited researchers who published documents on *Dactylopius coccus*, carminic acid (CA) and its derivatives, in the most cited mainstream journals (1980-2019), which complement the authors listed in Table 6.

Author (H index)	Docs.	Citations	Institution	Research topics
Van Duyne, Richard P (SCI 98, GS 131)	5	533	Northwestern Univ., USA	Identification of fibers and dyes using SERS.
Lombardi, John R. (SCI 50, GS 57, S 51)	3	287	City College of NY, USA	SHALL be applied to forensic art and science.
Domingo, Concepción (SCI 34, S 36)	4	200	CSIC, Spain	Identification of fibers and dyes using SERS.

*(SCI: Science Citation Index Expanded, S: Scopus, GS: Google Scholar).

Gallegos, who in turn collaborates with A. Carnero and M. González; Maciej Jazros with Katarzyna Lech; Naoki Sugimoto with Hiroshi Akiyama; Pedro L. López de Alba with Leticia López-Ramírez; Mónica Rosenblueth with Esperanza Martínez-Romero, Arturo Vera-Ponce de León, C.K. Chávez-Moreno, Alberto Tecante and Shamayim T. Ramírez-Puebla; and Safapour Siyamak with Mousa Sadhegi Kiakhani (Figure 4).

Authors with highest production by countries and their relationship with the research topics, according to Keyword Plus

The authors by country who published a higher number of documents addressed specific topics, as can be seen in the diagram carried out in *bibliometrix* by countries-authors-Keyword Plus (Figure 5). It shows that Karapanagiotis from Greece, the author with the highest number of documents published was related to the terms HPLC, identification, dyes, textiles, cochineal, and anthraquinone, which as a whole make up the research area “identification of natural dyes and pigments, primarily from cochineal and anthraquinonas,

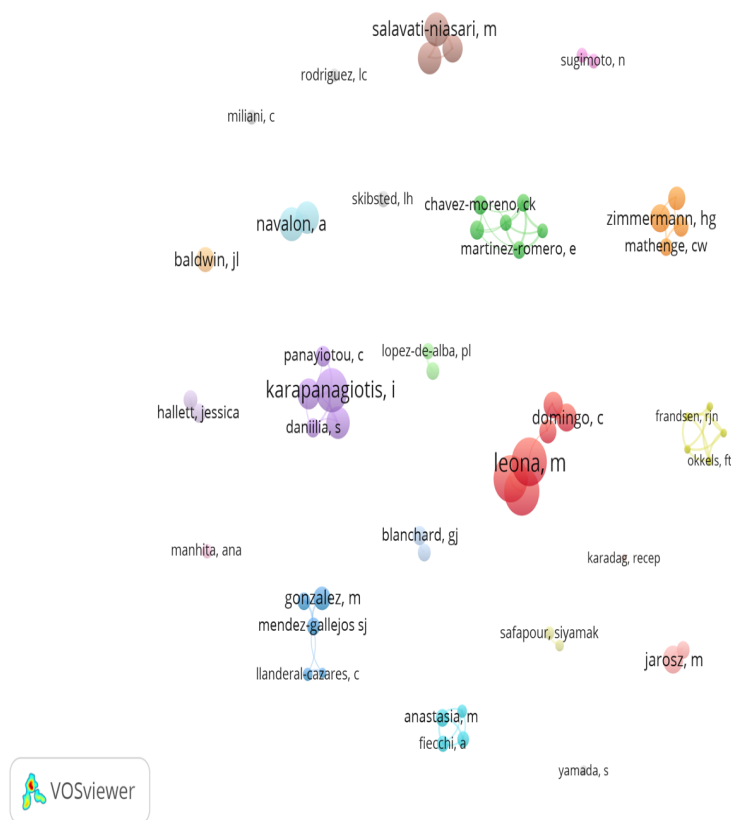


Figure 4. Collaboration networks of authors with four or more publications related to *Dactylopius coccus*, carminic acid (CA) and its derivatives, in mainstream journals (1980-2019). The visualization includes the weight according to the number of citations of the authors.

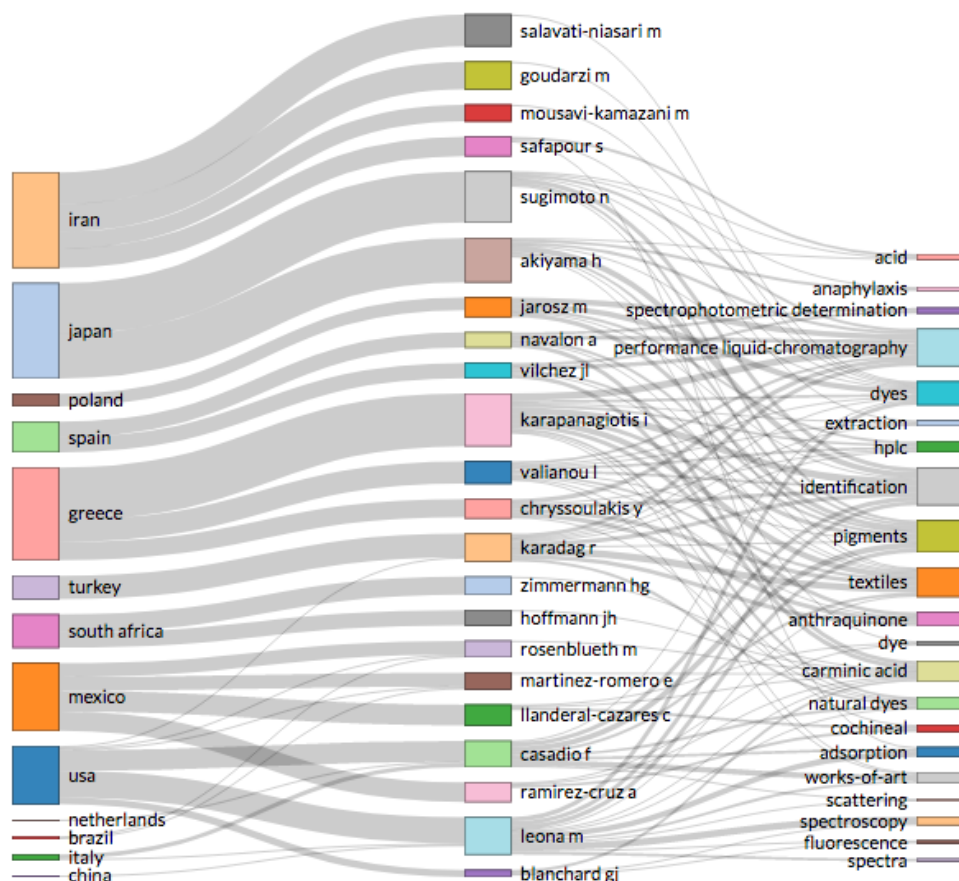


Figure 5. Countries-authors-Keywords Plus diagram (words or topics assigned by SCIE and SSCI) on *Dactylopius coccus*, carminic acid (CA) and its derivatives, in mainstream journals (1980-2019).

through HPLC”; these topics are shared by their fellow countrymen and colleagues, Vilanou and Chrysoulakis.

For his part, Marco Leona (from USA), the author with highest number of citations, was related to the words: spectroscopy, spectrum, fluorescence, adsorption, identification, pigments, dyes, natural dyes, textiles, and works of art; these topics are similar to those from his collaborator Casadio, who was also related with the words adsorption and dispersion. The Iranians Salavati-Niasari, Gourdazi and Mousavi Kamazini were related only with dyes, although Safapour was also related to CA and adsorption. Naoki Sugimoto and Hiroshi Akiyama, from Japan, were associated to HPLC, dyes, CA, anaphylaxis, pigments and textiles.

The Pole author, Jazros, was associated to HPCL, dyes, pigments and identification. The Spanish authors, Navalón and Vilchez, were associated to carminic acid (CA), pigments, HPCL, spectrophotometric determination and textiles. Karadag from Turkey was related to textiles, identification, natural coloring, dyes and anthraquinones. Zimmermann and

Hoffmann, from South Africa, were linked to CA; Llanderal-Cázares (from Mexico) was related to CA, cochineal and dye; also from Mexico, Martínez-Romero and Rosenblueth were associated to CA, the same as Ramírez-Cruz, with cochineal, CA and dye.

Authors with highest number of publications, over time

The production of authors who address the theme of study varied through time. In this regard, a way to determine if an author continues to be current or not, is to check the temporary nature of their contributions. Most of the most prolific authors still prevail. However, those who stand out for contributing with more documents published in recent years are the Iranians, Salavati-Niasari and Gourdazi. On the contrary, the Spanish Navalón and Vílchez ceased to publish since 2008. The author who has remained current for more time and with new contributions is the South African, H.G. Zimmermann (Figure 6).

Production and impact of the documents by countries

Regarding the scientific production by countries, a high participation of researchers was observed in the creation of new knowledge. The 10 countries with highest production were USA (84, 12.17%), Mexico (52, 7.54%), Spain (45, 6.52%), Japan (40, 5.80%), Italy (39, 5.65%), Iran (37, 5.36%), France (29, 4.20%), Germany (27, 3.91%), Poland (27, 3.91%) and Brazil (25, 3.62%), as represented in Figure 7.

The 10 countries with highest influence, when considering the number of citations received by the documents published were USA (2029, 15.82%), Spain (1289, 10.05%), Italy (755, 5.89%), Greece (641, 5.00%), Germany (636, 4.96%), Iran, (617, 4.81%), Poland

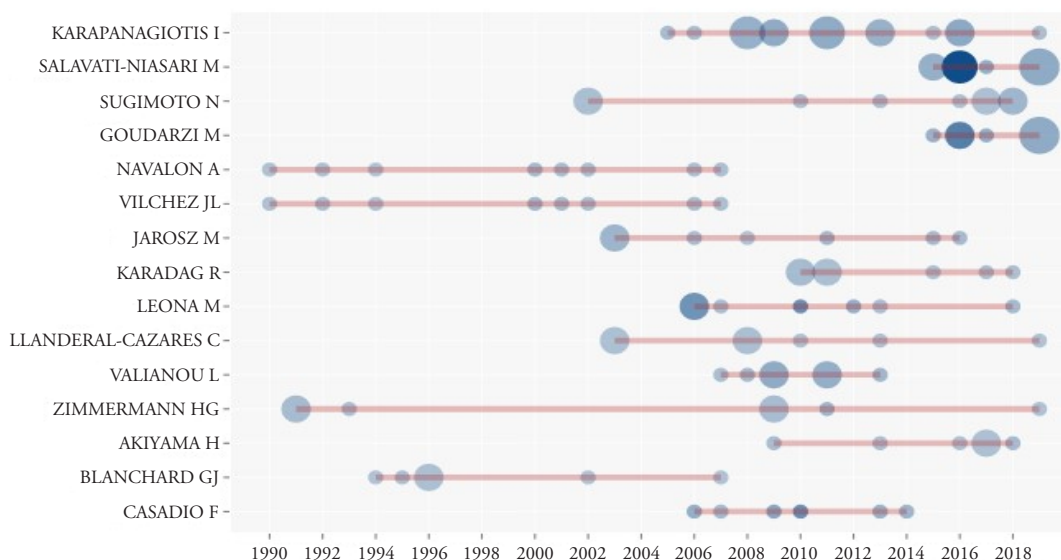


Figure 6. Publications, over time, of the authors with highest production on *Dactylopius coccus*, carminic acid (CA) and its derivatives in mainstream journals (1980-2019).

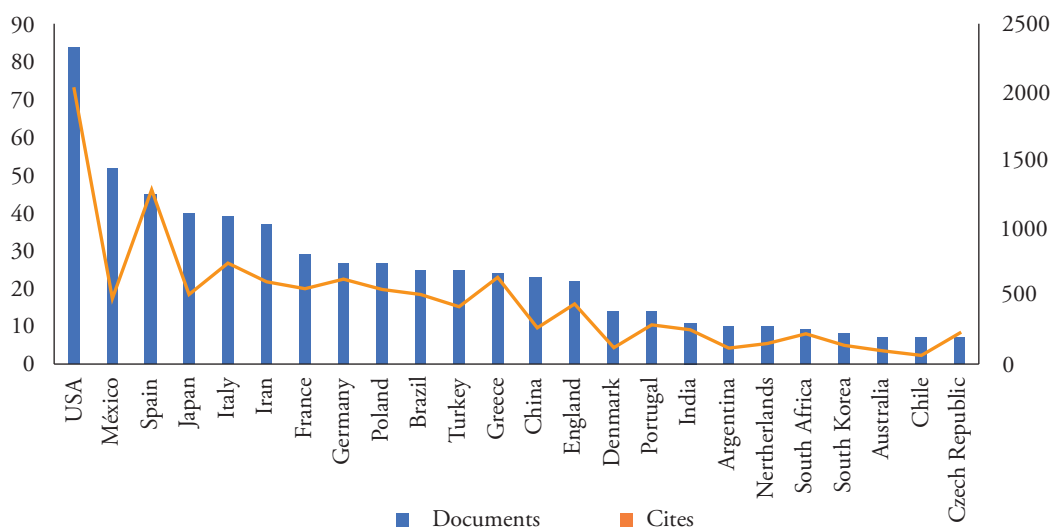


Figure 7. Production and impact of documents in different countries, on the topic *Dactylopius coccus*, carminic acid (CA) and its derivatives, in mainstream journals (1980-2019).

(544, 4.24%), Brazil (514, 4.01%), Japan (511, 3.99%), and Mexico (481, 3.75%). The 36 countries with six documents or less were not included; 15 countries published a single document (Figure 7).

Collaboration network between countries

The collaboration between authors from different countries contributes to strengthening scientific fields; with that, endemism and isolation of the research are avoided. Through VOSviewer, a collaboration network was generated between the countries with at least 10 citations; with the normalization method “association strength”, 10 clusters of countries were obtained (Figure 8). The visualization of the groups included the weight of the number of citations received, with the countries mentioned in Figure 7 standing out, such as United States, Spain, Italy and Greece, among others.

Some interesting trends to be highlighted also stand out in Figure 8; for example, some authors collaborate with those with whom they have geographic, cultural or linguistic proximity, such as Turkey with Egypt, United Arab Emirates, Saudi Arabia and Jordan; Japan with South Korea; Spain with Mexico; and South Africa with Australia. The behavior of the United States is of note, since it collaborates with most of the countries, primarily with Spain; however, it does not collaborate with some countries that have a notable impact such as Greece, Iran, France and Brazil, which could be associated with different thematic interests. It is notable that from the 45 countries included in the map, 17 European countries participated; Israel and Russia were not counted, although politically and economically they participate more in Europe than in Asia.

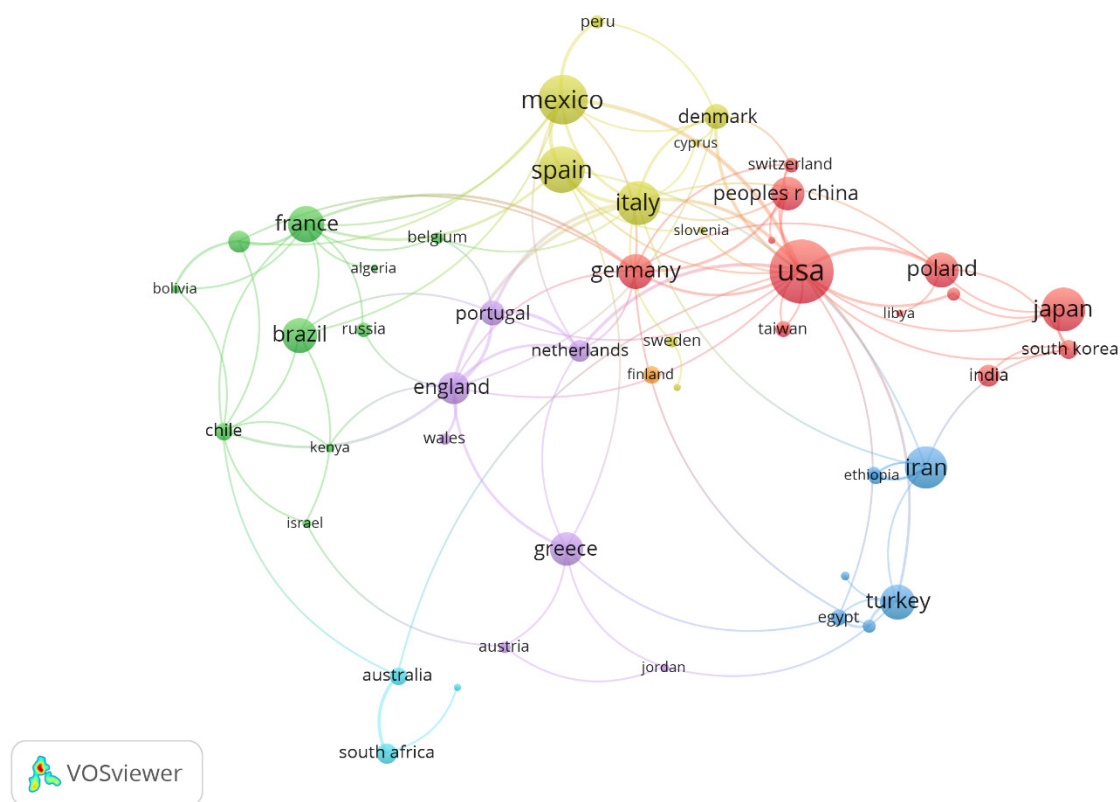


Figure 8. Collaboration network in the publication of documents between countries, related to *Dactylopius coccus*, carminic acid (CA) and its derivatives, in mainstream journals (1980-2019).

Identification of research topics

The databases SCIE and SSCI provided only the research topics according to the JCR categories in which the journals were classified, which have already been discussed before in the BI “Journals of publication”. The indicator of authors with highest productivity and influence also offers an idea of the research topics that are developed around *Dactylopius coccus*, carminic acid and its derivatives. To clarify the aforementioned, two BIs were combined, one which included the analysis of joint words, the keywords or descriptors of the authors and the indexers; the other was based on the analysis of the information contained in the titles and in the abstracts of the documents, better known as text mining.

Identification of research topics through a joint words network map, based on authors’ keywords and Keyword Plus

The analysis of joint words conducted in VOSviewer with the use of bibliographic records and the LingLog normalization method, and its visualization by number of occurrences (in substitution of the number of links) which considers five or more occurrences; by authors’

keywords; and in the SCIE and SSCI databases (Keyword Plus), showed that the research topic was focused mainly on the identification and analysis of natural dye and pigments in textiles, archaeological pieces, works of art, both in canvas and in murals, and other cultural heritage objects of historical interest through different detection, characterization and identification techniques.

Among them, Raman spectroscopy or Surface-Enhanced Raman Spectroscopy–SERS (Leona *et al.*, 2006; Casadio *et al.*, 2010; Luo *et al.*, 2019), gas and liquid chromatography, or High Performance Liquid Chromatography–HPLC (Karapanagiotis *et al.*, 2008; 2019); the use of techniques such as electrospray ionization, mass spectrometry, or Fourier Transform Infrared Spectroscopy–FTIR (Ben Messaoud *et al.*, 2016), among others, included in the green and red clusters (Figure 9).

This trend agrees with the topics mentioned in the BI of most productive and cited authors, such as Karapanagiotis and Leona, as well as with the JCR areas of the journals that published most. One current and innovative topic that stands out is the application of CA and its derivatives as photosynthesizing pigment in solar cells (such as the Grätzel cell), also known as dye-sensitized solar cell (Mousavi-Kamazani *et al.*, 2016; Sun *et al.*, 2016), grouped in the blue cluster (Figure 9). It was also seen that the coloring compounds alizarin and other anthraquinones are addressed jointly when *Dactylopius coccus* and the CA were studied as a secondary theme.

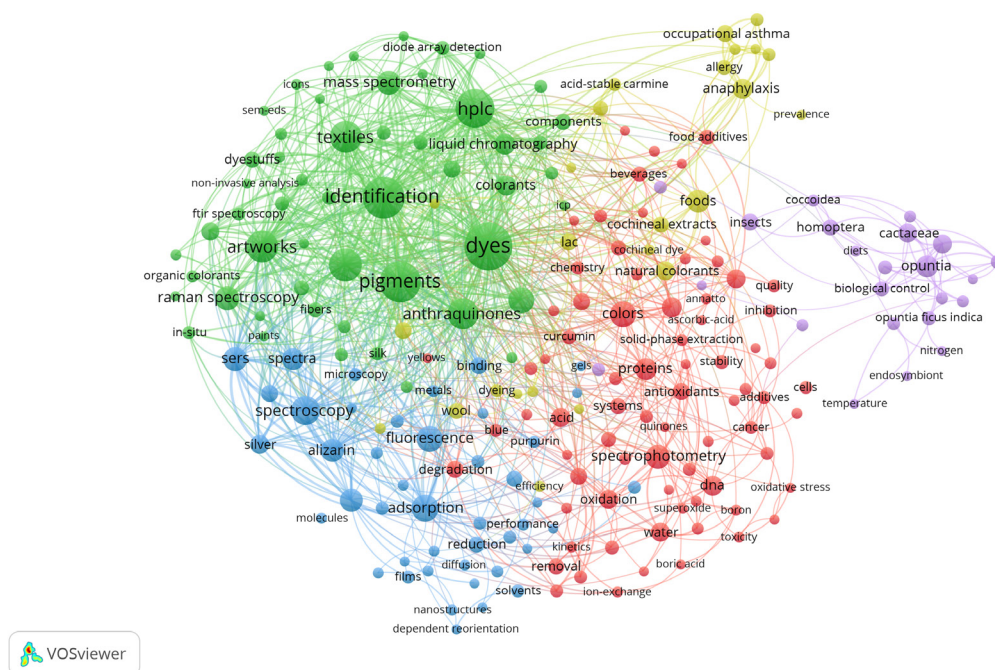


Figure 9. Joint words analysis using authors' and database keywords with five occurrences or more, on *Dactylopius coccus*, carminic acid (CA) and its derivatives, in mainstream journals (1980-2019).

Some of the topics that stand out included aspects of biology (purple cluster), such as phylogenetics (Ramírez-Puebla *et al.*, 2010), biotypes (Van Dam and May, 2012), study of endosymbionts (Bustamante-Brito *et al.*, 2019), and limiting biotic and abiotic factors. Similarly, the secondary effects associated with the consumption or exposure to CA and its derivatives are addressed (yellow cluster), such as anaphylaxis and asthma (Greenhawt *et al.*, 2009), caused by the consumption of foods where they were added, or else from contact or exposure during extraction or preparation processes (Pecquet, 2013). This cluster also grouped the dyeing of natural or animal fibers with dyes obtained from *Dactylopius coccus* (Mirnezhad *et al.*, 2017).

Other important research topics stood out in the red cluster, for example the use of food additive (Miller *et al.*, 2017), which includes purity and quality, stability, degradation and decoloring. In addition, studies were grouped by those focused on defining its therapeutic properties for cancer prevention (Goudarzi *et al.*, 2019a; 2019b), characterization as food additive in combination with anthocyanins and carotenoids (Fernández-López *et al.*, 2013; Cosentino *et al.*, 2016), and the main techniques used for its study such as photo spectrometry, HPLC (Bonan *et al.*, 2013).

Thematic evolution of the research, according to the words in the documents' title

The analysis with *bibliometrix* of the words contained in the documents' titles about *Dactylopius coccus*, carminic acid and its derivatives, divided into four publication periods (1980–1998, 1999–2007, 2008–2015 and 2016–2019), allowed to determine a clearer trend of the evolution of the topics addressed throughout the years. During the first 20 years of the study period, it was seen that the research was focused on carminic acid and its applications in foods and beverages, as well as the evaluation of hosts for the insect's breeding. In contrast, during the 1999-2007 period, the topics were centered on the analysis and identification of natural dyes, including carminic acid, as well as the continuation of studies about the hosts, their analysis and determination in foods, and research about the determination and identification (Figure 10). In the 2008-2015 period, studies related to evaluating methodologies for its identification and determination continued, as well as research about dyes, membranes and solar panels. In 2016-2019, the studies were focused on the application of *Dactylopius coccus* and CA as pigments and dyes, and studies continued to appear focused on the identification of extracts, although in this period the topic of their use in foods does not prevail anymore (Figure 10).

CONCLUSIONS

During the study period, a growing publishing trend was observed similar to that shown in all areas of science, due to the increase in research activities globally that are part of scientific and technological development. The scientific article was the main type of publication in the journals that published about the topic; this indicates that the scientific article is the path to publish most of the research results. The co-authorship index

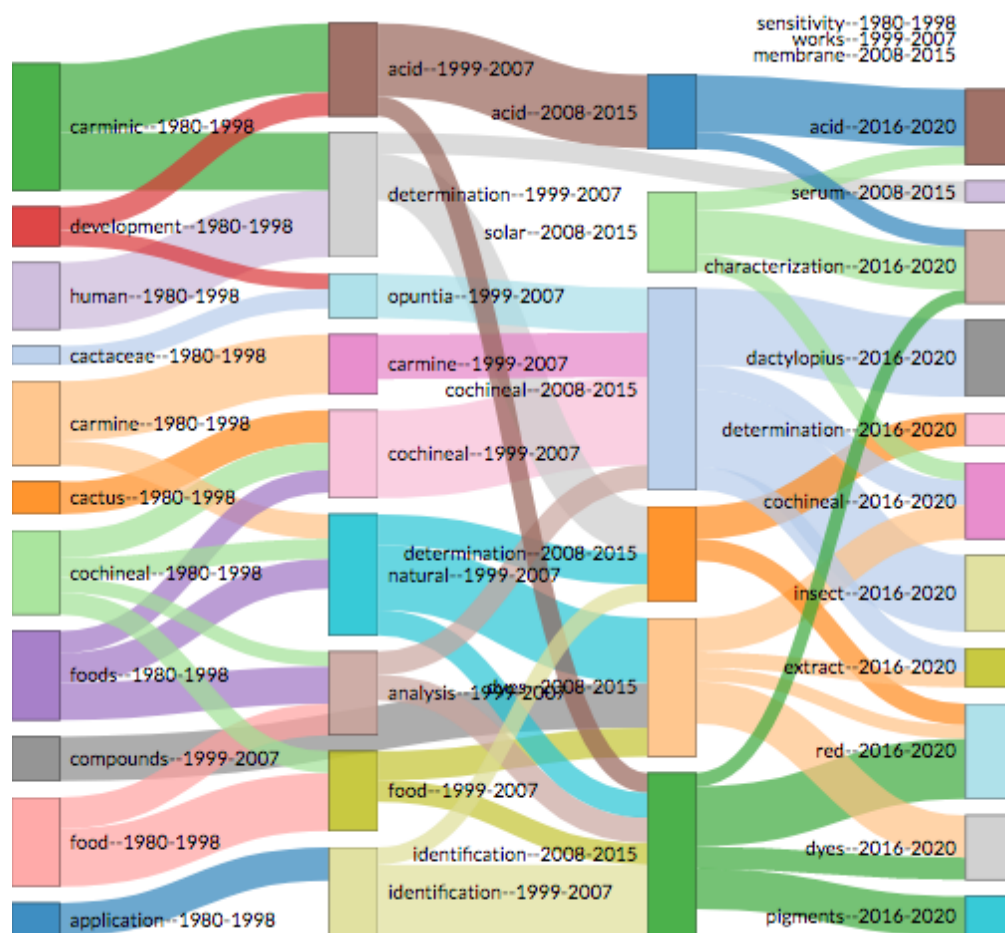


Figure 10. Thematic evolution of the research considering the words included in the titles of the documents on *Dactylopius coccus*, carminic acid (CA) and its derivatives, in mainstream journals (1980-2019).

increased through time; it shows the trend towards a closer collaboration that can be associated with the pressure for publishing and gaining access to the systems of stimuli for research and teaching by country, savings in costs and investments, and more efficient use of institutional infrastructure.

The journals that concentrated publications on these natural pigments are in the areas of food science and technology and analytical chemistry. The ones that concentrated the most cited articles were specialized in spectral analysis methods, showing their importance as food additives and the interest in ensuring their quality and safety. The analysis of co-citations applied to journals identified main emerging research topics such as analytical chemistry, food science and technology, allergies, natural dye spectroscopy, textiles and fibers.

The authors with highest productivity published documents identified by search words (keywords) and abstracts; their study was focused on the analysis and characterization of

pigments through spectrographic techniques. Three of the most cited authors received more than 500 citations in the area studied. Most of the collaborations happened between authors of the same country, with geographic proximity and the same language. The main topic was Food Science and Technology. Despite the small number of countries that participated in the commercial breeding of the insect, a broad diversity of countries performs research, with a high participation of authors. However, there is a scarce connection between authors from different countries. The United States was the country that showed the highest collaboration.

Text mining allowed identifying research topics related with three main axes: determination, detection, concentration of carminic acid, analysis of dyes and pigments through different spectroscopic techniques; breeding and culture, quality and yield; and studies about the biology and development of the insect *Dactylopius coccus*. The bibliometric analysis over time allowed determining the thematic evolution, although some topics remain, such as fiber dyeing, collateral effects of consumption or contact, and insect culture techniques. Lastly, in the most recent years some emerging topics stand out, such as nanotechnology, therapeutic activity and use as photosynthesizing pigment in solar cells.

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