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Trends in *Ilex paraguariensis* researches: a bibliometric analysis

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Abstract

Background Yerba-mate (*Ilex paraguariensis* St. Hil) is a perennial South American plant widely investigated due to its effects on human health and chemical composition. Due to the presence of high levels of methylxanthines, phenolic compounds and saponins, yerba-mate is attractive under chemical and pharmacological aspects. Yerba-mate leaves are processed for the consumption of traditional beverages with a social, cultural and economic importance.

Results Totally, 839 publications on the topic yerba-mate were identified in the *Web of Science* database, accumulating 15,365 citations with an *h*-index = 55. A text-based analysis of the abstract articles identified three main research fields: plant science, chemical composition and biological effects. These publications were distributed in 378 journals and involved the efforts of 3169 authors distributed in 48 countries and 681 organizations.

Conclusion The results reported here are a first graphic overview of the yerba-mate scientific production considering the research areas, journals citation coupling and cooperation among countries, organizations and authors.

Keywords Yerba-mate, *Ilex paraguariensis*, Bibliometric analysis, Scientific production

Introduction

Yerba-mate (*Ilex paraguariensis* St. Hil) is a native species of South America that naturally occurs in Brazil, Argentine and Paraguay which is cultivated in homogeneous crops or in forest systems. This species has many important phytochemical compounds with an expressive role in human health, such as methylxanthines, polyphenols and saponins [1].

Industrial yerba-mate leaves processing involves different phases, including roasting, drying and trituration, and changes in these steps may produce alterations in the product color, flavor and composition [2, 3]. Another condition able to modify these properties is the genetic aspects linked to groups of yerba-mate plants [4].

Although the *chimarrão* is one of the most consumed beverages prepared from infusion of processed yerba-mate leaves and small branches, the development of new beverages with this plant is an interesting approach widely explored. About this may be highlighted the oxidation of yerba-mate leaves, aiming for a beverage with similarity to black tea obtained from *Camellia sinensis* leaves [5, 6]. In addition to their beneficial properties on health, yerba-mate extracts have shown potential in food preservation and the effects of their addition in the sensorial, physicochemical and microbiological properties of many types of food have been studied, for example, sausage [7], cheese [8], yogurt [9] hamburger [10], chocolate [11] and bread [12].

In the last 20 years, some research areas linked to yerba-mate gained attention. A bibliometric analysis using statistical tools exploring networks is very useful

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in the definition of the ways of the new investigations. The use of this tool may answer the questions "what and where are being made the investigations related to this important plant?" and provide a rapid overview about themes, countries, organizations, authors and journals involved with investigations [13]. Due to the increasing advances in yerba-mate researches and the necessity of to summarize the data about this plant, we performed the first bibliometric study of the scientific production about yerba-mate.

Materials and methods
Data acquisition
The Web of Science database (http://apps.webofknowledge.com) was searched for the literature on yerba-mate. Web of Science is one of the widest scientific databases in the world. The terms used in the search were "yerba-mate", "*Ilex paraguariensis*", "*I. paraguariensis*", "mate tea", "mate extract" or "chimarrão". Articles with these words in the field title were included, aiming to exclude publications unspecific about related themes. The search included the period from inception to 2022, the final retrieval execution time was November 2022, and the original articles and review articles were considered as documents. Data were used from publications from all the areas of knowledge and all countries. Original articles and reviews published in English Portuguese and Spanish were included in our analysis, being excluded others categories of publications indexed on Web of Science. A very limited number of publications about the theme searched occur in languages different of these. Although the English is the official language of the science, we included Portuguese and Spanish in our search due to the geographical origin of the plant target of the analysis.

Data analysis
After the full register, results were exported from Web of Science as *txt* file separated by tabulations and loaded in VOSviewer environment [14] for the construction of bibliometric networks. A thesaurus txt file was created to aggregate the same authors, institutions and or modes of writing terms (presence of space, hyphen or punctuation).

A set of nodes and edges form a bibliometric network. The nodes can be, for instance, publications, journals, researchers, or keywords, while the edges specify relations between pairs of nodes. The most commonly studied types of bibliometric networks are based on citation relations, keyword co-occurrence relations and co-authorship relations. In a bibliometric network, the distance between two nodes approximately indicates the relatedness of the nodes and the node size represents highly cited publications, keywords or highly prolific researchers, institutions or countries. The nodes are placed in a set of closely related nodes reported in the same color and identified as clusters [15].

For the investigation of the trends in publications and citations, the data from Web of Science were analyzed in GraphPad Prism 9.2 software.

Results and discussion
In this article were evaluated the publications about yerba-mate using bibliometric aspects. Bibliometric networks are a tool that allows large amounts of complex bibliographic data to be analyzed in a relatively fast way. The data from 839 documents were analyzed, involving 48 countries, 681 organizations, 3169 authors and published in 378 academic journals. These articles received 15,365 citations, having a h-index$=55$. These aspects are better discussed in the following text.

Growth trend in publications
Figure 1 shows a chronological rise in yerba-mate scientific production from 1990 to 2021, quantified by measurement in the number of articles (a) and the number of citations (b). It is evident from Fig. 1 that interest in yerba-mate increased exponentially in the last two decades. In this period were published 839 articles, which
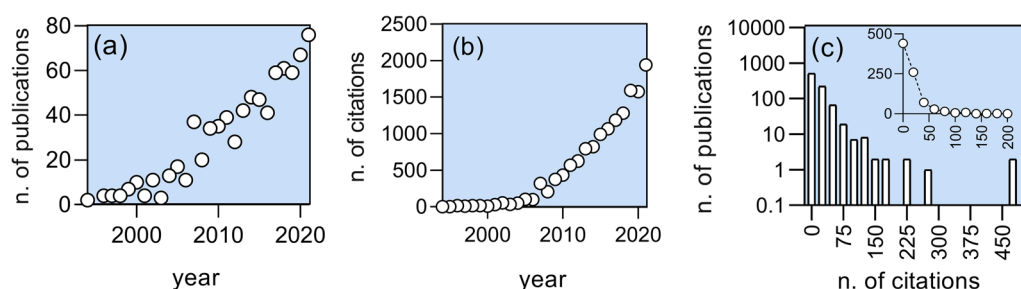

Fig. 1 Rise in yerba-mate scientific production. In **a** is shown the number of articles against the time; in **b** is shown the number of citations against the time and **c** the distribution of these citations. The data were obtained from the *Web of Science* using the terms "yerba-mate", "*Ilex paraguariensis*", "*I. paraguariensis*", "*chimarrão*", "*mate tea*", and "*mate extract*"

gained 15,365 citations (of these, 9205 are without self-citations) no evenly distributed, as may be shown in Fig. 1c. Due to the asymmetry on the citations distribution, the axis y of Fig. 1c was represented in logarithmic scale, and the expansion overlapped showed part of this distribution in non-logarithmic scale. Only a limited number of articles gained a high number of citations. The top 10 most cited articles are represented in Table 1. It may be highlighted that the first two most cited documents are one investigation about the most efficient solvents for phenolic compounds extraction [16] and one review article mainly focused on chemistry and biologic propertied of yerba-mate [17]. In a general way, the most expressive articles about yerba-mate are focused on antioxidants, chemistry, health and technological applications. The *h*-index of all the publications related to yerba-mate is 55.

Abstract analysis

VOSviewer was used to visualize the main terms extracted from the abstracts of the articles in a text-based analysis. The abstract summarizes the main context and results of an article and many times contains the most important words of the title. The abstract analysis identified 16,672 different words; 444 of them meet the threshold minimum occurrence of 10 times and are reported in Fig. 2.

The map obtained from this analysis shows a clear distinction between three different research areas. Agronomic terms are located mainly in the left cluster of a map (Fig. 2a) and research linked to the biological effects of yerba-mate mainly right cluster, shown in green color in Fig. 2a. In addition, in the upper part of the map may be identified the terms linked with the obtaining of yerba-mate extracts and their phytochemical composition. The same map when analyzed considering the citation number (Fig. 2b) shows that the terms related to the chemical and biological aspects are present in the most cited articles (green and yellow rectangles).

Countries cooperation analyses

The contribution of different countries in yerba-mate investigations has been investigated using co-authorship analysis. Brazil published the most articles (517 documents, 61.26%). Argentina was ranked second in the number of publications (184 documents, 21.93%), followed by the USA (60 documents, 7.15%). The top three countries published the majority of the articles. Thus, 5 was set as the minimum document threshold of a country for Fig. 3 construction. Of the total of 48 countries, 20 of them meet this threshold and are listed in Fig. 3.

In Fig. 3a the size of frames is proportional to the number of published documents. Two main clusters of countries may be observed: the cluster of Brazil in green and the cluster of Argentine in red. These two countries kept a wide range of cooperation with other regions, mainly with European and American countries. Yerba-mate has a strong presence in the Northern Hemisphere; the analysis of Fig. 3 also reports that the interest in yerba-mate is rising in Europa and North America. The investigations with yerba-mate in Europe are stimulated by the consumption of products containing yerba-mate and the importation of yerba-mate leaves from South America. The South Korea appears as an emerging place in this field mainly due to the phytochemistry and technologic similarity between *Ilex paraguariensis* and *Camellia sissensis* [1].

The number of citations/document is an indicator of the publication impact in the field of knowledge. Although Brazil and Argentine show the most expressive number of articles, these countries have an intermediary number of citations per document (14.53 and 17.11 citations/document, respectively). The highest values of citations/document were found for the USA

Table 1 Top 10 cited publications based on published documents on yerba-mate

Rank	Year	Journal	Country	Topic	Citations	Refs.
1	2006	Food Chemistry	Turkey	Phenolic antioxidants	483	[16]
2	2007	Journal of Food Science	USA	Chemistry, health and technology	470	[17]
3	2011	Journal of Ethnopharmacology	USA and Uruguay	Health	265	[18]
4	2007	Molecules	Brazil	Phenolic antioxidants	222	[19]
5	2007	Food Research International	Spain	Phenolic antioxidants	215	[20]
6	2016	Carbohydrate Polymers	Argentine and Venezuela	Technology	187	[21]
7	2004	Journal of Agricultural and Food Chemistry	University of Illinois	Phenolic antioxidants	175	[22]
8	2008	Carbohydrate Polymers	Argentine	Technology	157	[23]
9	2010	Journal of Agricultural and Food Chemistry	Germany	Phenolic antioxidants	153	[24]
10	2009	Fitoterapia	USA, Brazil	Phenolic antioxidants	129	[25]

Fig. 2 Text-based network of abstract words in yerba-mate publications. In **a** network visualization was based on terms occurrence and in **b** overlay visualization was based on documents citations

with 38.78 citations/document. These data may be better observed in Table 2 and in Fig. 3b, in which the countries with higher number of citations are shown in yellow. It may be highlighted from this analysis that although Poland is in the sixth position, its publication does not occur in collaboration with others regions, having the null total link strength. The link strength indicates the number of publications that two countries have co-authored.

Institutions cooperation analyses

For the institution cooperation analysis, 5 was set as the minimum document threshold of a university, and of the 681 organizations 45 meet the limit. In Table 3, the top 15 most productive institutions on yerba-mate are listed. These organizations were divided in four clusters, represented by different colors. The node size is proportional to the articles number and the line connecting two nodes measures the strength cooperation
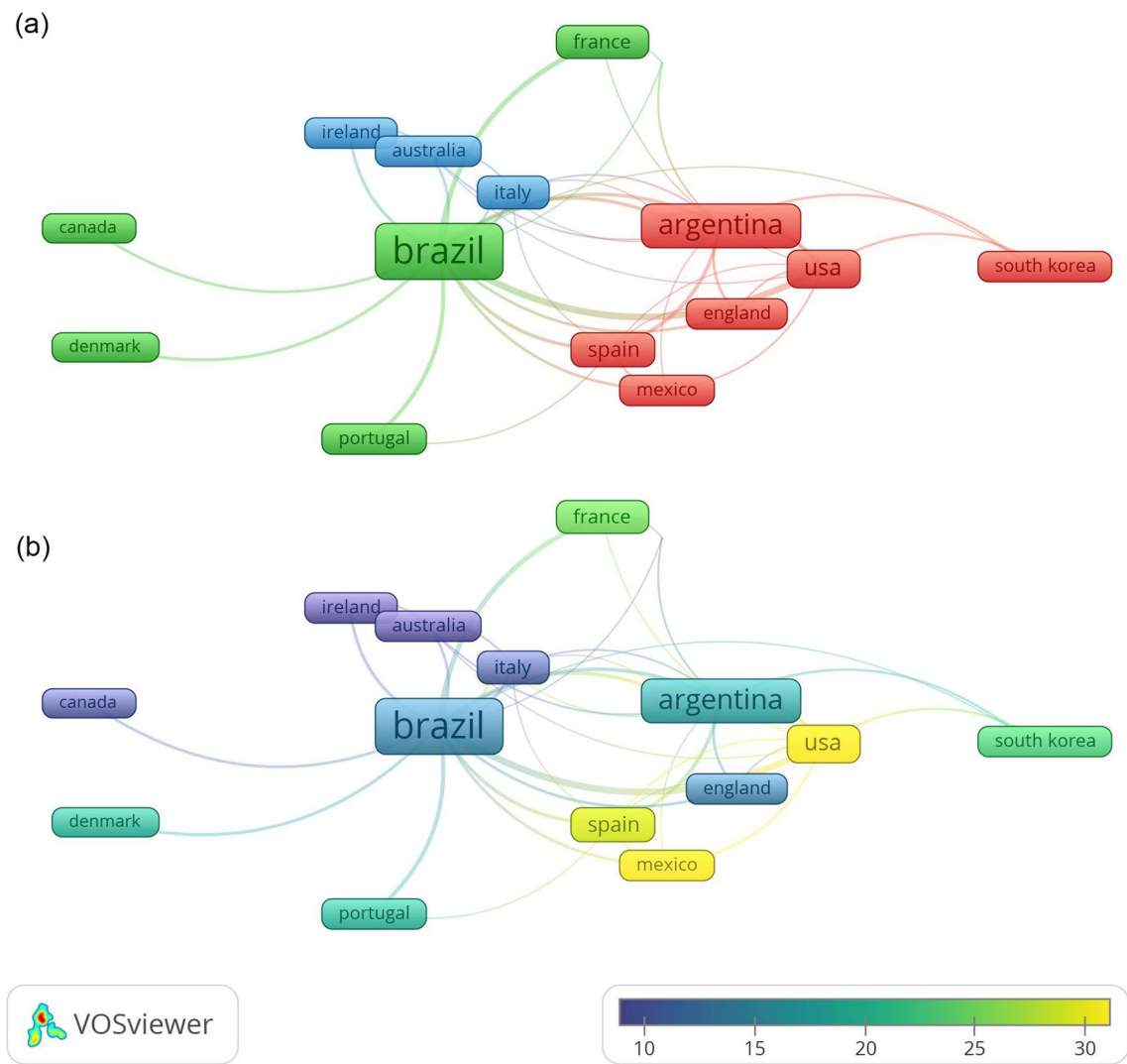
Fig. 3 Co-authorship visualization map of countries. In **a** network visualization map of countries clusters with node size based on number of documents, and in **b** a color scale based on number of citations was overlapped

Table 2 The countries with more expressive scientific production on yerba-mate

Ranking	Country	Documents	Citations	Citations/documents	Total link strength
1	Brazil	517	7510	14.53	94
2	Argentina	184	3149	17.11	35
3	USA	60	2327	38.78	40
4	Spain	28	795	28.39	19
5	Uruguay	19	536	28.21	14
6	Poland	15	131	8.73	0
7	France	15	369	24.60	14
8	Italy	14	157	11.21	10
9	Australia	12	93	7.75	11
10	Germany	11	315	28.64	5

between the institutions. Four representative clusters were identified: in red, yellow and green Brazilian institutions and in blue argentine institutions, according to Fig. 4a. The clusters from Argentine and Brazil are well separated and have a limited number of connections.

In Fig. 4b are depicted in yellow the organizations with a higher number of citations. It may be observed that USP, UNICAMP, USF, UDELAR and UNLP produced the most cited articles. The map described in Fig. 4b is in agreement with the number of citations/document reported in Table 3. The highest numbers in this parameter among the top 15 institutions were 54.07, 28.95 and 28.10 citations/document, respectively, for USF, UNLP and USP.

Table 3 The countries with more expressive scientific production on yerba-mate

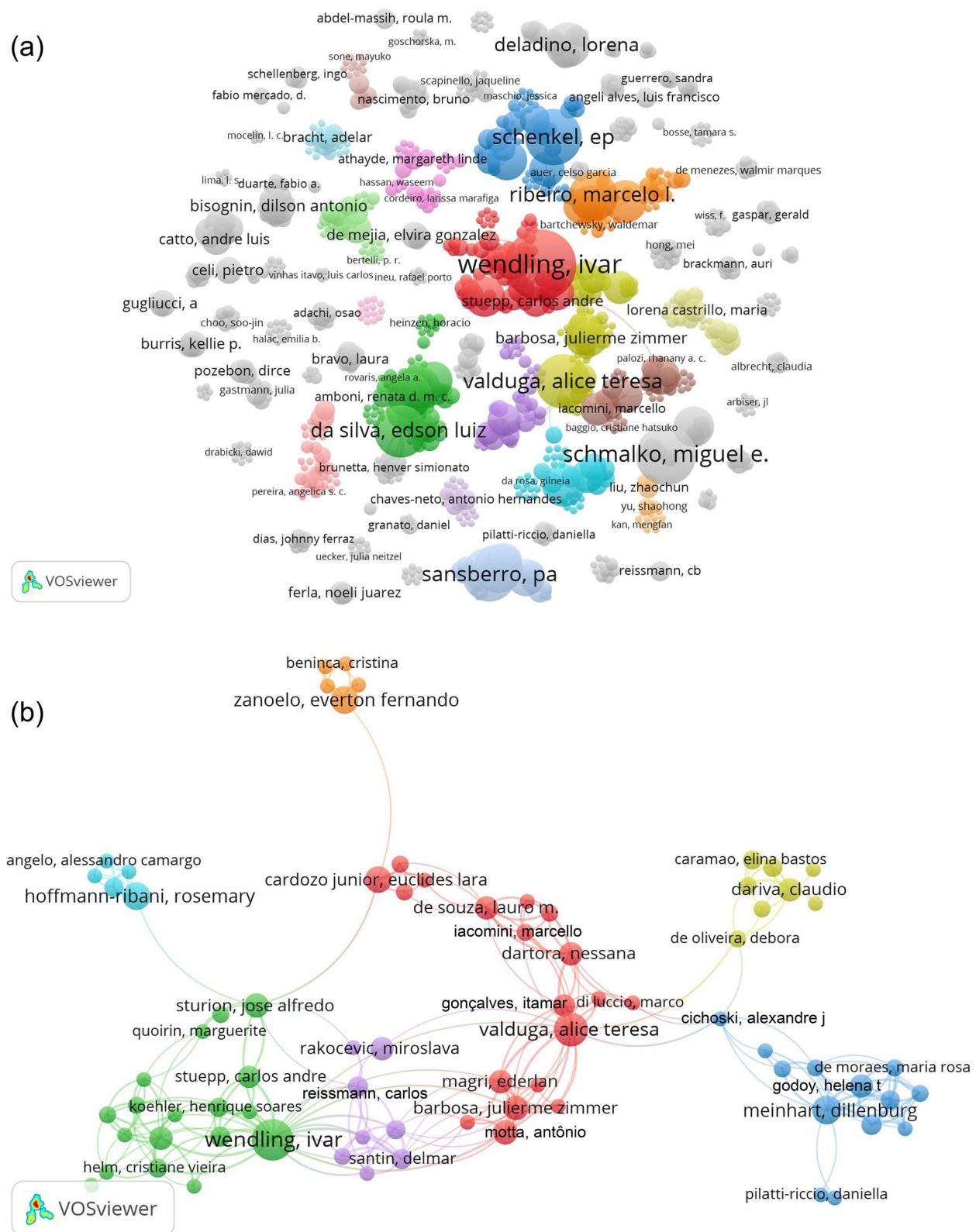|	Organization	Documents	Citations	Cit/doc	Total link strength
1	Federal University of Paraná (BR)	100	1100	11.00	77
2	Federal University of Rio Grande do Sul (BR)	73	1334	18.27	35
3	Federal University Santa Catarina (BR)	60	1329	22.15	34
4	Federal University of Santa Maria (BR)	59	601	10.19	38
5	National University of Misiones (AR)	49	530	10.82	12
6	University of Buenos Aires (AR)	48	1204	25.08	17
7	University of São Paulo (BR)	42	1180	28.10	31
8	Brazilian Agricultural Research Corporation – Forestry (BR)	36	292	8.11	50
9	State University of Campinas (BR)	31	851	27.45	20
10	The National Scientific and Technical Research Council (AR)	29	302	10.41	20
11	Regional Integrated University of Alto Uruguai and Missões (BR)	27	389	14.41	16
12	National University of La Plata (AR)	21	608	28.95	9
13	Federal University of Pelotas (BR)	18	204	11.33	26
14	São Francisco University (BR)	15	811	54.07	11
15	State University of Maringá (BR)	15	281	18.73	7x'

BR Brazil; *AR* Argentine
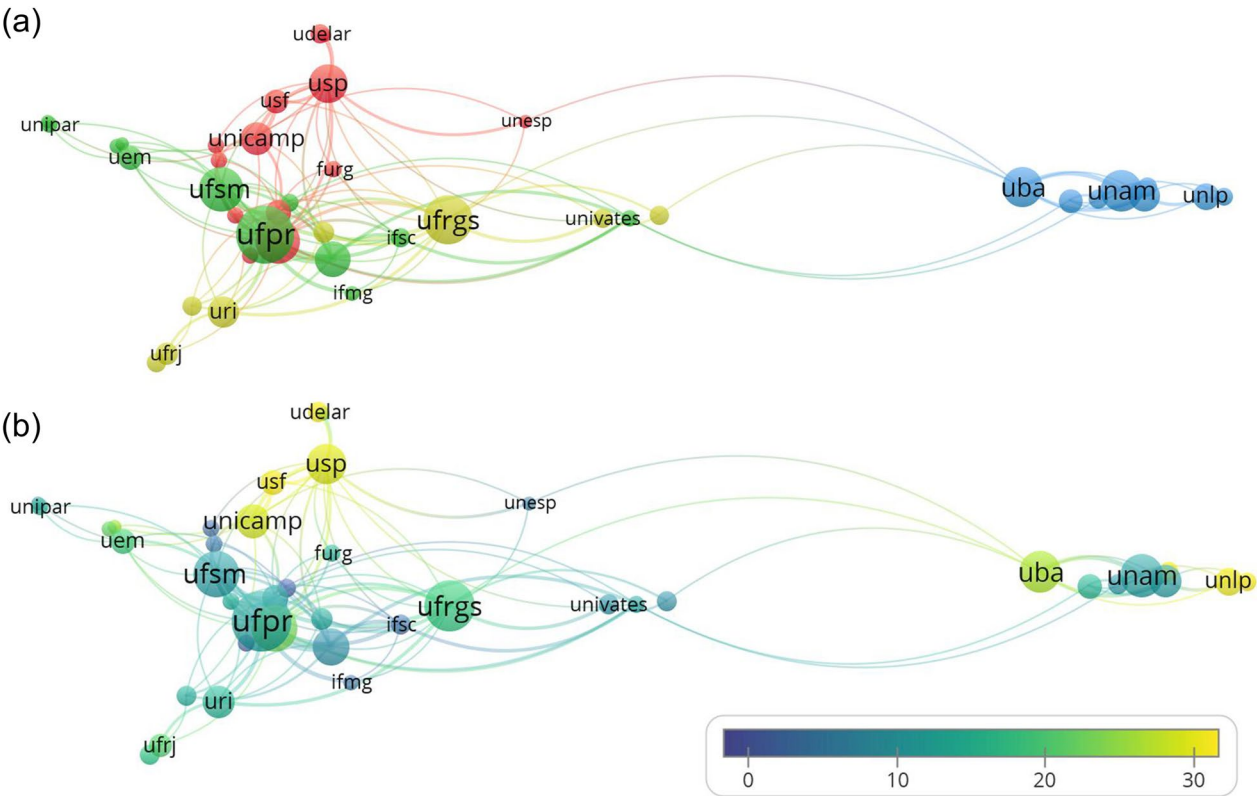
Fig. 4 Co-authorship visualization map of organizations. In **a** clusters of countries with node sizes based on number of documents; in **b** a color scale based on number of citations was overlapped
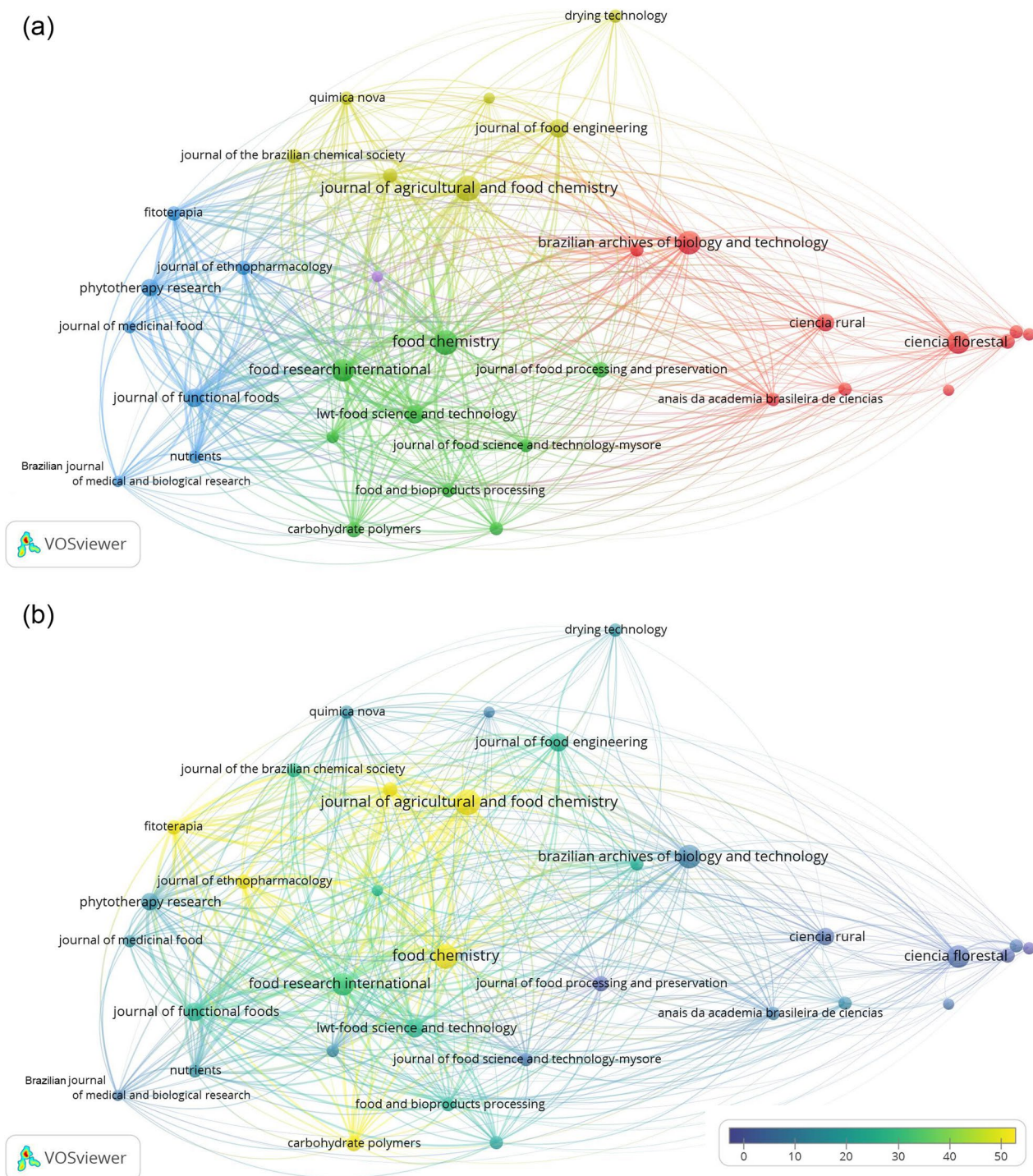
Fig. 5 Authors cooperation network on yerba-mate research. In **a**, a map with the totality of 3169 authors is depicted, and the node sizes are based on the number of documents. In **b** the largest set of connected items consists 1014 authors and 76 of them are shown

(a)

(b)

Fig. 6 Journal publications map according to bibliographic coupling. In **a** map was generated according to clusters of journals and the nodes size represent the documents number; in **b** the map was generated according to the most cited journals

Authors cooperation analysis

There are a high number of researchers involved with the investigations on yerba-mate, so 3169 authors were identified in 839 publications. The co-authorship network of all these authors was constructed in VOSviewer. If an author used different names in their publications, it was merged using a thesaurus txt file in the VOSviewer environment [26].

Table 4 The journals with more expressive scientific production on yerba-mate

Rank	Journal	Documents	Citations	Cit/doc	Total link strength
1	Journal of Agricultural and Food Chemistry	25	1260	50.40	1079
2	Food Chemistry	24	1279	53.29	816
3	Brazilian Archives of Biology and Technology	22	210	9.55	1977
4	Ciencia Florestal	19	91	4.79	880
5	Food Research International	19	591	31.11	1598
6	Journal of Food Engineering	13	321	24.69	187
7	Journal of Functional Foods	13	327	25.15	661
8	LWT-Food Science and Technology	13	334	25.69	610
9	Ciencia Rural	12	58	4.83	354
10	Phytotherapy Research	12	161	13.42	2634
11	Carbohydrate Polymers	9	685	76.11	1577
12	Journal of Food Processing and Preservation	9	27	3.00	5265
13	Cerne	8	23	2.88	4977
14	Fitoterapia	8	410	51.25	362
15	Journal of Ethnopharmacology	8	446	55.75	1168

Figure 5a shows the distribution of all the 3169 authors, in gray it may be observed that some of them were not connected one each other and in different colors may be observed the different clusters. The largest group presented 1014 authors, and it is reported in Fig. 5b. For Fig. 5b construction, the data of 76 authors of 1014 researchers which reach the threshold of 3 documents were used.

Journals publishing on yerba-mate

The relation among the journals publishing on yerba-mate was investigated using bibliographic coupling. Like co-citation, bibliographic coupling uses citation analysis to establish an association among documents. Bibliographic coupling occurs when two works refer a third common work in their reference lists [27]. The 839 publications were distributed in 378 journals. When the threshold of 5 couplings was defined, 34 journals meet the limit and are depicted in Fig. 6.

These journals were clustered in 4 groups according to their bibliographic coupling in the map shown in Fig. 6. The blue cluster shows the journals focused on the medicinal aspects of foods and plants and in the green and yellow clusters journals mainly linked with and food science engineering. The red cluster placed in the right is formed by Brazilian journals principally linked to plant science (Fig. 6a). A list of the top 10 most productive journals on yerba-mate research is reported in Table 4, and in Fig. 6b are observed in yellow nodes the journals with a higher number of citations by article. The high

value of total strength of a link was identified for Journal of Food Processing and Preservation, representing a high density of bibliographic couplings.

Conclusions

Research on yerba-mate in Web of Science has increased expressively since 2000. The most cited papers were focused on the antioxidant activity and chemical composition of yerba-mate and technological applications. Based on text abstracts analysis were found three main investigations fields related to yerba-mate: plant science, biological activity and chemical aspects. Despite its limited geographic origin, a great number of international collaborations were identified, mainly with the USA, the South Korea and Europe. Brazil and Argentine organizations made the most expressive contribution to this important field. The researchers were distributed in many non-connected one each other cluster, and the largest of them involved 1014 authors. Journals involving medicinal plants, food technology and plant science were involved with yerba-mate publications.

Declarations

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