

Analysis of three decades of sugarcane researches focusing on ethanol and bioethanol.

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Abstract

Biofuel production from sugarcane has been researched in terms of the environment. Performing a bibliometric method and visual network analysis, the purpose of this study is to assess the trends in sugarcane and bioethanol researches and recognize the associated hotspots based on 4958 publications from 1991 to 2020. The geographical distribution of articles and per capita sugarcane production in the world were also examined. As a widely used database in the field of bibliometric, the Scopus database was used in this research to collect relevant literature. The research method includes the bibliometric analysis of documents and citations, subject categories, journals, countries, institutions, authors, geographical distribution status of articles and annual sugarcane production, top articles. Finally, the social network of the author's keywords was reviewed. The VOSviewer software was used for performing graphic maps showing the co-authorship and communication of countries, authors and keywords. The results show a high growth in the number of published documents in this field and the tendency change from agricultural sciences to environmental sciences in documents and journals. Based on the study's gained results, Brazil is the undisputed leader, publishing 43.8% of the documents in last three decades, followed by the USA and India.

Highlights

- The analysis on countries, authors and author keyword by “VOSviewer” software.
- The most productive journals, institutes and countries are valued.
- The geographical distribution of articles is analyzed.

1. Introduction

In recent years, the world has faced a dramatic rise in fossil fuel consumption. With the increasing use of oil reserves, environmental concerns and energy security issues have intensified. Global warming increasing resulted from rising greenhouse gases has prompted researchers to discover alternative fuels against fossil fuels. The crops and plant residues can be used as sustainable biofuels (Neves et al., 2016), one of the proposed alternatives, especially used in transportation. Bioethanol, biodiesel and pure vegetable oils are the three main types of biofuels. The first-generation biofuels are produced from food sources like corn, sugarcane and sugar beet as main sources. The second-generation biofuels like sugarcane bagasse are not produced from a direct source of food (Correa et al., 2019). Sugarcane is a multi-purpose plant that is used to produce sugar. Its main features include high biomass yield, sucrose content and efficiency in absorbing solar energy (Benjamin et al., 2014). Sugarcane bagasse is one of the most abundant lignocellulosic substances in tropical countries. Although crop residue biomass is considered as industrial waste, there are advantages in its agricultural development aspect, just like producing cheap and economic fuels (Rabelo et al., 2011). Due to its high cellulose and hemicellulose, bagasse is a promising agricultural product for bioethanol and electricity production (Hamelinck et al., 2005). The Brazilian power plants with boiler systems produce 12 kWh of electricity, 330 kWh of thermal energy and 16 kWh of mechanical energy from each ton of sugarcane bagasse averagely (Turdera, 2013).

Sugarcane is cut when harvesting after 12-16 months of growth. Manual harvesting involves burning the product for collection, which facilitates the cutting process. Manual vesting is still being used in many companies globally, although mechanized sugarcane harvesting is recommended due to worker safety and environmental concerns. Sugarcane is then placed in a chopper to open cells containing sugars and facilitate the process of sucrose extraction (Viana & Perez, 2013a). Grinding is the process of extracting agricultural elements and residues. Usually, the first extracted group is used to produce sugar and about 55% is used to produce ethanol (Viana & Perez, 2013b). Fuel ethanol or bioethanol is produced from pre-treatment and fermentation of crop products and residues (Demirbas, 2009).

Oil fuels can lead to dangerous environmental issues. These kinds of fuels are non-renewable resources and making concerns and risks, which led to research on alternative renewable fuels such as biofuel (Turdera, 2013). Biofuels contain between 10% and 45% oxygen increasing the fuel efficiency and decreasing the pollution created by hydrocarbons (Demirbas, 2009). The biofuels markets in North America and the European Union are almost entirely dependent on political guidelines and financial incentives, which are expected to contribute to reducing greenhouse gas emissions, the security of supply and employment

targets, including the influential cases. For example, the EU's latest policy aimed to use at least 10% biofuels by 2020 (Margeot et al., 2009). Energy used in the EU transport sector was 8.4% from renewable sources, end of 2019 (*Shares of energy from renewable sources used in transport in Europe – European Environment Agency*, n.d.). According to a report released in December 2020, the 10% target for 2020 does not appear to be being met (Merce Almuni (VITO), Tom Dauwe (VITO), Ils Moorkens (VITO), 2020).

The present study aims to analyze previous researches done throughout the world on sugarcane and bioethanol between 1991 to 2020 to help researchers identify the future trends through bibliometric methods. The geographical distribution of articles and per capita sugarcane production in the world were also examined.

2. Methodological Approach

Bibliometric is a method by which the research process and its historical course are investigated (Ye et al., 2014). Impact factor (IF) and H-index are used for evaluation. IF was used to investigate the features of publication statistics for journals and authors, which evaluates qualitatively based on a journal's citations and publications in the last two years (Buela-Casal & Zych, 2012). H-index is defined as the h number of articles that have at least h number of citations each. H-index was proposed by Hirsch (2005), used in scientometrics as a quantitative measurement for evaluating a researcher, giving an estimate of the importance, significance and broad impact of a scientist's cumulative research contributions (Hirsch, 2005). Another index used in this study is CiteScore. Cite Score estimates the average citations received per document published in this title. Cite Score values are based on the number of citations in a mentioned year (2020) to documents published in three prior years (2014-2016), divided by documents count in these three previous years (2017-2019). (*How are CiteScore metrics used in Scopus? - Scopus: Access and use Support Center*, n.d.). This bibliometric study was performed based on keywords using CiteScore 2019 data extracted from Scopus as an appropriate database due to its extensive resources and discipline. The selected data were evaluated through VOSviewer software. Analysis and interpretation were performed based on countries, institutions, authors, journals and keywords. Keywords and countries were visually extracted through the relationship between different social networks and clusters in the authors' groups. Currently, Derwent, WoS and Scopus are used as data sources amongst the databases (Wang et al., 2021). The Scopus database was chosen for this research.

The data were analyzed using Visualization of Similarities (VOS) viewer software version 1.6.15. This software is freely available for making bibliometric maps to evaluate the communication and cooperation networks between countries and authors, as well as the keywords used; furthermore, the research fields can be interpreted.

3. Results And Discussion

In January 2021, seeking the words "cane" or "sugarcane" and "ethanol" or "bioethanol" through the Scopus database for 30 years from 1991 to 2020, included in articles title, abstract and keywords, a total of 4958 documents were found. The most significant share was assigned to English documents (95.03%), followed by Portuguese documents (9.98%).

3.1 The evolution of publications over the years

These 4958 documents included 3555 articles (71.70%), 537 conference papers (10.83%), 338 book chapters (6.81%) and 295 review articles (5.94%). Other research items such as business articles, short surveys, books, and conference reviews make up less than 5% in total.

Figure 1 describes the documents retrieved from Scopus by distributing of publication categories each year. By 2006, fewer than 100 publications were published each year. The 2001s were a turning point in publishing, with the highest publishing growth percentage occurring during those years. The number of publications in this decade is higher than the total of all publications in previous years. That while, the number of publications increased by about 1000%. The production and demand for sugarcane also increased in 2001s. Consequently, the crop production system needed to improve by replacing the mechanized sugarcane harvesting instead of burning and manual harvesting, which coincided with the mentioned scientific milestone (Martíni et al., 2020). The global ethanol production from sugarcane, beet and sugar was about 20 billion liters in 2001, which grew to 40

billion liters by 2005 (Demirbas, 2009). In 2010, the last year of the 2001s, global ethanol production reached more than 88 billion liters (*Alternative Fuels Data Center: Maps and Data - Global Ethanol Production*, n.d.). This 340% increase in production in this decade was also influential in research in this field. For this reason, the 2001s became a turning point. These changes and developments can be the reason for the acceleration of research in this field. In 2007, the European Union set a target of reducing GHG[1] emissions by 20% from 1990 levels, including a 10% share of biofuels for each member state (Demirbas, 2009). On January 23, 2008, a proposal was issued by the European Parliament and the Council to promote the use of renewable energy sources. The first measure of sustainability defined in the European proposal was a 35% reduction in GHG emissions for biofuels compared to their fossil fuel samples (Demirbas, 2009). In 2009, the European Union (EU) approved a directive (Directive 2009/30 / EC) through which, from 2011/01/01, the level of gasoline at the pump will be changed to 10% ethanol (E10) in 27 EU countries (*EUR-Lex - 32009L0030 - EN - EUR-Lex*, n.d.)

In 2011s, global ethanol production increased by 34%, which is not comparable to the previous decade. Also, the number of publications in those years grew slightly more than 25%. In 2016, the Paris Agreement was ratified, which commits for the first time to all countries to reduce greenhouse gas emissions (*The Paris Agreement | UNFCCC*, n.d.). Given this trend, political incentives were expected to require the rapid adoption of renewable energy systems to replace fossil fuels. For this reason, throughout these years, the general trend of publications has been increasing, as far as the highest number of publications is in 2017 with 428 documents. But since 2017, the increasing trend was broken and the number of publications reduced. This year, the USA ceased all participation in the Paris Agreement. Figure 1 presents the trend of changing the annual number of citations (TC[2]). In 2010, 10112 citations were registered, which is the highest. The annual number of citations during 2011-2020 in TC trend reduced later because the recent published documents have not been seen much yet.

All data for the specifications of publications each year during 1991-2020 are enclosed in Table 1. In the last 20 years, the number of publications has increased from 24 in 2001 to 405 in 2020, as well as the number of authors from 76 to 1587. This increase means that more persons are working in this field. The highest number of authors is assigned to 2017, with the participation of 1733 authors. The number of citations per publication reached 1.59 in 2020, while the highest TC /total publications (TP) value was 88.22 in 1999. It has risen from 63.71 in 2001 to 1.59 in 2020, and the highest average number of the citation in the past 20 years was in 2001. In 1991s, TC / TP recorded higher numbers than its next two decades. According to Table 1, a total of 3885 documents were cited at least once, which is equal to 78.35% of the total. In 1994, 1997, 1998 and 1999 all documents have at least one citation; 39.26% for documents with at least 10 citations and 3.81% for at least 100 citations. For further study, the three decades of 1991, 2001 and 2011s were considered. The investigation showed 93.33% of all 1991s documents had at least one citation. In 2011s, more than 80% of documents had at least one citation and most documents with more than 100 citations are in 2001s. (Table. 1)

Table 1. Characteristics of publications from 1991 to 2020.

year	TP	AU	AU/TP	TC	TC/TP	≥100	≥10	≥1
2020	405	1587	4.04	645	1.59	0	12	183
2019	390	1400	3.58	1823	4.67	0	54	295
2018	389	1598	4.12	3111	8.00	0	113	327
2017	428	1733	3.97	4463	10.43	0	163	363
2016	394	1528	3.88	5471	13.89	1	180	341
2015	323	1303	4.02	6869	21.27	6	165	285
2014	367	1338	3.65	6471	17.63	6	163	317
2013	338	1267	3.75	7864	23.27	13	192	304
2012	318	1106	3.48	9302	29.25	19	159	274
2011	322	1046	3.25	9229	28.66	27	165	250
2010	272	848	3.12	10112	37.18	24	135	214
2009	222	629	2.83	8375	37.73	26	104	169
2008	195	459	2.35	8312	42.63	15	81	120
2007	157	351	2.24	5129	32.67	18	62	97
2006	96	207	2.16	2407	25.07	6	35	60
2005	63	193	3.06	1064	16.89	1	22	41
2004	36	113	3.14	2191	60.86	4	18	29
2003	30	61	2.03	1804	60.13	2	14	24
2002	39	117	3.00	1406	36.05	4	16	30
2001	24	76	3.17	1529	63.71	3	12	22
2000	19	78	4.11	1007	53.00	2	14	17
1999	9	35	3.89	794	88.22	2	7	9
1998	21	65	3.10	861	41.00	4	12	21
1997	12	41	3.42	180	15.00	0	6	12
1996	20	48	2.40	705	35.25	3	12	19
1995	15	38	2.53	342	22.80	1	6	14
1994	14	32	2.46	251	17.93	0	7	14
1993	12	48	4.00	237	19.75	0	4	11
1992	10	22	2.20	129	12.90	0	3	7
1991	18	40	2.22	493	27.39	2	11	16
TOTAL	4958	17448	-	102576	-	189	1947	3885

TP total number of publications, AU number of authors, TC total citations, AU/TP, TC/TP average number of authors, citations, respectively. ≥ 100 , ≥ 10 , ≥ 1 = Number of papers with equal or more than 100, 10 and 1 citations.

3.2 Subject categories

As revealing in Figure 2, in 1991s, subject categories were more related to biochemistry, immunology and microbiology. In 2001s, two groups of chemical engineering and agricultural and biological science were among the major groups. But in 2011s, the two main groups of environmental science and energy performed 16% of all publications, indicating that researchers have focused on energy and the environmental fields in recent years.

3.3 Journals

Focusing on publishing articles' references, journals in this field were distributed in various fields such as environmental science, engineering, fuel, agriculture, energy, socioeconomic, etc. It shows that sugarcane and ethanol have attracted the attention of many authors in various fields. 15 important publications are presented in Table 2 alongside their characteristics. In terms of quality, these journals are also ranked with IF and H-index. Bio-resource Technology has the highest-ranking with 187 documents. This journal also has the best ranking based on H-index among these 15 publications. The subject field of the Bio-resource Technology Journal is related to Environmental Science, Energy and Chemical Engineering. The second most published journal is Biomass and Bioenergy addressing Agricultural and Biological Sciences, Environmental Science and Energy. Each journal's publication share is less than 4% of all documents, which indicates the high distribution of documents among the various journals.

The Journal of Renewable and Sustainable Energy Reviews and the International Sugar Journal had the highest and the lowest ranking in Citescore, respectively. However, the International Sugar Journal ranked third in terms of TPs with a subject field of Agricultural and Biological Sciences. Also, the Journal of Renewable and Sustainable Energy Reviews covers Energy in the subject field. In all three indicators, TP, Citescore and H-index, the journals ranked first belong to the Netherlands. Out of these 15 journals, seven are from UK[3].

Table. 2 The top 15 publications during 1991-2020.

#	Journal	TP*	Country**	H-index (R***)	CiteScore 2019 (R)	IF 2019 (R)
1	Bioresource Technology	187	Netherlands	273 (1)	12.8 (3)	7.5 (3)
2	Biomass And Bioenergy	115	UK	169 (7)	6.6 (10)	3.5 (10)
3	International Sugar Journal	95	UK	19 (15)	0.3 (15)	0.2 (14)
4	Industrial Crops And Products	80	Netherlands	116 (8)	6.9 (9)	4.2 (9)
5	Sugar Tech	75	India	24 (14)	1.9 (13)	1.1 (12)
6	Renewable And Sustainable Energy Reviews	66	Netherlands	258 (2)	25.5 (1)	12.1 (1)
7	Journal Of Cleaner Production	65	Netherlands	173 (6)	10.9 (5)	7.2 (4)
8	Applied Biochemistry And Biotechnology	65	USA	103 (9)	4.2 (12)	2.2 (11)
9	Renewable Energy	62	UK	174 (5)	11.2 (4)	6.3 (5)
10	Chemical Engineering Transactions	60	Italy	32 (13)	1.3 (14)	0.8 (13)
11	Biotechnology For Biofuels	58	UK	84 (11)	8.9 (7)	5.6 (7)
12	Biofuels Bioproducts And Biorefining	51	UK	78 (12)	6.4 (11)	-
13	Applied Energy	50	UK	189 (4)	16.4 (2)	8.8 (2)
14	Energy	48	UK	173 (6)	9.9 (6)	6.1 (6)
15	Energy Policy	45	UK	197 (3)	8.7 (8)	5 (8)

* TP is assigned to the total number of the documents.

** R: Rank

*** The country is referred to the journal's publisher area.

According to Figure 3, the top seven journals' annual publications with the highest TP during 1991-2020, more than 40% of Bioresource Technology journal documents were from the last five years. The International Sugar Journal had four publications in the previous five years. More than 72% of its publications were from 2001s. It demonstrates that this journal was more popular in 2001s than it was in 2011s and its third rank in Table. 2 is the outcome of the documents of this journal in 2001s. The journal's categories including Agricultural and Biological Sciences show that these issues were of interest in 2001s but have not been hot topics recently.

The Journal of Cleaner Production's first issue was published in 2010 and TP of this journal are from 2010 to 2020. More than 63% of this journal's publications from the last three years and its categories include Environmental Science, Renewable Energy and Sustainability, which show the attractiveness of these fields to researchers in recent years.

3.4 Countries, institutions and authors

Details of the top 20 countries of the publication and citations are presented in Table. 3. The type of independent publications (IP) refers to those all written by authors of institutions from one country. In contrast, the type of collaborative publications (CP) represents documents written by authors from different countries.

The highest number of CP (472) is assigned to Brazil, accounting for 22.32% of Brazilian publications, followed by the USA (309) and the UK (92). Among the top 20 countries, Canada has no CP and Sweden has the highest one with 73.56%.

The seven major industrialized nations known as the G7 are among the top 20 countries, including USA, Britain, France, Italy, Germany, Canada and Japan. In terms of TC / TP, Canada is higher than other countries with a value of 39.3, denoting that it has received the highest recognition per publication, followed by Netherlands (38.73), Sweden (38.02), Cuba (32.74) and the USA (31.75). TP of the six countries with the highest annual production are presented in Figure 4. In the 1990s Thailand had no document and China had only one. For three decades, China was the fourth-largest producer of documents, but it did not play a significant role in 1991-2000. It shows that China's development has been very rapid, reaching 206 publications during 2011-2020. As revealed in Figure 4, Brazil has widened its distance from other countries over the years. It can be said that Brazil started to distance itself from other countries since 2005. Brazil was the only country with more than 100 publications since 2011. In 2017, it had the highest number of documents per country with 242. It also reveals that the USA trend has been decreasing in recent years and that India could overtake the US in 2019. The number of publications in the USA is accelerating, because of the enactment of the Energy Policy Act of 2005, the Security Act of 2007 and mainly their licenses for ethanol compounds. In 2011, it was published the largest number of documents during the last three decades. Since then, with the emergence of the global financial crisis, which lasted until 2012, the number of publications reduced slightly. However, with the agreement of the representatives of 195 countries at the 2015 United Nations Climate Change Conference in Paris (approved and signed in New York), TP of the USA experienced a new growth rate. The USA ceased all participation in the Paris Agreement in 2017, which was a part of the United Nations Framework Convention on Climate Change (UNFCCC) on reducing greenhouse gas emissions. The USA has stated that it will boost its coal and oil industries by ceasing all participation in the agreement. Sugarcane and the resulting fuel ethanol are known to replace fossil fuels. After that, the USA decreasing trend in sugarcane and ethanol research intensified (Figure 4). This was an evident so that in 2019, TP of the USA for the first time was less than India and in 2020. Besides, the TP of China was more than the USA. Thailand had no document until 2005 and was ranked sixth and lower than the UK by 2012. But since 2013, there has been competition between Thailand and the UK in terms of the number of publications per year. Since 2013, except in 2012 and 2020, Thailand had more documents than the UK.

Table. 3 Top 20 leading countries in sugarcane and bioethanol research during 1991-2020.

R	country	TP	IP (%)	CP (%)	TC	TC/TP	≥10	≥100	≥200
1	Brazil	2174	77.68	22.32	40986	18.85	932	66	16
2	USA	659	52.75	47.25	20927	31.75	319	48	17
3	India	398	82.53	17.47	9087	22.83	138	19	8
4	China	247	73.25	26.75	4325	17.51	109	5	2
5	UK	159	41.77	58.23	3627	22.81	66	4	2
6	Thailand	129	77.95	22.05	2254	17.47	48	5	1
7	Australia	125	52.80	47.20	2742	21.93	58	7	2
8	Japan	113	60.53	39.47	2197	19.44	43	3	2
9	Colombia	109	66.06	33.94	3251	29.82	34	5	3
10	Netherlands	106	32.04	67.96	4106	38.73	69	11	4
11	Mexico	105	64.08	35.92	1760	16.62	39	4	1
12	Germany	102	37.62	62.38	2885	27.61	42	6	3
13	France	100	35.00	65.00	2850	27.81	49	2	2
14	Spain	100	26.80	73.20	2054	21.18	52	3	0
15	Sweden	88	26.44	73.56	3308	38.02	63	8	1
16	Italy	82	38.27	61.73	1329	16.41	41	0	0
17	South Africa	80	52.50	47.50	1411	17.64	36	2	0
18	Cuba	70	31.43	68.57	2292	32.74	35	8	1
19	Canada	63	100.00	0.00	2519	39.98	30	3	2
20	Argentina	57	52.63	47.37	865	15.18	21	1	0

IP: Independent publications, CP: Collaborative publications.

A total of 44 countries were identified with more than 10 documents with 310 international links (Figure 5). Among them, Brazil and the USA had the strongest links (146 links). Brazil has links with 34 other countries with a total link strength of 1329. Brazil is in the same group as Chile, Colombia, Peru and Italy. USA has 38 links and its total link strength is 368. This country has the most links with other countries.

The geographical distribution of papers and sugarcane production is presented in Figure 6. As shown, USA and countries from South America, Southeast Asia and Western Europe are among the countries where the relevant papers have been distributed.

In this term, Brazil is the top country with 2174 documents, followed by the USA, India, China and the UK, far behind Brazil. So that the total publications of these four countries do not reach the publications of Brazil.

Figure 6 also shows the sugarcane production of the top 30 producing countries in 2018 (*Sugar cane production quantity, n.d.*). The top six sugarcane producers were Brazil, India, China, Thailand, Pakistan and Mexico, with sugarcane productions of 746.82, 376.9, 108.71, 104.36, 67.17 and 56.84 million tons, respectively.

Brazil's leading position in scientific research in this field is determined by the number of institutions and authors with the most publications. Twelve of the top fifteen institutes, institutes and eight of the top ten authors were from Brazil.

According to Table. 4, 13.51% of the publications were assigned to Universidade de Sao Paulo - USP with 673 documents, followed by Universidade Estadual de Campinas (8.72%) and Laboratório Nacional de Biorrenováveis (4.67%).

These three institutions are located in the Brazilian state of Sao Paulo. The next two institutions belong to Sao Paulo state. All five institutions with the highest number of publications belong to this state with 35.21% of the world's total documents. The reason for this ranking and special attention of the Brazilian state of Sao Paulo could be that Sao Paulo has 53% of Brazilian sugarcane under cultivation (Nadaleti et al., 2020).

The production of more than 50% of Brazilian sugarcane in Sao Paulo's state has become a factor in increasing research in this field in this state.

Table. 4 List of top 15 institutions in sugarcane and bioethanol research.

#	Affiliation	Country	documents	%
1	Universidade de Sao Paulo - USP	Brazil	673	13.51
2	Universidade Estadual de Campinas	Brazil	433	8.72
3	Laboratório Nacional de Biorrenováveis	Brazil	233	4.67
4	UNESP-Universidade Estadual Paulista	Brazil	228	4.56
5	Universidade Federal de Sao Carlos	Brazil	188	3.75
6	Universidade Federal do Rio de Janeiro	Brazil	132	2.66
7	Empresa Brasileira de Pesquisa Agropecuária	Brazil	126	2.56
8	Centro Nacional de Pesquisa em Energia e Materiais	Brazil	119	2.35
9	Universidade Federal de Vicosa	Brazil	76	1.54
10	Universidade Federal do Parana	Brazil	72	1.44
11	University of Florida	USA	58	1.18
12	Universidade Federal do ABC	Brazil	55	1.10
13	University of Illinois at Urbana-Champaign	USA	48	0.97
15	Universidade Federal de Pernambuco	Brazil	45	0.91

A total of 13015 authors contributed to sugarcane and bioethanol research from 1991 to 2020. The top ten authors of the dataset are presented in Table. 5. All data for TP, TC, country of researchers, publications release year range of one author (PR) and H-index evaluation of these researchers are enclosed in this Table. These indicators are used for two important reasons. First, these indicators can measure the overall status of publications and are commonly used in bibliometric research. Second, the characteristics of documents can be assessed with a strong theoretical H-index.

Bonomi, A. has the highest number of documents and citations and Cerri, C.E.P. has the first place in H-index, both from Brazil.

Among them, eight authors are from Brazil, which shows Brazilian researchers' attention and their leadership in this field. It should be noted that although Switzerland is not one of the top ten countries in the set, Ensinas, A.V. from Switzerland ranks

second in terms of the number of documents.

Vosviewer analyzed the contributions of 117 authors with at least 10 publications. 94 of them were related and their co-authorship map can be seen in Figure 7.

23 researchers had no collaboration with anyone. According to the analysis, there were 362 links in 10 clusters with total link strength of 1657. Bonomi. A had the highest total link strength of 275 with 75 publications and 31 links.

Table. 5 The top ten productive authors.

#	author	TP	country	TC	h-index	PR
1	Bonomi, Antonio	76	Brazil	2315 (1)	26 (2)	2010-2020
2	Ensinas, Adriano V.	45	Switzerland	1099 (7)	20 (4)	2006-2020
3	Cavalett, Otavio	44	Brazil	1430 (4)	24 (3)	2011-2020
4	Nebra, Sílvia Azucena	43	Brazil	942 (8)	22 (5)	2000-2020
5	Cerri, Carlos Eduardo Pelegrino	36	Brazil	818 (9)	40 (1)	2009-2020
6	Junqueira, Tassia Lopes	35	Brazil	1102 (6)	16 (8)	2011-2020
7	Rossell, Carlos Eduardo Vaz	34	Brazil	1673 (2)	17 (7)	2001-2019
8	Leal, Manoel Régis Lima Verde	33	Brazil	619 (10)	12 (9)	2001-2020
9	Dias, Marina O.S.	32	Brazil	1518 (3)	19 (6)	2008-2020
10	Chandel, Ashwani Kumar	30	India	1249 (5)	9 (10)	2007-2020

PR: Publication release year ranges of authors.

3.5 Main research fields

Table. 6 lists the top 10 most cited articles from 1991 to 2020. These articles are from 2001 to 2012. Most of these articles deal with ethanol production from waste, the amount of greenhouse gases produced in this way and ethanol as a sustainable energy source.

As shown in Table. 6, authors from New Zealand, the USA and Brazil each have their names mentioned twice and once from other countries.

Among the articles "biodiesel from microalgae beats bioethanol" (2008) by Y. Chisti (Chisti, 2008) with 1414 citations had the highest number of citations. The highest number of citations per year was 117.83 times. An article from REH Sims, W. Mabee, JN Saddler and M. Taylor (2010) (Sims et al., 2010) was the only participatory article written with Canada and New Zealand's participation, with 905 citations ranked 6th. Due to the identified limitations in the production of first-generation biofuels from food products, this study has a review on the second-generation biofuel technologies (Sims et al., 2010). The most recent article in Table. 6 "bioethanol production from agricultural waste: an overview", is related to 2012, which ranks second in citation per year with 106.75. In this review, available technologies for bioethanol production from agricultural waste are discussed (Sarkar et al., 2012).

Table. 6 Top ten articles in terms of number of citations.

	Title	Reference	Citation	Journal	Year	Citation/ Year	Document Type	Country
1	Biodiesel from microalgae beats bioethanol	(Chisti, 2008)	1414	Trends biotechnology	2008	117.83	Article	New Zealand
2	Hemicellulose bioconversion	(Saha, 2003)	1339	Journal of Industrial Microbiology and Biotechnology	2003	78.76	Conference Paper	USA
3	Global potential bioethanol production from wasted crops and crop residues	(Kim & Dale, 2004)	1269	Biomass and Bioenergy	2004	79.31	Article	USA
4	Trends in biotechnological production of fuel ethanol from different feedstocks	(Sanchez & Cardona, 2008)	1189	Bioresource Technology	2008	99.08	Review	Colombia
5	Recent trends in global production and utilization of bio-ethanol fuel	(Balat & Balat, 2009)	973	Applied Energy	2009	88.45	Review	Turkey
6	An overview of second generation biofuel technologies	(Sims et al., 2010)	905	Bioresource Technology	2010	90.50	Review	New Zealand, canada
7	Ethanol for a sustainable energy future	(Goldemberg, 2007)	871	science	2007	67	Short Survey	Brazil
8	Bioethanol production from agricultural wastes: An overview	(Sarkar et al., 2012)	854	Renewable Energy	2012	106.75	Review	India
9	Fuel ethanol production from lignocellulose: A challenge for metabolic engineering and process integration	(Zaldivar et al., 2001)	704	Microbiology and Biotechnology	2001	37.05	Short Survey	Denmark
10	Greenhouse gases emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 averages and a prediction for 2020	(Macedo et al., 2008)	580	Biomass and bioenergy	2008	48.33	Article	Brazil

3.6 Keywords

Evaluating and analyzing keywords help to understand the hot topics of research. It has been proven to be essential for monitoring the development of research topics. The authors determine the keywords according to the purpose of the article (Li et al., 2009).

In order to understand popular words and topics, the relationships between them and keywords were investigated by social network analysis software.

86 keywords were used more than 20 times. Close and similar words were removed from them, 75 keywords remained and the relationship between them is given in five clusters, each marked with a specific color in Figure 8.

It was found that the words ethanol, sugarcane, bioethanol, sugarcane bagasse and biofuels were the most repetitive words. After them, the words fermentation, enzymatic hydrolysis and biomass were prominent.

In order to focus more on the author's keywords, they were evaluated over three decades (Figure 9). The similar words and the ones from the initial search (such as bioethanol, ethanol and sugarcane) were removed for better evaluation. Figure 9 visually shows the extracted results obtained from VOSviewer.

In 1990s, author-keywords were focused on fermentation, biomass, yeast, sugar cane bagasse, pretreatment and molasses. Fermentation is the most frequent author-keyword with occurrences (9) and total link strength (15).

In 2000s, as the number of publications increased, so did the number of keywords. In addition to the author-keywords used in 1990s, there are biofuels, renewable energy and sustainability related and close to each other. In another group, *saccharomyces cerevisiae*, molasses and alcoholic fermentation could be seen.

In 2010s, greenhouse gas emissions, life cycle assessment, enzymatic hydrolysis, land-use change, LCA and anaerobic digestion were used a lot. The used words related to the environment and sustainability increased in 2000s and 2010s, indicating that parts of studies focused on these fields and they became hot topics.

[1] - Greenhouse gas.

[2] - Total citations

[3] - United Kingdom

4. Conclusion

According to data from the Scopus search database, the literature review was based on sugarcane and bioethanol studies from 1991 to 2020. Various aspects were investigated, including language, institutions, field of subject, authors, keywords and countries.

Brazil was known as the leader in sugarcane and ethanol studies with the largest number of authors and institutes. It also had many international collaborations with the USA.

Among the leading manufacturing institutions (the Universidade de Sao Paulo - USP, Universidade Estadual de Campinas and Laboratório Nacional de Biorrenováveis) all from Brazil with the highest publications, were ranked from first to third, respectively.

Although the highest number of documents were published in 2010s, the 2000s saw the largest increase in the number of documents. From 24 documents in 2001 to 322 documents in 2011, the highest growth rate was reached during 1991 to 2020.

The political incentives and related laws were among the factors that cause research to fluctuate. The more international laws and treaties in field of bioenergy, alternative fuels for fossil fuels, agreements to reduce greenhouse gas emissions, related tax exemptions and guiding laws in this field, the more growth can be expected in studies in this field. It seems that the USA withdrawal from the Paris Agreement (2017) had a negative impact on research, reaching a record of the highest number of documents in 2017, but since then number of publications have declined. In the following years, the USA's rank as the second-largest document producer of sugarcane and ethanol was threatened by India and China.

In 2011s, Environmental sciences and energy were the most important parts of the study and in keywords, focus of studies was on sustainable development, LCA and environment. According to the maps, subjects such as "life cycle evaluation" seem significant in the future.

In the subject category of documents, studies in 1991s focused more on biochemistry, genetics, immunology and microbiology, which changed to Environmental Science and Energy by the 2011s. Agricultural and Biological Sciences journals became more popular in 2001s and environmental science and energy journals became more popular in 2011s.

The overview of the research could help the researchers to have a better understanding of the priorities of their future researches.

Declarations

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Availability of data and materials

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Conflict of interest

The authors declare no competing interests.

Contributions

Arsham Tajvar, Mohammad Reza Sabour, Amir Mostafa Hatami & Fateme Mohammadi have contributed equally. All authors read and approved the final manuscript.

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Figures

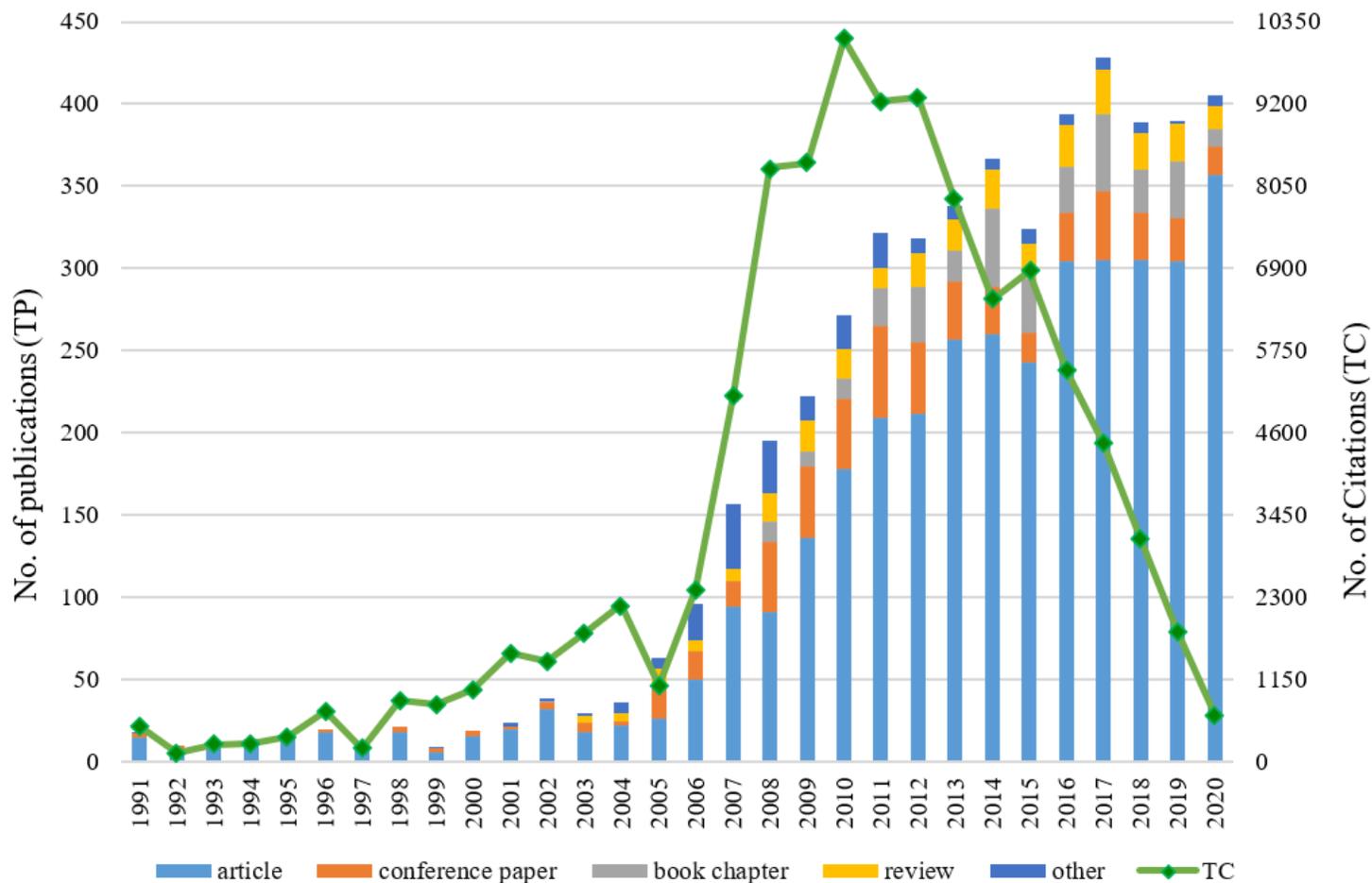


Figure 1

Evolution of publications and citations from 1991 to 2020.

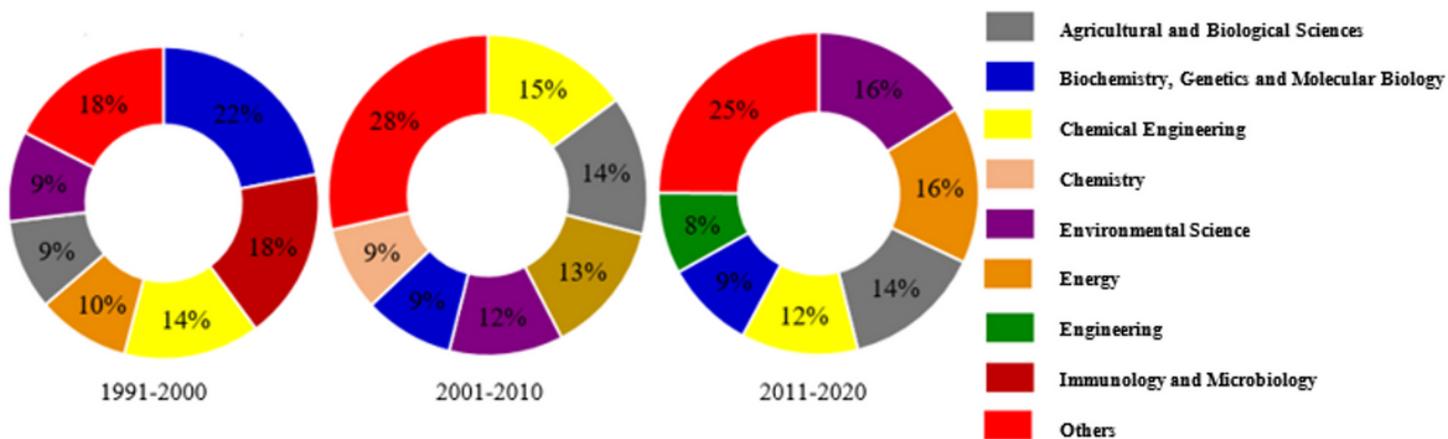


Figure 2

Result of Subject categories analysis in the last three decades.

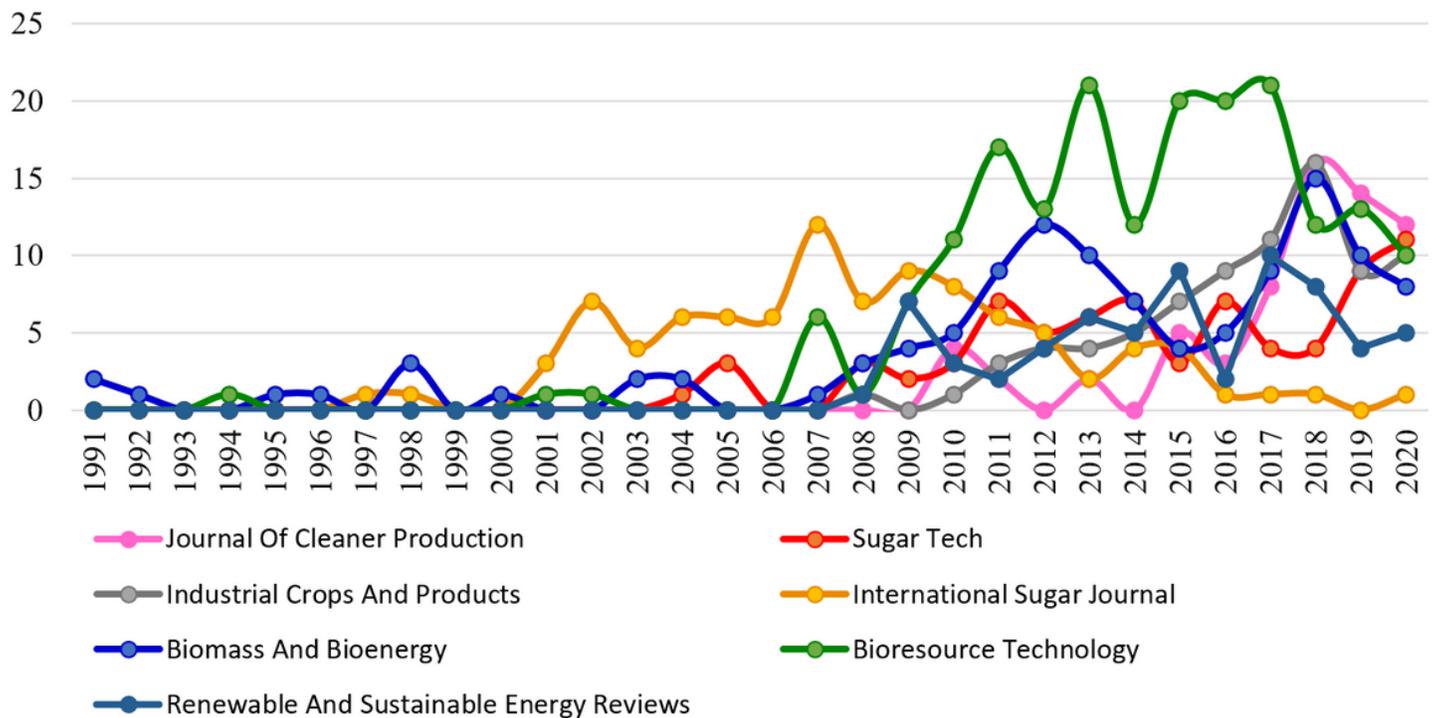


Figure 3

The yearly output of the top seven productive journals in sugarcane and bioethanol research from 1991 to 2020.

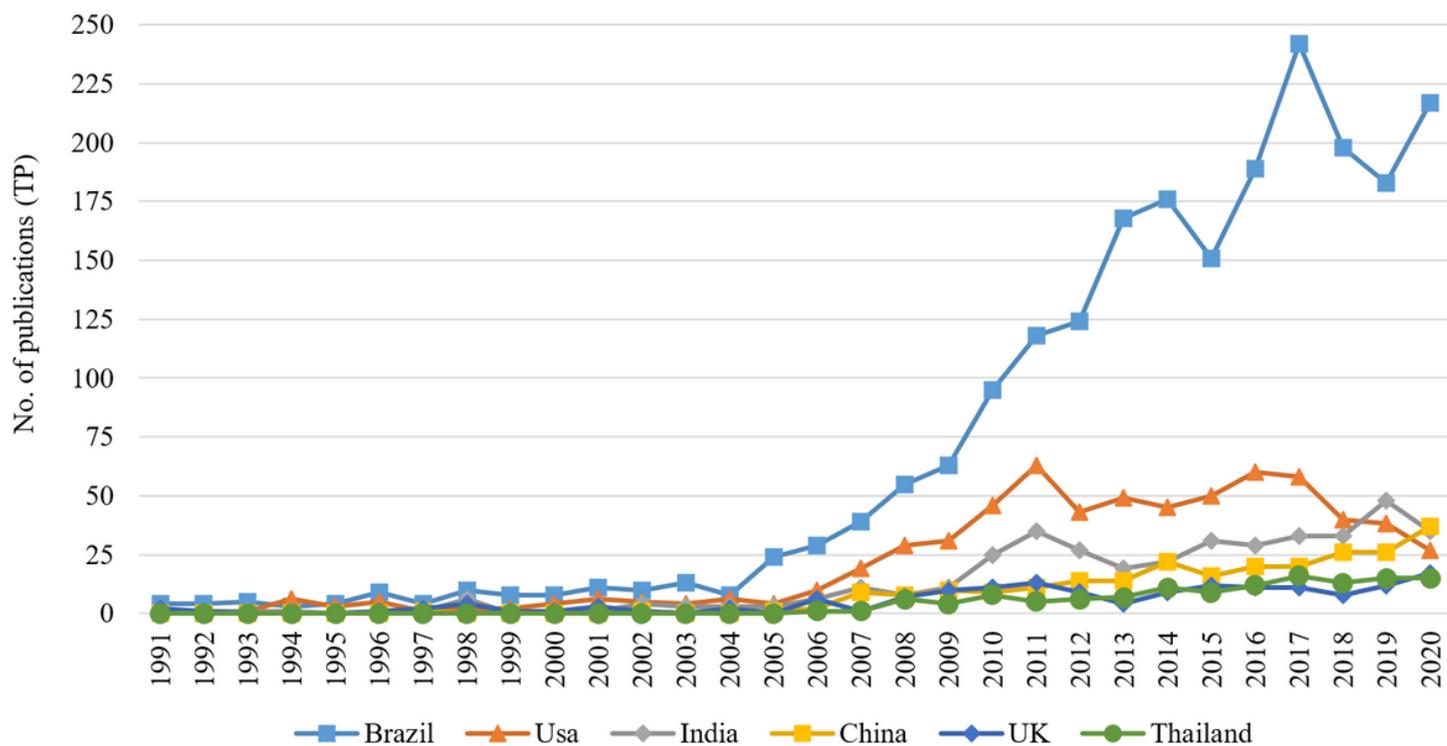


Figure 4

Comparison of publications of the top 6 countries in sugarcane and bioethanol research from 1991 to 2020.

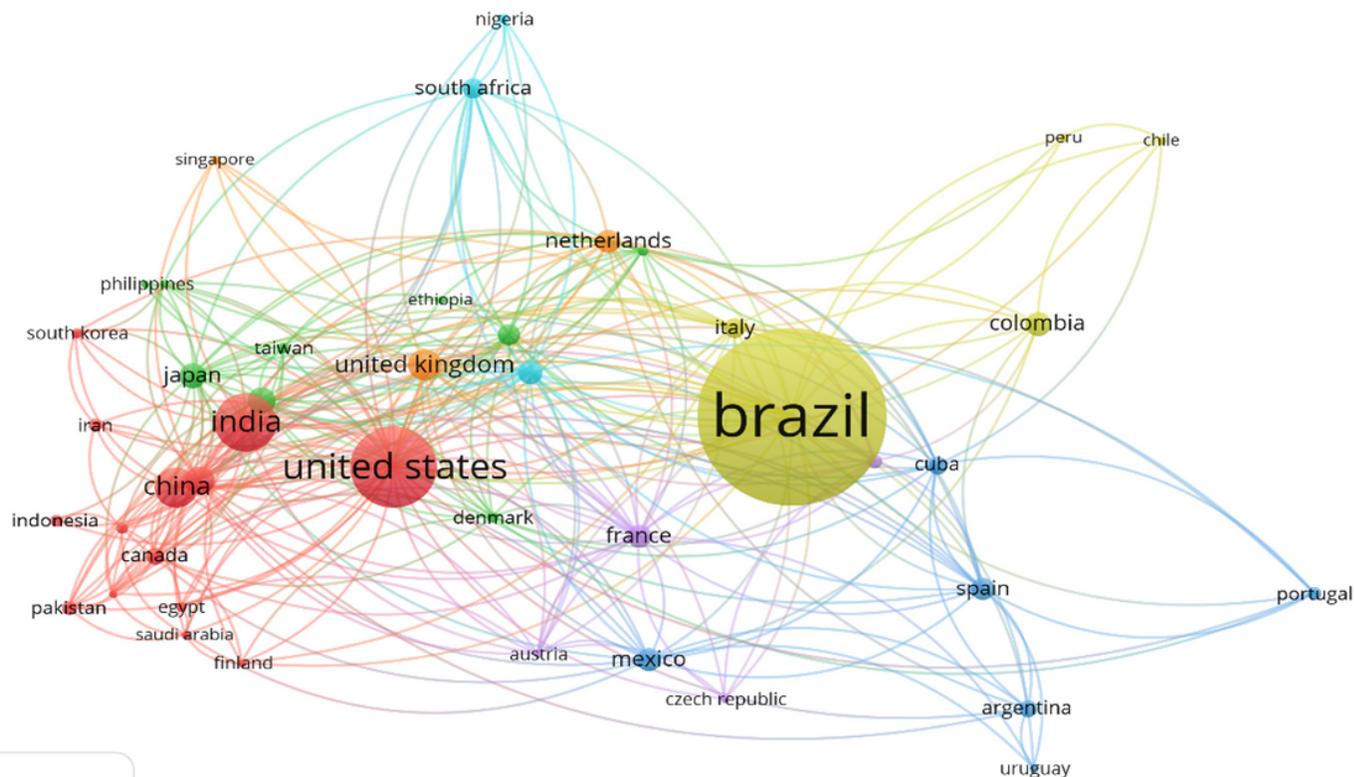


Figure 5

Bibliographic coupling of countries during 1991-2020.

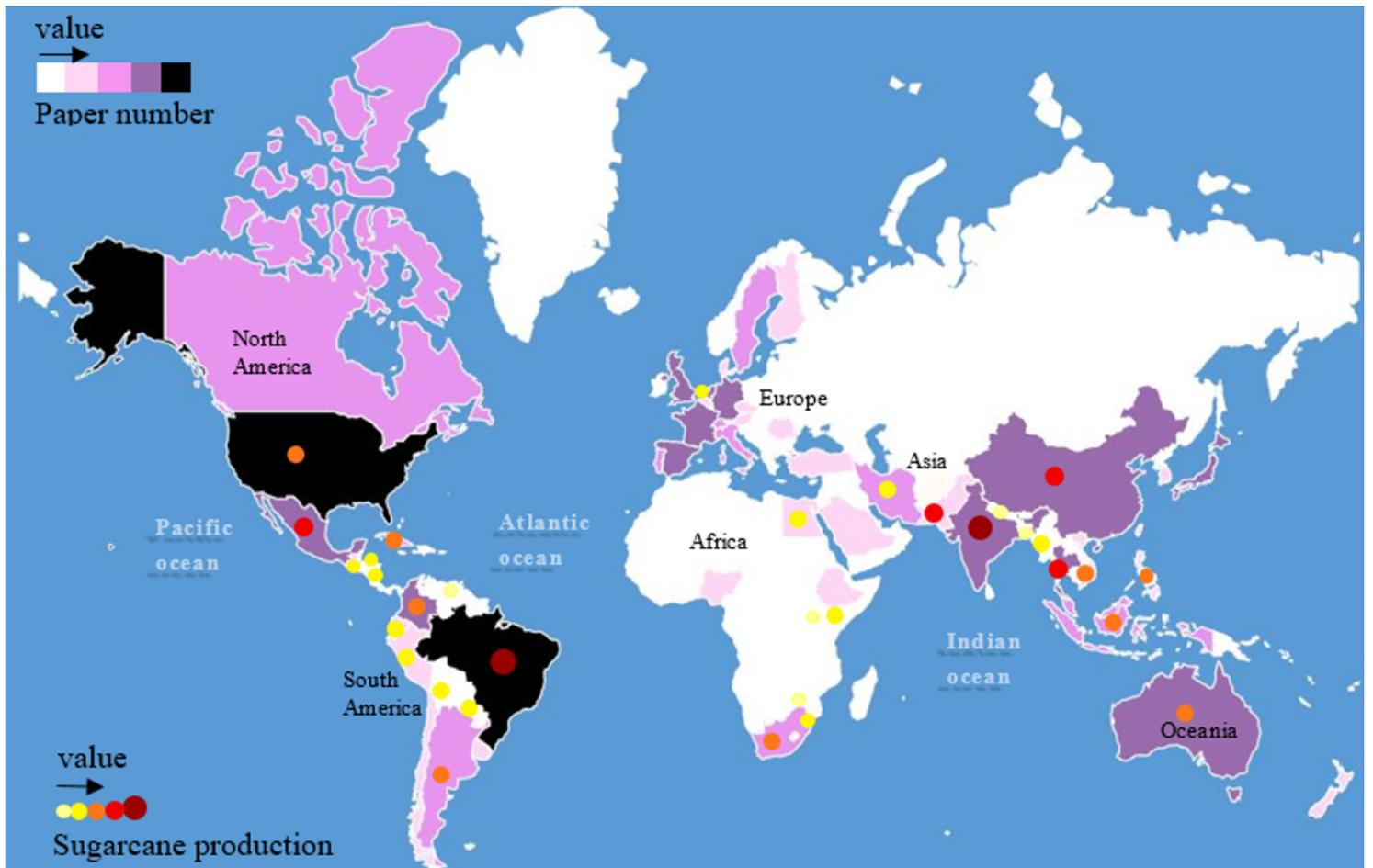


Figure 6

Geographical distribution of papers and sugarcane production. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

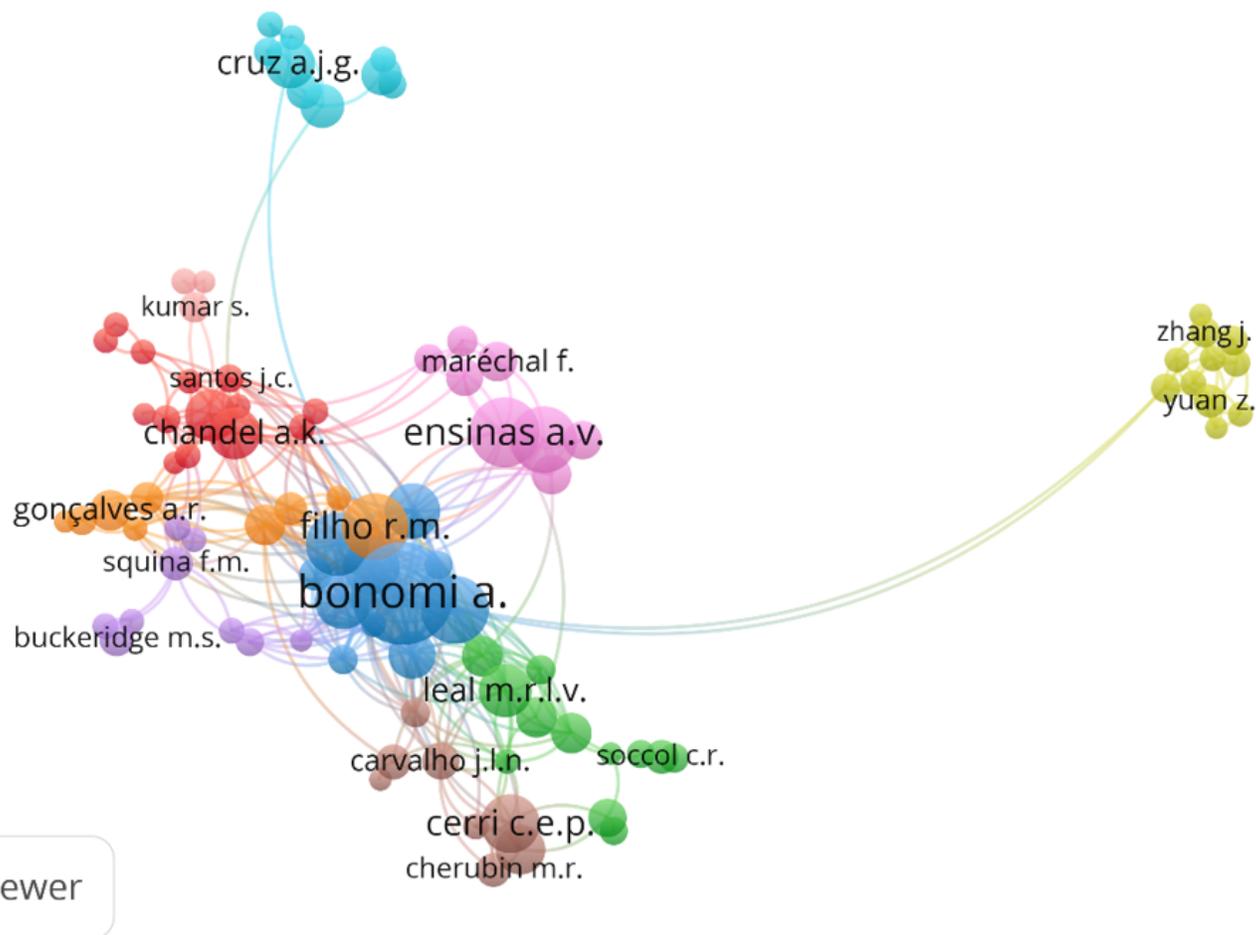


Figure 7

Bibliographic coupling of authors whit more than ten publications.

