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Systematic Review

Paulownia spp.: A Bibliometric Trend Analysis of a Global Multi-Use Tree

Linda Lugli [1], Giustino Mezzalira [2], Maurizio Lambardi [3], Huaxin Zhang [4] and Nicola La Porta [1,5,*]

[1] IASMA Research and Innovation Centre, Edmund Mach Foundation, I-38098 San Michele a/Adige, Trento, Italy; linda.lugli@fmach.it
[2] Research and Agroforestry Management, Veneto Agriculture, I-35020 Legnaro, Padua, Italy; mezzaliragiustino@gmail.com
[3] National Research Council CNR, IBE Institute BioEcon, I-50019 Florence, Tuscany, Italy; maurizio.lambardi@ibe.cnr.it
[4] Institute of Ecological Protection and Restoration, Chinese Academy of Forestry, Haidian District, Beijing 100091, China; zhanghx1998@126.com
[5] European Forest Institute Project Centre on Mountain Forests, I-38098 San Michele a/Adige, Trento, Italy
* Correspondence: nicola.laporta@fmach.it

Abstract: The research on *Paulownia* spp. has increased in the last twenty years thanks to the growing interest in the application modalities of this plant in various sectors such as wood, phytoremediation, environmental protection, paper, biofuel, chemistry and medicine. For the first time, this study analyzed the papers present in the Web of Science Core Collection on "Paulownia" to obtain a set of characteristics in the work carried out from 1971 to 2021. This analysis selected and took into account 820 articles and provided evidence of the scientific production of authors, institutions, and countries. This work showed that the most studied species was *Paulownia tomentosa*, followed by *P. fortunei* and *P. elongate*. The JCR category and research area with the most publications was plant science, with 20.4% of the total. The papers were published in 460 journals and in a book series. The journals with the most publications were *Bioresources*, *Advanced Material Research*, *Agroforestry Systems*, *Journal of Wood Science* and *Industrial Crops and Products*. The institutions with the most prolific affiliation with the field of *Paulownia* spp. research were Henan University, the US Department of Agriculture, Belgrade University, the Chinese Academy, and Georgia University. Finally, the 3842 keywords were divided into nine different clusters and the trends of interest in the last fifteen years were highlighted.

Keywords: bibliometric review; VOSviewer; Web of Science; WoS; forestry; fast-growing tree; emerging trends; science citation index; ornamental tree; exotic tree

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1. Introduction

Paulownia spp. belongs to the Paulowniaceae family. There are at least eight species of paulownia divided into two clades: the first clade includes *P. tomentosa*, *P. kawakamii and P. coreana*, while the second clade comprises *P. australis*, *P. fortunei*, *P. elongata*, *P. catalpifolia* and *P. fargesii* [1]. The main bases for species classification are the characteristics of the inflorescences and fruits, while the main silvicultural differences between the species are cold resistance and growth capacity. The optimum temperature for growth in diameter and height is 24–29 °C and is similar in all species. As for cold resistance, *P. tomentosa* is the hardiest species and can withstand temperatures of around −20 °C, while *P. elongate* and *P. catalpifoglia* can withstand −15° to −18 °C, and *P. fortunei*, *P. australis*, *P. kawakamii* and *P. fargesii* can withstand −5° to −10 °C [2].

Paulownia originated in China and has been cultivated there for a long time. To date, it has been widely introduced in Japan, Australia, Brazil, Europe and the USA [3,4]. In particular, in the USA, *Paulownia tomentosa* is considered invasive because it produces abundant, prolific, wind-dispersible small seeds, and it has strong sprouting ability and

fast growth [5]. Introduced ca. 200 years ago in this country [5,6], it can now reproduce and spread on its own in its non-native range. In contrast, *P. elongata* and *P. fortunei*, which were not present in the USA until 1970, require human intervention to thrive [7].

But paulownia is also frequently described as having "low competitive ability", particularly during the first years of age [8,9], due to a strong intolerance to shade [10,11]. Thus, due to apparent growth interference by neighboring vegetation and its inability to reproduce in shade, paulownia should be considered a transient invader following disturbances [12]. Paulownia, in China, is widely used in traditional medicine thanks to phenolics and antioxidant compounds present in different parts of the plant. Compounds extracted from paulownia are used for the treatment of infectious disease and for neuroprotective, antioxidant, antibacterial, antiphlogistic, antiviral, and cytotoxic actions [13–16]. Vulgar names of paulownia include t'ung (China), kiri (Japan), royal paulownia, cotton tree, and princess tree. The last name was coined by the German naturalists Philip Franz von Siebold and Joseph Gerhard Zuccarini [17], who brought back seeds of this species from a scientific expedition to Japan at the beginning of 19th century. The name paulownia was in honor of the Queen Consort of the Netherlands, Anna Paulownia Romanova, daughter of Tsar Paul I of Russia who financed the expedition. Initially, paulownia was imported only for ornamental purposes. In fact, the tree is very attractive, especially due to its plentiful flowering, ranging from a white to purple color. Later, it also became evident and appreciated for its great economic importance.

Paulownia is a fast-growing tree species that can grow over 5 m in one year and can produce approximately 1 m^3 of wood per tree from the age of 5–7 years [18,19]. The official maximum size recorded for this tree is 579 cm for the girth and 21.90 m for the height [20]. To date, the plant with the largest diameter is in Cloverly Park, Philadelphia, USA, and the tallest plant is in Topolcianky, Nitra, Slovakia. The oldest plant, 132 years old in 2018, is located in Villa Massari, Ferrara, Italy [20]. Aside from this official record, it is quite possible that, in China, there are trees that are even bigger and older. Its wood presents a series of excellent characteristics: it is lighter than balsa wood, with a basic density, depending on the paulownia species and clones, of 0.272 g cm^{-3} calculated for *P. tomentosa* [21].

Paulownia wood lacks splitting, deformation, shrinkage, and expansion traits during drying and has moisture-proof, sound-insulating and fire- and corrosion-resistant properties. At the same time, it is robust enough to be used for several purposes. As a matter of fact, it is used in building materials, sawn timber, veneer or plywood for furniture, agricultural tools, handicrafts, packaging, disposable tools for fast foods, paper pulps, cultural articles, musical instruments, and surfboards [21–23]. Also, paulownia flowers, leaves, fruits, and bark can be used as medicine, with anti-inflammatory, cough-relieving, diuretic and antihypertensive effects [13,24,25]. Moreover, paulownia is also an ornamental plant with lush inflorescence and various flower colors and is often used as a garden and street tree [26].

It is also possible to use paulownia wood for biofuels and value-added compounds, thanks to its glucan-rich feedstock that make it suitable for bioenergy purposes [27–30]. Moreover, waste materials from paulownia (i.e., leaves, petioles) represent a great ecological resource. Their high nitrogen content makes them suitable as animal fodder [31] or fertilizer [32,33]. This tree is also used in environmental protection, in phytoremediation of soils with heavy metal stress [34–36] and in reforestation because it can grow in nutrient-poor soil, can adapt to different soil conditions and climates [37,38], has an extensive root system [39,40], and has high drought and salt tolerance [41–43].

In short, *Paulownia* spp. is an important ecological, economic and ornamental tree species with a wide range of uses and, as one of the fastest growing tree species in the world, the *Paulownia* has attracted enormous industrial and scientific interest in recent years.

The aim of this study was to analyze scientific publications on paulownia from Web of Science (WoS) from 1971 to 2021, to analyze trends in publications involving content changes over time. This includes quantitative measures like keyword frequency and

qualitative assessments of WoS research areas and categories. The work performed by the VOSviewer includes temporal analysis, citation, and collaboration studies. The goal is to uncover evolving patterns, influential works, and interdisciplinary connections within a body of the paulownia literature.

2. Data and Methods

2.1. Web of Science

Clarivate Analytics Web of Science is one of the world's largest and complete collection of publications in the scientific field with over 21,000 peer-reviewed, high-quality scholarly journals published worldwide (including Open Access journals). It is a website that collects papers, articles, reviews in over 250 sectors of science, social sciences and humanities disciplines from different databases: the Science Citation Index Expanded (SCIE), Conference Proceeding Citation Index-Science (CPCI-S), Index Chemicus (IC), Emerging Source Citation Index (ESCI), Current Chemical Reactions (CCR-EXPANDED), Arts & Humanities Citation Index (A&HCI), Social Science Citation Index (SSCI), Social Sciences Citation Index (SSCI), Conference Proceedings Citation Index-Social Science & Humanities (CPCI-SSH), Book Citation Index—Science (BKCI-S).

2.2. Data Collection and Analysis

Bibliometric and scientometric methods were applied in this study to analyze and map articles, books, proceedings and other publications across various fields where paulownia was utilized.

A bibliometric analysis is a statistical evaluation of published productions, and it is used to measure the influence of publications, scholars or institutions in the scientific community. The bibliometric technique has already been employed in several research areas such as grafting in horticultural plants [44], in potato [45], in cucumber sativus [46] and Cucumis melo [47], and in essential oil-bearing plants under water stress [48].

This work considered publications in the WoS Core Collection, from 1971 to the end of 2021. To obtain our data, we used the keyword "paulownia" and set the research parameter on "all field". We found 871 papers. The results were refined, eliminating the articles with "paulownia" not in a main role and setting the research parameter on "topic". All records were extracted at other reference software file formats and elaborated into VOSviewer (version 1.6.17, 2021, Leiden University, Leiden, The Netherlands) to create maps based on the bibliographic data. We considered all the categories and research areas in which WoS classified paulownia articles, the different languages used in the articles, the different authors, and the collaborations and institutions involved in the studies that led to these publications.

To analyze the main authors of articles concerning paulownia, a search was made on WoS, each time setting the name of the author of interest and paulownia in "Topic" as a parameter. The affiliation and h index, only related to paulownia, of each author were then derived.

2.3. VOSviewer

VOSviewer can be used to construct networks of scientific publications, scientific journals, researchers, research affiliations, countries, keywords, or terms. It is possible to link elements by co-authorship, co-occurrence, citation, bibliographic coupling, or co-citation links [49].

In this work, the software VOSviewer was used on WoS data to determine correlation and clusters of authors, institutions, countries, and the keywords. After evaluating the parameter options offered by VOSviewer (https://www.vosviewer.com; accessed on 29 August 2023), we assessed and used the default values of this software because they were the clearest and most convenient for this study. Items are represented by a label and a circle, and their size is determined by the weight of the items. In some cases, the labels may not be displayed to not overlap with each other. All elements that belong to the same

cluster have the same color and the links between inter- and intra-cluster elements are represented by lines. The distance between the items indicates the strength of relationships. The stronger the link between two items, the thicker the line that is used to display the link in the visualization of the currently active map [49]. By default, the 1000 strongest links between items are represented.

3. Results

3.1. Document Type and Language of Publication

Based on Clarivate Analytic's WoS Index, we collected 820 papers, including 28 reviews, from 1971 to 2021 (Table S1).

Most of the documents are Articles (678; 82.2%), followed by Proceeding Papers (73; 9.0%), Meeting Abstracts (22; 2.7%), Review Articles (11; 1.3%), Notes (9; 1.1%), Book Chapters (6; 0.7%), Early Access (6; 0.7%), Corrections (5; 0.6%), News Items (5; 0.6%), Editorial Materials (3; 0.4%), Book Reviews (1; 0.1%), and Data Papers (1; 0.1%) (Figure 1). Most of the publications are in English (over 95%). The second most-used language was Spanish with 1.1%, and the third most-used language was Chinese with 0.6% which was on a par with French and Japanese. All the other languages were under 0.5%.

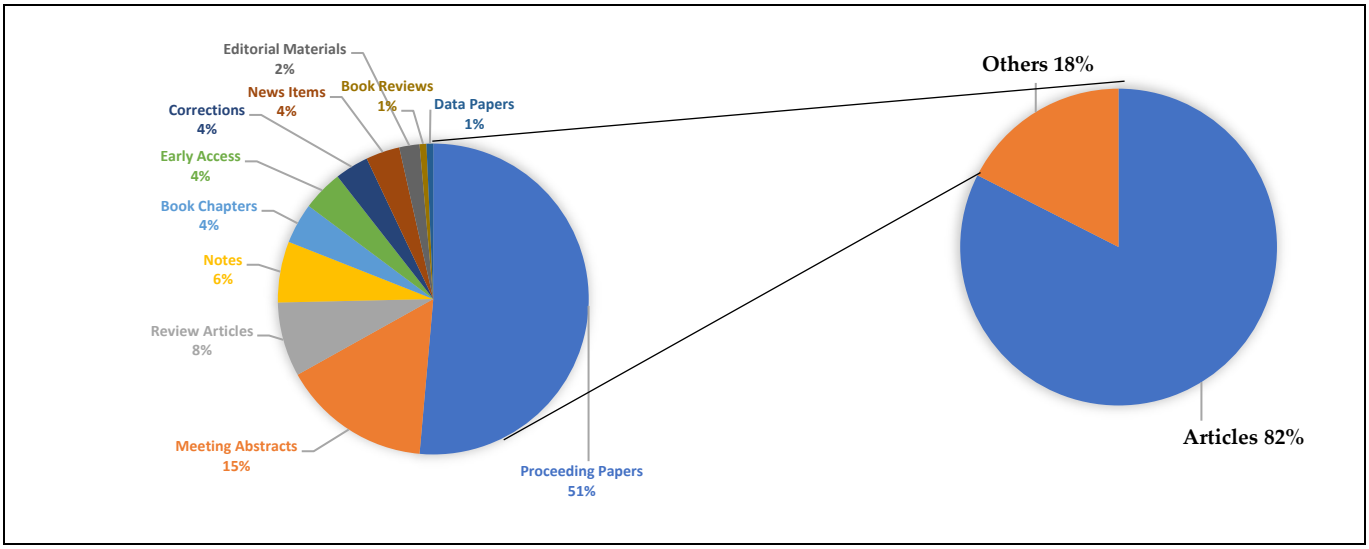

Figure 1. Pie chart of the categories of documents about paulownia and corresponding percentage in WoS.

3.2. Publication Output

In the trend analysis of paulownia research, we considered the period between 1971 and 2021. Figure 2 reports the trend of publications, year by year. In general, it is possible to see an increasing trend of publication on paulownia. The peak is in 2020, with 62 publications, or 7.6% of all publications in the 51 years. In contrast, 2000 is the year with the fewest publications with two publications, or 0.2%. However, since considering the full period (1997–2021), there are no years without publications.

The same trend can be seen in Table 1. In general, the interest in research on paulownia grew throughout the entire period, especially over the past 30 years. In the first period (1971–1980), only 15 articles were published on paulownia; in the second period (1981–1985), there was an increase with 25 articles published but from 1986 to 1990, there was a small decline, with only 14 publications. By 1991, publications about paulownia started to increase again, and in the period 1991–1995, there were 37 publications. By the period 2006–2010, the publications numbered more than 100, and in the last six years, a peak with 326 publications was recorded. Similarly, the number of authors, the number of countries, and the number of journals involved in the publications had a steady increase from 1971 to 2021, except for the period between 1986 and 1990 and between 1996 and 2000.

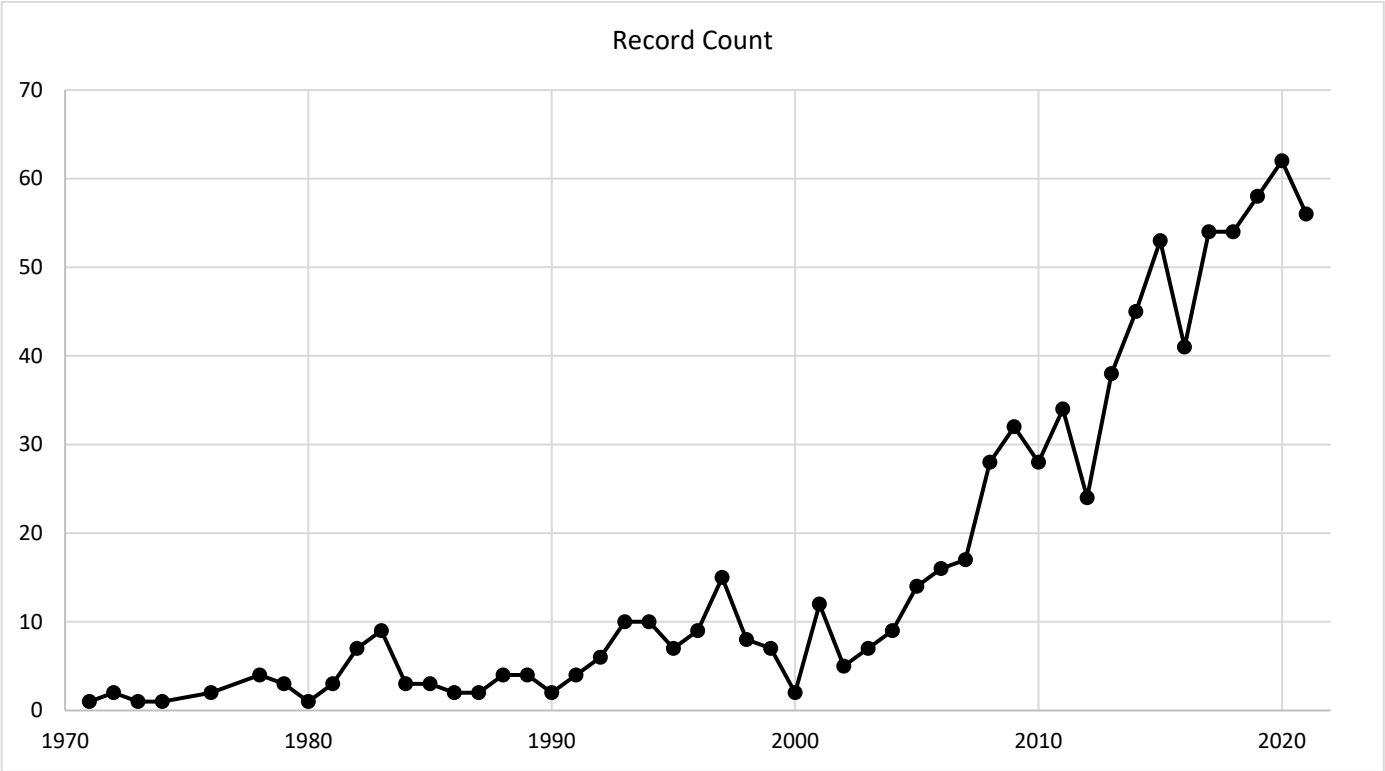

Figure 2. Trends of publications about paulownia from January 1971 to December 2021.

Table 1. Bibliometric analysis of the articles covering paulownia, from 1971 to 2021. For each five-year period, the number of articles published, the number of authors who contributed to the articles, the number of countries to which the authors belonged, the number of citations recorded, the ratio of the number of citations to the number of articles, and the number of journals involved in the publication of the articles are reported. The term "n.a." means not applicable because for each year period, the number of authors, the number of countries and the number of Journals could be repeated.

Years	Number of Articles	Number of Authors	Number of Countries	Annual Number of Citations	Number Citation/Number Articles	Number of Journals
1971–1980	15	21	5	52	3.5	12
1981–1985	25	40	10	249	10.0	16
1986–1990	14	26	5	121	8.6	14
1991–1995	37	67	11	1389	37.5	29
1996–2000	41	88	12	828	20.2	32
2001–2005	47	123	21	1151	24.5	36
2006–2010	121	393	25	3177	26.3	92
2011–2015	194	597	35	3259	16.8	151
2016–2021	326	1078	52	1950	6.0	217
Total	820	n.a.	n.a.	12176	153.4	n.a.

The most treated species was *P. tomentosa*, with 336 publications in WoS, followed by *P. fortunei* with 160 publications, and *P. elongata* with 104. The other species, *coreana*, *kawakamii*, *catalpifolia*, *australis*, and *fargesii* were less examined and had far fewer publications on WoS, with 18, 15, 11.9, and 2 publications, respectively (Figure 3).

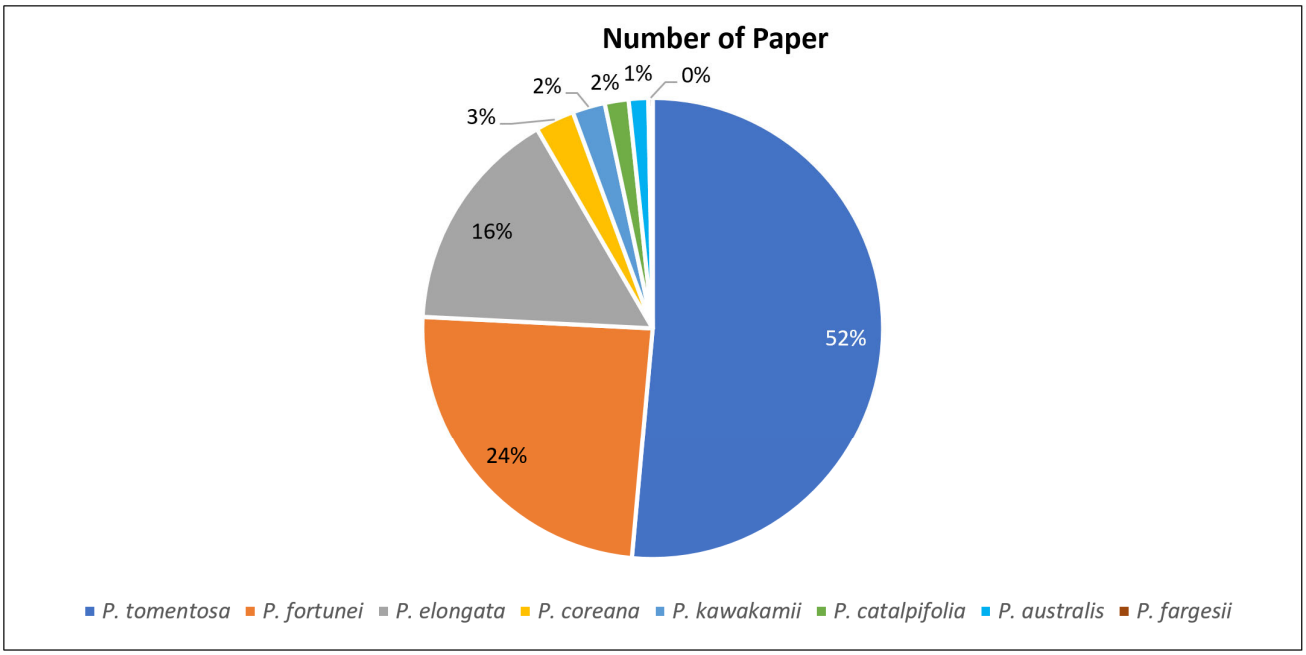

Figure 3. Pie chart of paulownia species and percentage of papers in WoS for each species.

3.3. Web of Science Categories and Research Areas

There are a total of 96 WoS categories about paulownia in which papers have been published, and 60 research areas. Tables 2 and 3 show the item with almost a 10 record count. The first five WoS categories are Plant Science (167; 20.4%), Forestry (117, 14.3%), Materials Science Paper and Wood (106; 13.0%), Environmental Science (61, 7.5%), and Biochemistry Molecular Biology (58; 7.1%). The first five research areas are Plant Science (167, 20.4%), Material Science (160; 19.5%), Forestry (117; 14.3%), Agriculture (103; 12.6), and Chemistry (102; 12.5%).

Table 2. WoS "category" for paulownia bibliometric analysis.

WoS Categories	Record Count	% of Total No. of Articles
Plant Sciences	167	20.4
Forestry	117	14.3
Materials Science Paper and Wood	106	13.0
Environmental Sciences	61	7.5
Biochemistry Molecular Biology	58	7.1
Biotechnology Applied Microbiology	58	7.1
Chemistry Multidisciplinary	56	6.8
Chemistry Medicinal	44	5.4
Agronomy	43	5.3
Engineering Chemical	36	4.4
Materials Science Multidisciplinary	36	4.4
Multidisciplinary Sciences	35	4.3
Pharmacology Pharmacy	34	4.2
Ecology	29	3.6
Energy Fuels	29	3.6
Genetics Heredity	27	3.3

Table 2. *Cont.*

WoS Categories	Record Count	% of Total No. of Articles
Agricultural Engineering	25	3.1
Horticulture	25	3.1
Engineering Environmental	19	2.3
Chemistry Applied	18	2.2
Agriculture Multidisciplinary	17	2.1
Chemistry Organic	17	2.1
Materials Science Composites	15	1.8
Biochemical Research Methods	13	1.6
Chemistry Analytical	13	1.6
Green Sustainable Science Technology	12	1.7
Engineering Multidisciplinary	11	1.3
Entomology	11	1.3
Polymer Science	11	1.3

Table 3. WoS "research area" for paulownia bibliometric analysis.

Research Areas	Record Count	% of Total No. of Articles
Plant Sciences	167	20.4
Materials Science	160	19.5
Forestry	117	14.3
Agriculture	103	12.6
Chemistry	102	12.5
Environmental Sciences Ecology	85	10.4
Engineering	73	9.0
Biochemistry Molecular Biology	69	8.4
Biotechnology Applied Microbiology	58	7.1
Pharmacology Pharmacy	56	6.8
Science Technology Other Topics	52	6.4
Energy Fuels	29	3.5
Genetics Heredity	27	3.3
Entomology	11	1.3
Polymer Science	11	1.3

Table 4 shows the absolute number and percentage of articles univocally classified with one, two, three, four, or five WoS categories and research areas.

Table 4. Absolute number and % of articles divided for numbers of category.

	Number of Categories for Each Article of Total Collection									
	1		2		3		4		5	
	N	%	N	%	N	%	N	%	N	%
WoS category	437	53.2	245	30	109	13.3	24	3	4	0.5
Research area	458	55.6	273	33.4	79	9.7	10	1.2	1	0.1

3.4. Core Journals

Papers on paulownia have been published in 460 journals. Table 5 reports publication titles with at least five reports. In the first five positions, there are *Bioresources* with 24 publications (2.9%; IF = 1.6; QC = Q2; category = Materials Science, Paper and Wood), *Advanced Material Research*, a book series, with 13 publications (1.6%), *PLOS one* with 13 (1.6%, IF = 3.2; QC= Q2; category = Multidisciplinary Sciences), *Agroforestry Systems* with 10 (1.2%; IF = 2.549; QC = Q2; categories = Agronomy and Forestry), which is on par with *Journal of Wood Science* (IF = 2.2; QC = Q2; categories = Forestry and Materials Science, Paper and Wood), and *Industrial Crop and Products* with 9 (1.1%; IF = 5.6; QC = Q1; categories = Agricultural Engineering and Agronomy). In these top five positions, all the journals are in Q2, except *Industrial Crop and Products*, which is in Q1.

Table 5. Journals with at least 5 reports on paulownia research in "Topic" in WoS from 1971 to 2021, advanced materials research and abstracts of papers of the American Chemical Society not calculated.

Publication Titles	Record Count	% of Total No. of Articles	QC	IF (2 Years)
Bioresources	24	2.9	2	1.6
Advanced Materials Research	13	1.6		
PLOS One	13	1.6	2	3.2
Agroforestry Systems	10	1.3	2	2.5
Journalof Wood Science	10	1.3	2	2.2
Industrial Cropsand Products	9	1.1	1	5.6
Forests	8	1	1	2.6
Journalof Natural Products	8	1	1	4.1
Plant Cell Tissueand Organ Culture	8	1	2	2.7
Abstractsof Papers American Chemical Society	7	0.9		
European Journalof Woodand Wood Products	7	0.9	2	2.0
Holzforschung	7	0.9	1	2.4
Mokuzai Gakkaishi	7	0.9	4	0.2
Molecules	7	0.9	2	4.4
American Forests	6	0.7		
Bioresource Technology	6	0.7	1	9.6
Bulgarian Chemical Communications	6	0.7	4	0.2
Cellulose Chemistryand Technology	6	0.7	2	1.5
Phytochemistry	6	0.7	1	4.1
Plant Disease	6	0.7	1	4.4
Planta Medica	6	0.7	2	3.4
Acta Physiologiae Plantarum	5	0.6	2	2.4
Australasian Plant Pathology	5	0.6	3	1.6
Forest Ecologyand Management	5	0.6	1	3.6
Hortscience	5	0.6	2	1.5
International Journalof Molecular Sciences	5	0.6	1	5.9
Journalof Forestry Research	5	0.6	2	2.1
New Forests	5	0.6	1	2.6

Table 5. *Cont.*

Publication Titles	Record Count	% of Total No. of Articles	QC	IF (2 Years)
Physiologia Plantarum	5	0.6	1	4.5
Phytochemistry Letters	5	0.6	3	1.7
Plant Cell Reports	5	0.6	1	4.6
Scientific Reports	5	0.6	1	4.4
Seed Scienceand Technology	5	0.6	3	0.9

3.5. Authors' Co-Authorship Analysis

A total of 2379 authors were involved in publishing 820 publications; of them, 201 met the threshold of 3 publications. The VOS analysis in the field of paulownia brought out 54 clusters with different colors (Figure 4). The largest set of connected items consists of 22 items. The colors of the ten largest clusters were red, green, yellow, blue, orange, light blue, violet, pink, and brown. The size of the circles relates to the total number of records (a larger number of publications, a larger circle). Authors who have studied in a similar field or in a same research group and have closely collaborated with each other are grouped in a single cluster.

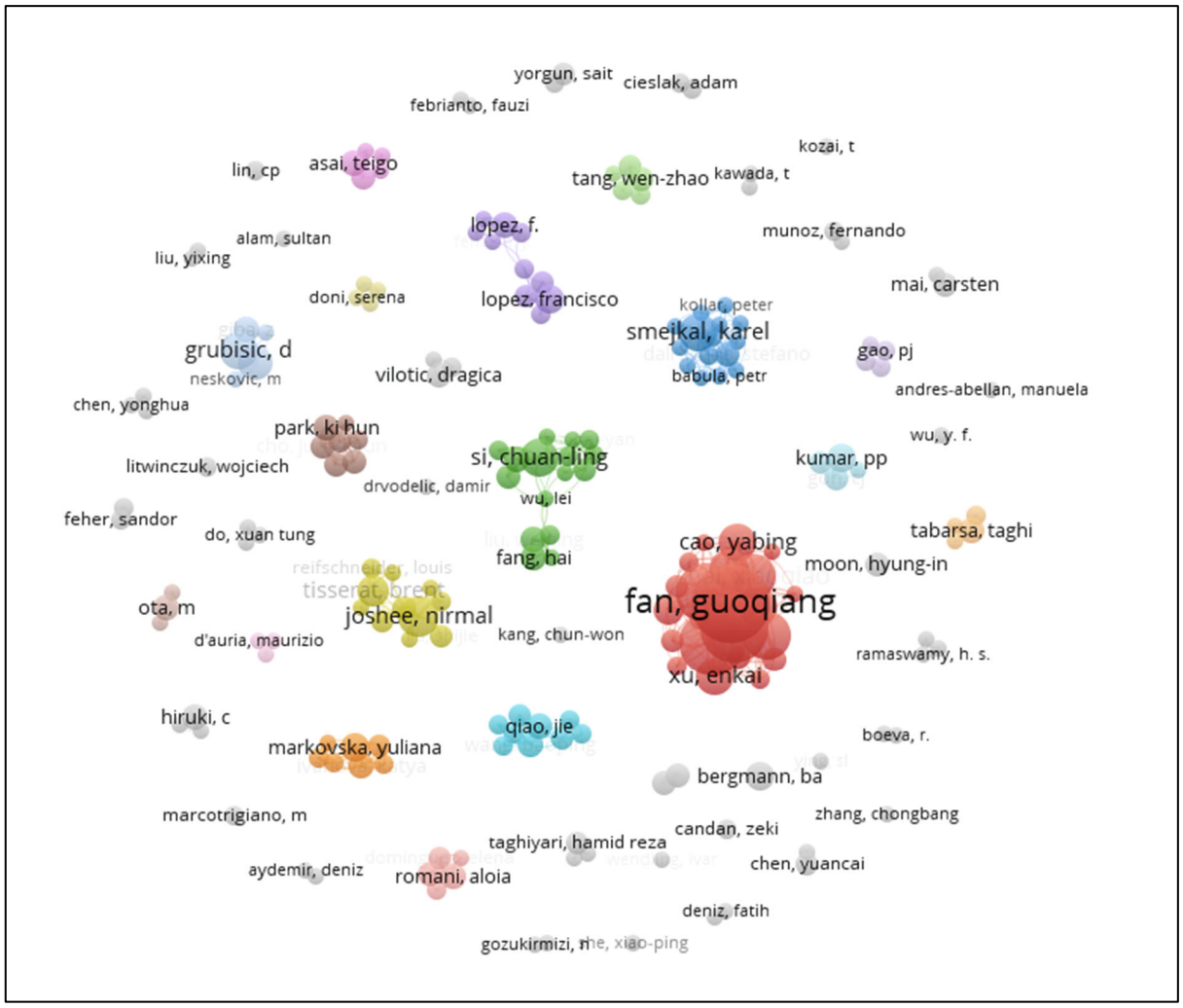

Figure 4. Network visualization maps of authors in paulownia research with 201 items and 54 clusters, shown with different colors.

The top ten authors for publication on *Paulownia* spp. were Fan GQ, Zhao ZL, Deng YP, Niu SY, Zhai XQ, Joshee N, Wang Z, Cao XB, and Smejkal K (Figure 5). There were eight authors from the People's Republic of China, one from the USA and one from the Czech Republic. Regarding the h-index of the authors, the first four ranged between 16 and 18. The following five authors ranged between 9 and 11, while the last one was 14. The ratio of the h-index to the number of articles showed an inverse trend to the number of publications. The lowest value, corresponding to author Fan GQ, was 2.5, while the highest value, corresponding to author Smajkal K, was 7.2.

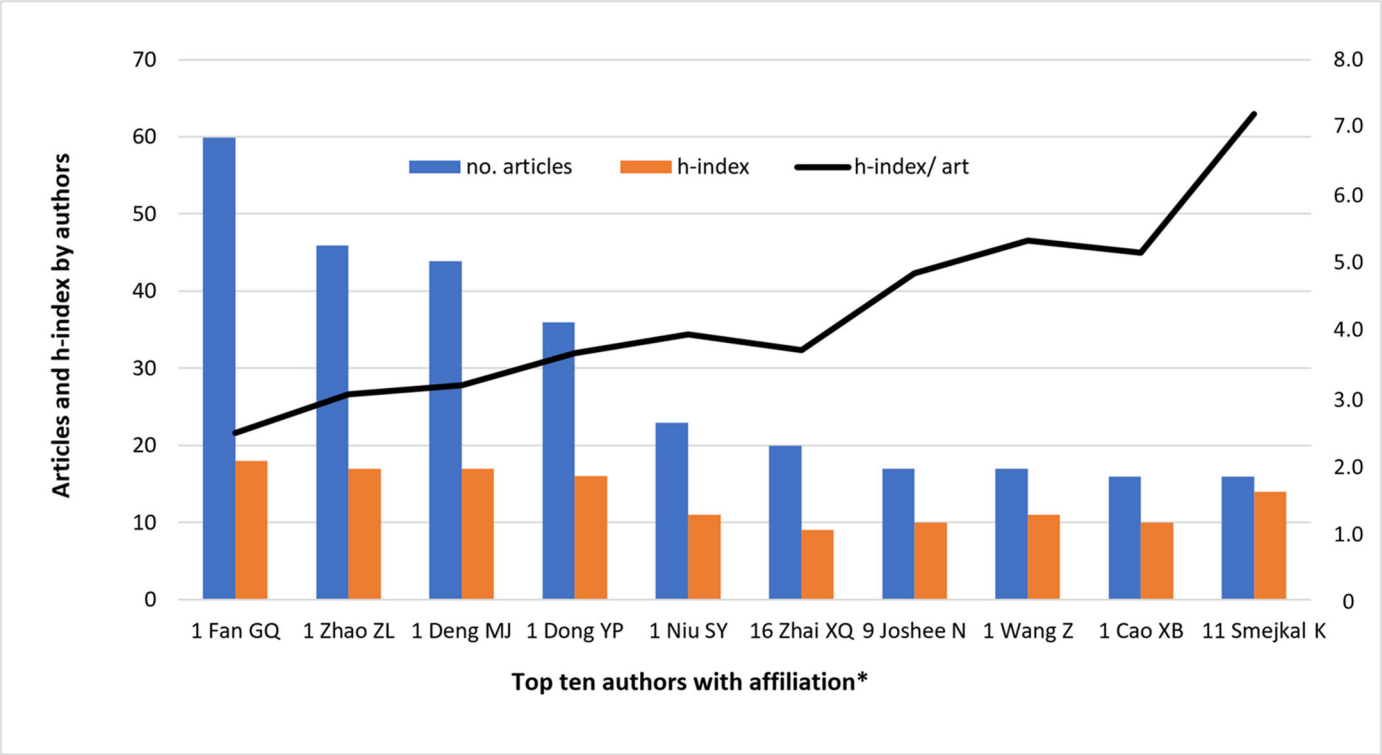

Figure 5. Top ten authors publishing papers in the field of *Paulownia* spp. For each author, the percentage of articles written about paulownia and the h-index was analyzed. The authors' affiliation is indicated with the numbering next to the name referring to Table 6 *.

Table 6. The list of major affiliations of paulownia research, countries of membership, number of papers published, and time cited in WoS.

Affiliations	Papers	Time Cited WoS	No. Citation/No. Articles	Country
1. Henan Agricultural University	71	725	10.2	People's Republic of China
2. U.S. Department of Agriculture- USDA	27	1016	37.6	USA
3. University of Belgrade	25	305	12.2	Serbia
4. Chinese Academy of Sciences	24	635	26.5	People's Republic of China
5. University System of Georgia	24	388	16.2	USA
6. Chinese Academy of Forestry	22	243	11.1	People's Republic of China
7. Universidad de Huelva	19	334	17.6	Spain
8. Consejo Superior de Investig. Cientificas	17	321	18.9	Spain
9. Fort Valley State University	17	222	13.1	USA
10. University of North Carolina	17	275	16.2	USA

Table 6. *Cont.*

Affiliations	Papers	Time Cited WoS	No. Citation/No. Articles	Country
11. University of Veterinary Sciences Brno	17	504	29.7	Czech Republic
12. Bulgarian Academy of Sciences	16	105	6.6	Bulgaria
13. Central South Univ. Forestry Technology	16	85	5.3	People's Republic of China
14. Tianjin University Science Technology	16	188	11.8	People's Republic of China
15. Universidade de Vigo	15	147	9.8	Spain
16. Forestry Acad Henan	14	96	6.9	People's Republic of China
17. Kangwon National University	13	191	14.7	People's Republic of China
18. North Carolina State University	12	233	19.4	USA
19. University of Sofia	12	68	5.7	Bulgaria
20. Gorgan Univ Agr Sci Nat Resources	11	102	9.3	Iran
21. Nanjing Tech University	11	89	8.1	People's Republic of China
22. Istanbul University	10	306	30.6	Turkey
Total	426	6578	337.5	

3.6. Countries/Regions Co-Authorship Analysis

There were 66 regions involved in the publications of *Paulownia* spp., and out of them 39 met the threshold of three publications. The VOS analysis evidenced nine clusters and the largest set of connected items consisted of 38 items (Figure 6). Only Singapore was not connected with the other countries. The colors of the nine clusters are red, green, blue, yellow, violet, light blue, orange, brown, and pink. The red cluster includes Brazil, Chile, England, Kenia, Mexico, North Ireland, Portugal, Spain and Sweden; the green cluster includes Bulgaria, Croatia, Germany, Pakistan, Russia, and Serbia; in the blue cluster there are Egypt, Hungary, Poland, Saudi Arabia, and Slovakia; the yellow cluster includes Australia, Canada, the People's Republic of China, Romania and Turkey; the violet cluster includes Australia, the People's Republic of China and Romania; in the light blue cluster, there were Austria, Belgium, the Czech Republic, and Italy; the orange cluster included Indonesia and South Korea; the brown cluster included Taiwan and the USA. In the last cluster, pink, there was only Singapore. The size of the circle reflects the total number of papers, and the distance between clusters and between countries is representative of the strength of the collaborative relationship.

Among the 18 countries with at least ten publications, the People's Republic of China was in first place with 31.1% publications about paulownia; followed by the USA with 15.3%; Spain with 7.3%; Japan and South Korea with 5.5%; Turkey with 4.8%; Iran with 4%; Bulgaria with 3% which is on a par with the Czech Republic, Poland, and Serbia; Canada and Italy with 2.8%; Germany with 2.7%; Taiwan with 2.2%; Australia with 1.8%; Mexico with 1.5%; and Portugal with 1.3% (Figure 7). The percentage of citations for China and the USA was similar, at around 30. The citations for Spain, Japan, and South Korea ranged from six to eight. Apart from Turkey (12%), all the other countries had less than five citations.

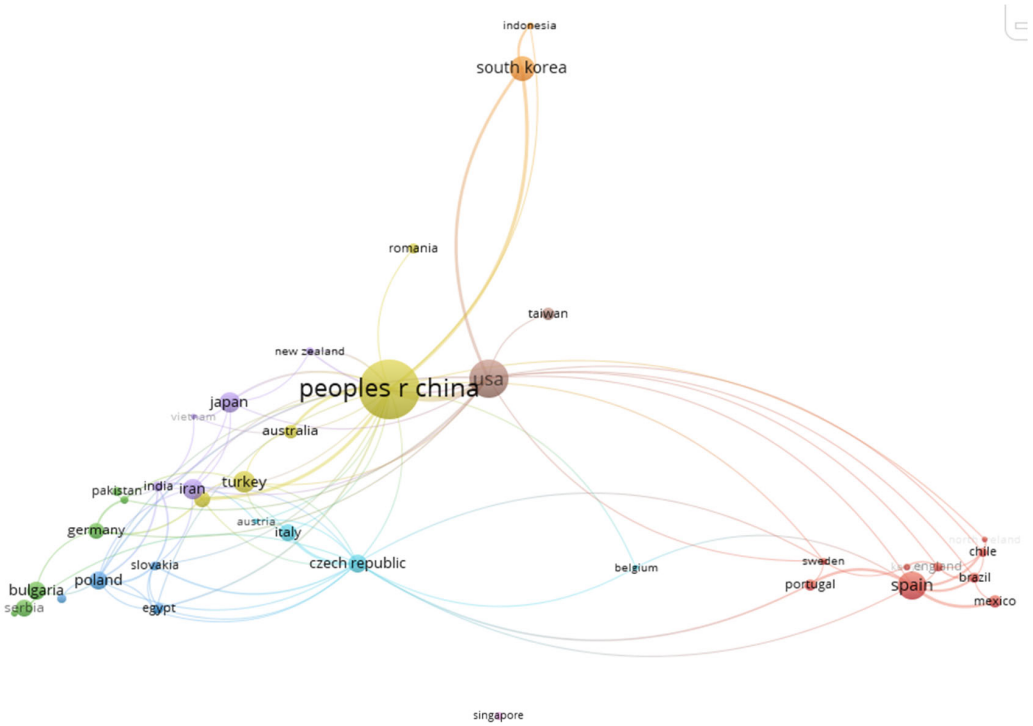

Figure 6. The 66 country-wide co-authorship network of *Paulownia* spp. divided into 10 clusters.

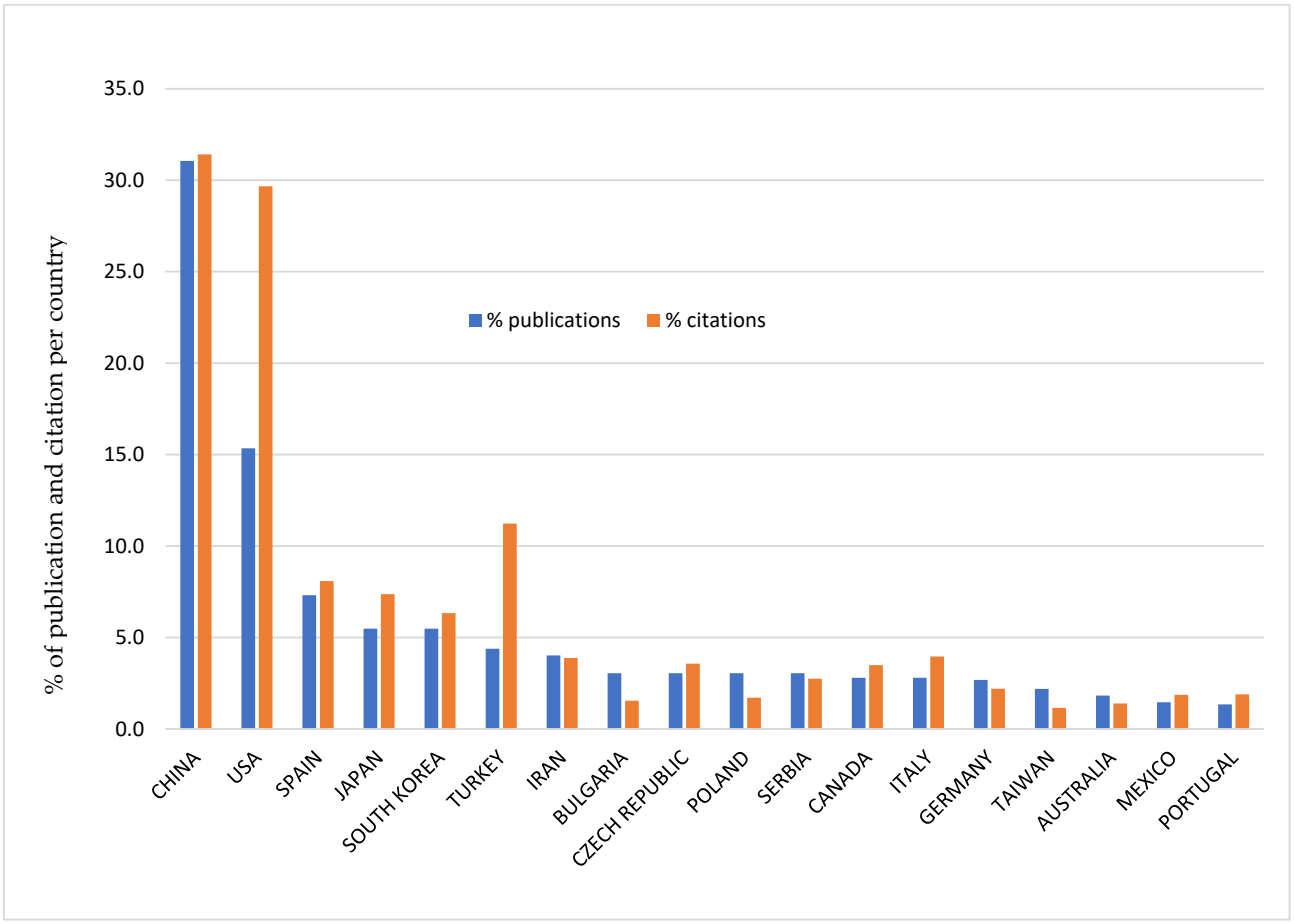

Figure 7. Publication and citation percentages of countries/regions with at least ten publications about paulownia (years 1971 to 2021).

3.7. Affiliations Co-Authorship Analysis

A total of 720 affiliations published 820 publications about paulownia. Table 6 lists the top 22 affiliations with at least 10 papers published.

In the top ten, there are Henan Agricultural University, the United States Department of Agriculture (USDA), University of Belgrade, Chinese Academy of Sciences, University System of Georgia, Chinese Academy of Forestry, Universidad de Huelva, Consejo Superior de Investigaciones Cientificas (CSIC), Fort Valley State University, and University of North Carolina. These institutions comprise four in the USA, three in the People's Republic of China, and three in Spain. For the average citations per paper, in the first position is the United States Department of Agriculture (USDA) in the USA, in the second position is the Istanbul University in Turkey, and in third position is the University of Veterinary Sciences Brno in the Czech Republic.

Figure 8 reports the VOSviewer analysis of the co-authorship affiliation correlation.

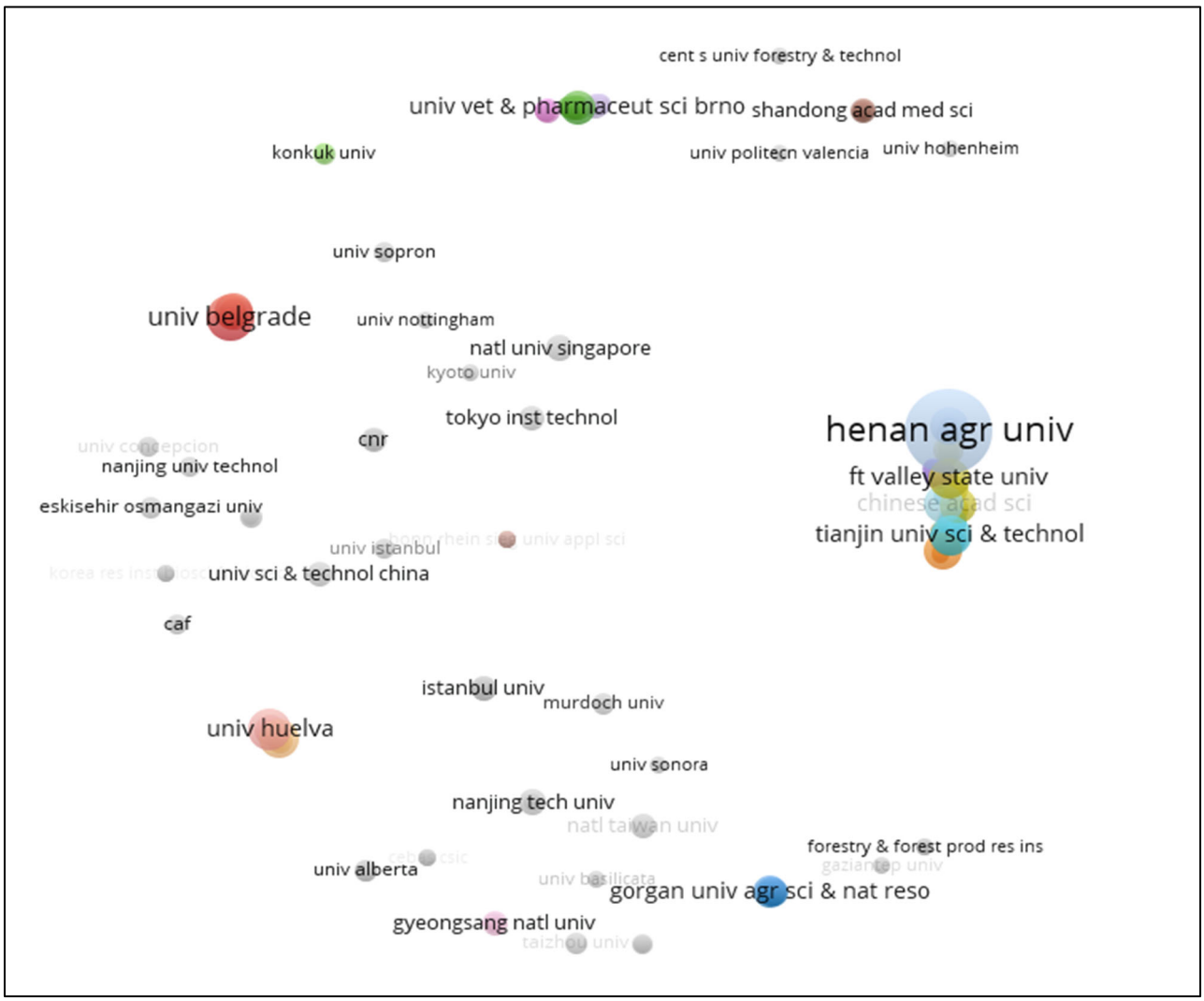

Figure 8. The affiliations co-authorship network of paulownia research. The VOSviewer software divided these 670 institutes into 47 clusters with different colors.

Among the affiliations involved in the publications of 820 papers on paulownia, 134 met the threshold of at least three publications. There were 47 clusters gathered, the largest with nine items and the smallest with only one item: the largest set of connected items consisted of 38 affiliations.

3.8. All Keywords Co-Occurrence Analysis

In the 820 papers about paulownia, 3842 keywords were highlighted. Of these, only 493 met the threshold of more than three occurrences and were divided into nine clusters: red, yellow, violet, blue, light blue, orange, brown, pink, and green (Figure 9).

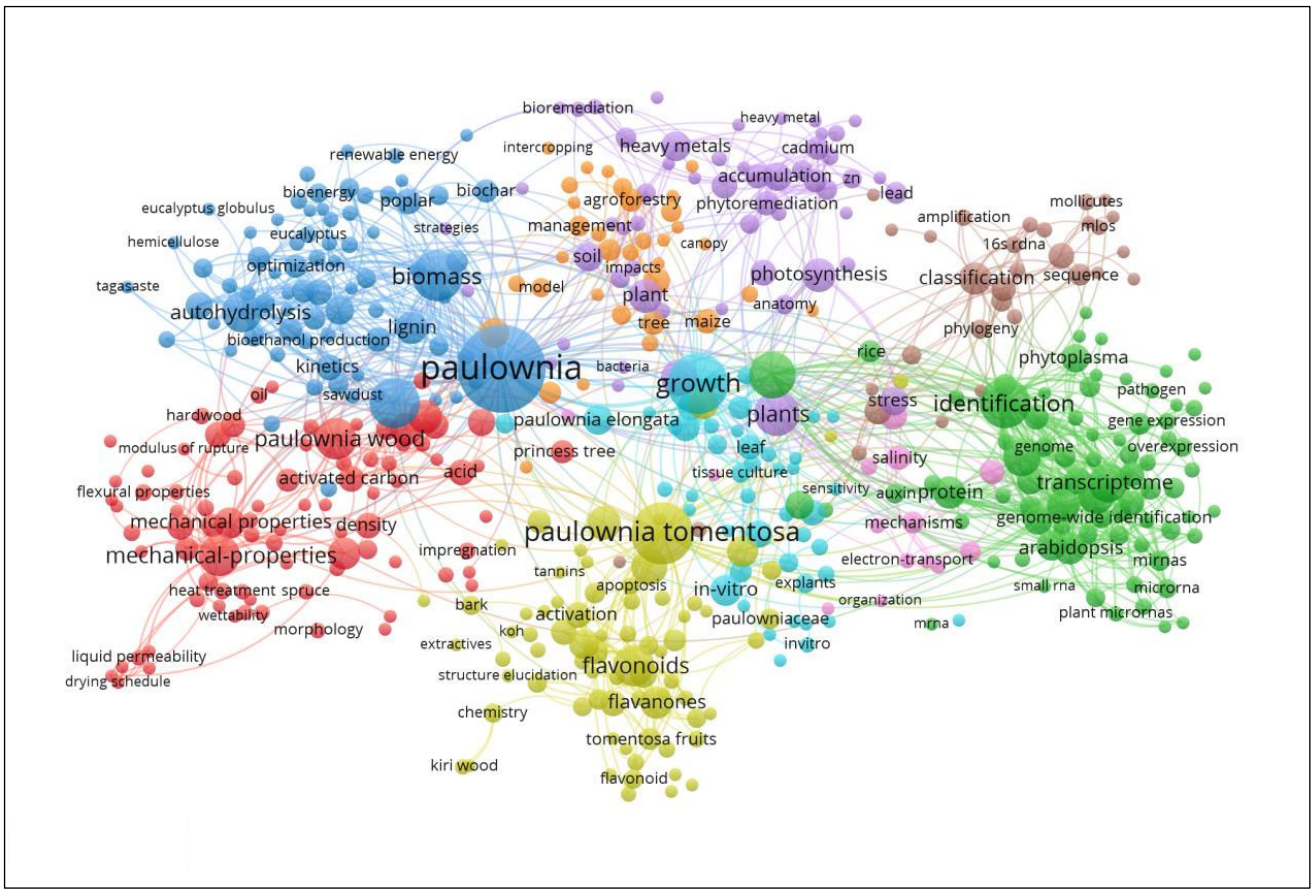

Figure 9. VOSviewer co-occurrence network visualization mapping of the most frequent keywords in paulownia research. The VOSviewer software divided these 3842 keywords into 9 clusters with different colors.

The principal keywords for the red cluster were paulownia wood, mechanical properties, and temperature, for the yellow cluster the keywords were *Paulownia tomentosa*, flavanones, flavonoids, and leaves, for the blue cluster the keywords were paulownia, wood, biomass, and autohydrolysis, for the violet cluster the keywords were plant, photosynthesis, accumulation, and heavy metals, for the light blue cluster the keywords were growth, *Paulownia elongata*, micropropagation and in vitro, for the green cluster the keywords were identification, transcriptome, gene-expression, and protein, for the pink cluster the keywords were salt stress, responses, and salinity, for the orange cluster the keywords were agroforestry, yield, and water, and for the brown cluster the keywords were classification, sequence, disease, and polymerase chain reaction.

In Figure 10, the same keywords are reported as in Figure 9 according to the paulownia research period (2005–2021). As the legend explains, the blue/purple colors indicate earlier research topics, while the yellow and green colors indicate the latest topics.

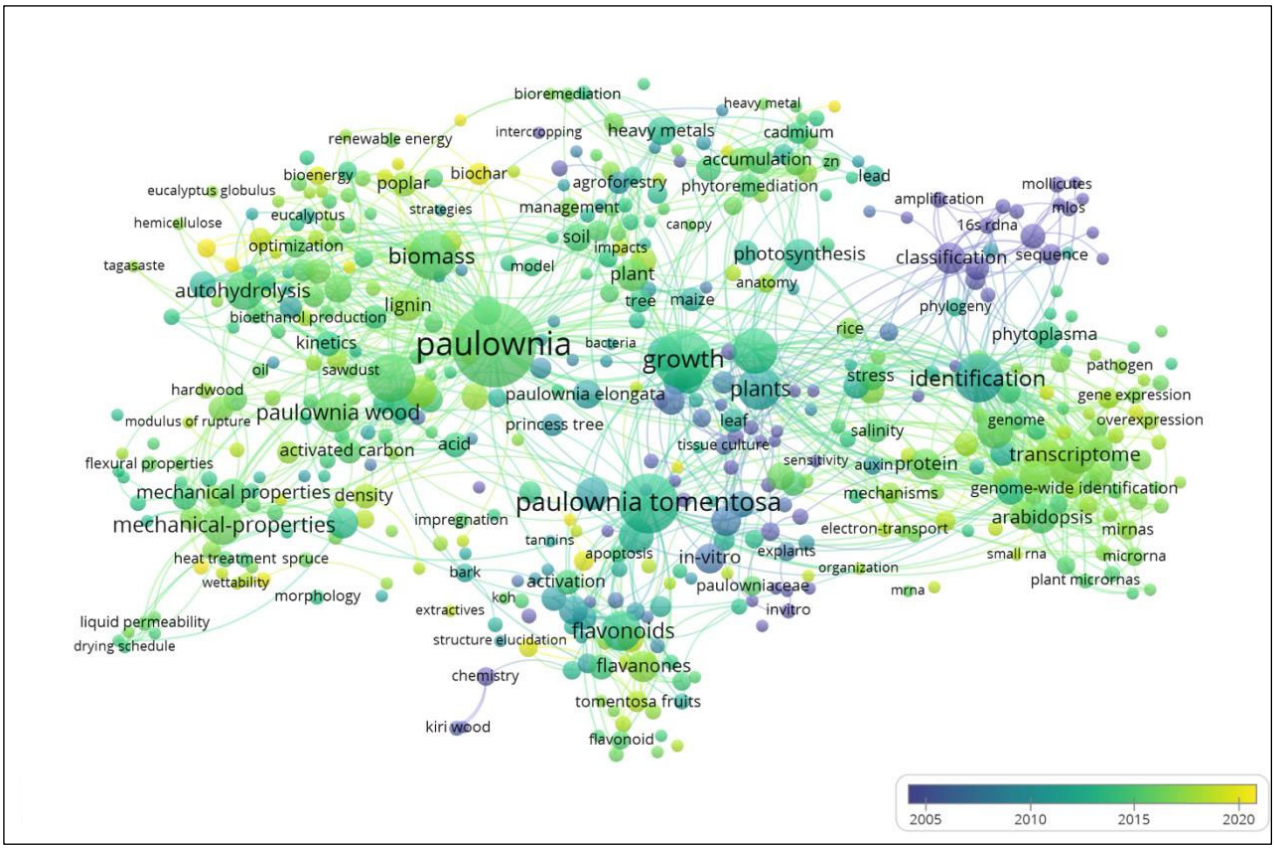

Figure 10. VOSviewer co-occurrence network visualization mapping of most frequent keywords in paulownia research represented according to paulownia research period (2005–2021).

4. Discussion

The bibliometric analysis on *Paulownia* ssp. carried out in the refined research of Web of Science showed interest in this species since the 1970s. The most studied species was *Paulownia tomentosa* with 336 articles out of 820, where this tree was the exclusive species considered; meanwhile, in 426 articles, *P. tomentosa* was studied together with one or more other *Paulownia* spp. This is probably because it was the first imported species, hence it is the most widespread and the most used in wood exploitation.

The interest in paulownia has increased in the last twenty years because people have begun to realize the great potential of this plant, first used for ornamental purposes, then for reforestation thanks to its vigor and rapid growth, for phytoremediation in the case of contaminated soils, and for multiple uses of its wood.

Regarding phytoremediation, *Paulownia tomentosa* produces good results in soils with Cd, Cu, Pb, and Zn [50–52]. It has also been tested by adding EDTA and/or tartrate and glutamate to check the effect of heavy metals on plant uptake and to verify possible signs of phytotoxicity [53]. *Paulownia fortunei*, on the other hand, has been used in contaminated sites with organic waste to dispose of waste, improve the soil quality [54,55], and achieve biomass gasification from contaminated soil with trace elements [34]. A study by Macci et al. [56] compared the decontaminating capacity of paulownia, poplar, and *Cytisus scoparius* in soil with spontaneous vegetation. In the study, horse manure that had heavy metals, hydrocarbons, and polychlorobiphenyls in it was added to the soil. After two years, the soil was reclaimed by the pollutants. Poplar demonstrated a greater capacity to remove organic compounds, while paulownia proved a better capacity to remove heavy metals. *Cytisus scoparius* was the least effective plant in decontamination.

In wood exploitation, the growing interest in paulownia has led to the development of numerous lumber companies all the world. In Europe, in the year 2000 [24], a significant interest in the cultivation of this plant grew. However, at the beginning, production differed

from the expected, probably due to the unsuitable territory where the plant had been cultivated or the inappropriate genetic material used. Subsequently, to obtain a better product according to the characteristics of the territory and its needs, better plants started to be selected and crossed until the desired clone was obtained. In recent years, many paulownia hybrids have been bred, e.g., Paulownia 9501, Paulownia 9503, and Paulownia 'Shan Tong' (*P. tomentosa x P. fortunei*) known in German as 'Nordmax 21' and 'Royal Treeme', which can provide up to 30% more wood volume than *P. elongate* [57].

The categories and research areas in which articles on paulownia has been most published are agriculture, forestry, environmental science, and materials science. The number of categories and research areas is higher than the total number of articles because every paper may belong to more than one category or area (Tables 2 and 3). Journals and books covered by the Web of Science Core Collection are assigned to at least one WoS category. Each WoS category is mapped in at least one research area. The journals or papers may be classified into two or more categories in the WoS, showing the multidisciplinary character of this research field [58]. In WoS, publications are also mapped to WoS categories which are in more detail than research areas [59].

On average, each article is presented in two or three categories and sometimes, it is presented in four. There are four exceptions, four articles that were present in five different categories: the study of Lee et al. [60] is present in the categories Archaeology; Art; Chemistry, Applied; Chemistry, Analytical; Spectroscopy; the study of Bajaj et al. [61] is present in the categories Biochemical Research Methods; Biochemistry & Molecular Biology; Biotechnology & Applied Microbiology; Green & Sustainable Science & Technology; Energy & Fuels categories; the study of Swiechowski et al. [29] is present in the categories Chemistry, Physical; Materials Science, Multidisciplinary; Metallurgy & Metallurgical Engineering; Physics, Applied; Physics, Condensed Matter categories; and the study of Chen and Sun [62] is present in the categories Computer Science, Interdisciplinary Applications; Environmental Sciences; Geography, Physical; Remote Sensing; Telecommunications categories.

Most of the articles were published in English because this made the papers more widely accepted [63]. Also, White-Gibson et al. [64] reported the importance of writing in the English language to allow studies to be more widely distributed and to be published in a journal with a high impact factor.

The paulownia plant is native to China and the most significant number of publications and affiliations interested in this species were in that territory. In the People's Republic of China, a paulownia group belongs to the Research Institute of Forestry. This institute has been engaged in paulownia research since the 1960s. There are 15 research fields: taxonomy, ecology, phenology, wood properties, wood use, resistance, selection, hybridization, induction, tissue culture, propagation, agroforestry model, afforestation, pests, and disease. Their publications are especially in the areas of cultivation, agroforestry and genetic improvement [65]. In the People's Republic of China, there is also the Weinan Research and Promotion Center for High Resistance Paulownia, a professional institution engaged in research into and cultivation of paulownia. This is a specialized team that deals with cultivation research and fine variety promotion for key scientific accomplishments on paulownia at the urban level [66].

Figure 5 shows an inverse correspondence between the number of publications, the relative h-indexes of the top 10 authors and the ratio between the two values. While the trend of publications and h-indexes decreases, the line indicating the ratio increases steadily.

Most authors who have published articles about paulownia, belong to the People's Republic of China. In addition, there is a wide exchange of collaborative groups among countries all over the world, except for Singapore (Figure 6). In Singapore, only one institution deals with paulownia that works independently. The published articles of this country were all by the same group of authors and were on the same topic, i.e., in vitro culture.

In the USA, two important research groups study paulownia. One of these is the American Paulownia Association, established in 1991 and formed by the collaboration between the University of Tennessee and the University of Kentucky. The association promotes paulownia as a forest/agricultural crop in the United States [67]. Another institute that deals with paulownia is the World Paulownia Institute, in Georgia (USA), entitled "world leaders in Paulownia plantations". They are the largest commercial supplier of paulownia plants, seedlings, liners, or saplings [68].

Figure 7 shows the dominance of China in terms of publications. Despite having ca. half of the publications, the USA has a citation value very similar to that of China. The other countries show much lower publication and citation trends (between a quarter and a tenth of China's). However, they are similar with a marked difference in Turkey, with a citation value of 2.5 times its publications. Looking at the EU countries (Spain, Bulgaria, the Czech Republic, Poland, Italy, Germany, and Portugal), publications and citations are 23.3 and 23.0, respectively. With these values, the EU ranks second in publications and third in citations.

Regarding the keywords, it is possible to see the evolution of the field of interest of paulownia. Comparing Figures 9 and 10, it is evident that the brown and the light blue clusters were the oldest and were searched before all the other keywords. The keywords in the blue and green clusters were the most recent, while those in the yellow, orange and purple clusters were analyzed between 2010 and 2012, and those in the green and red clusters between 2015 and 2018. From the keywords, it is possible to deduce that the first study on paulownia was completed in the molecular field to analyze and classify this plant into different species. After traditional studies in the chemical field, the study of its physiology, wood, and timber and its properties, the most recent works are related to the bioenergy field (biomasses, biochar, biofuel) because of the increasing new interest in green energy. Furthermore, in recent years, the molecular field (genomics, transcriptomics, proteomics, and metabolomics) has also shown constant growth thanks to the extraordinary recent development of advanced molecular technologies and instrumentations.

5. Conclusions

This is the first study to provide a bibliometric analysis of global research trends in *Paulownia* spp. studies during the years 1971–2021. The most important conclusions of this study are:

1. A total of 820 scientific documents in the field of *Paulownia* spp. covering all the scientific fields and disciplines were retrieved from 1971 to 2021. The temporal trend analysis did exhibit a limited and fairly constant production until 2004, with several publications almost always under 10 per year, while in 2008, a peak was recorded with 28 articles. After this year, with a few minor exceptions, annual article publications increased steadily and considerably until 2020, with over 60 articles.
2. The main *Paulownia* species studied in this article were, in descending order, *P. tomentosa* (52%), *P. fortunei* (24%), and *P. elongata* (16%).
3. The principal WoS categories were Plant Sciences; Forestry, Materials Science, Paper and Wood; and Environmental Sciences, which cover more than 55% of the articles. However, four more innovative categories, Biochemistry Molecular Biology, Biotechnology Applied Microbiology, Chemistry and Chemistry Medicinal, were over 5% of the total articles., With their different approaches, the research areas somehow show results comparable to the WoS categories.
4. The People's Republic of China, with its institutions, was the predominant country in publishing those documents, followed by the USA, Spain, Japan, and South Korea. The 66 countries co-authorship network of *Paulownia* spp. was divided into 10 clusters, with these five countries acting as leaders of the main clusters.
5. There were no preferred articles for a few specific journals. The articles were published in 460 journals, given the broad range of applications and interests of *Paulownia* spp.

The leading nine journals with at least 1% of the publications were reaching less than 15% of the total publications.

6. The first ten authors in terms of articles were almost all from institutions in the People's Republic of China, except for no. 7, from the USA, and no. 10 from the Czech Republic.
7. Among the 22 most productive research institutions with over 10 papers, 8 are from the People's Republic of China, 5 from the USA, 3 from Spain, 2 from Bulgaria, and only 1 from Serbia, the Czech Republic, Turkey, and Iran. That is coherent with the author and country rankings.
8. As expected, keyword analyses show that the most recent sectors of study concern both emerging technologies, such as genomics, and economically strategic sectors, such as renewable energy and biochar. Meanwhile, the older ones concerned, for example, classification, chemistry, and timber.

Thanks to the VOSviewer software, it is possible to see from the first to the last field of research, to understand the trend of interest over the years, and possible developments in the future.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/horticulturae9121352/s1, Table S1. Records of Paulownia.

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