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Review

Scientometric Analysis on Rice Research under Drought, Waterlogging or Abrupt Drought-Flood Alternation Stress

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Abstract: Many studies have shown that abiotic stresses could severely impact crop growth and yield, but a comprehensive review from a bibliometric perspective is lacking. This study explores how the research direction of rice under drought, waterlogging or both stresses has evolved over the past three decades, based on bibliometric analysis using Vosviewer 1.6.15 and HistCite Pro. Data were collected from the academic database of Web of Science. The results showed that 12 journals had a high number of publications and highly local citations. Meanwhile, the three journals of *Field Crops Research*, *Journal of Experimental Botany* and *Plant Physiology* could be the most influential leaders in this field. The author Arvind Kumar had the highest contribution to the output of articles, and Lizhong Xiong had a greater impact on the field. China, and Chinese institutions, were dominant in terms of the number of articles, but Japan, Germany, UK and institutions in USA and Japan had a higher quality of publications on average. Scholars are concerned with using transgenic methods for improving rice productivity with increasing abiotic stress tolerance; the research topics of rice cultivars, irrigation, water-use efficiency and soil fertility may be gradually shifting from a single theme to intertwining with the themes of genomics and abiotic/biotic resistance with climate change in the future.

Keywords: rice; bibliometric; drought stress; waterlogging stress; citations

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1. Introduction

More than half of the world's population relies on rice as its staple food [1]. As one of the most critical food crops, it is necessary to ensure an increase of the rice yield. Drought or waterlogging stress could generate adverse effects on yield and the quality of crops [2,3]; however, considerable drought stress is favorable for crop developing and limiting nitrogen losses, which could significantly impact the grain yield and improve nitrogen uptake [4]. On the one hand, scholars have been concerned about the effects of water stress on crops. Water stress could increase canopy photosynthesis and antioxidant metabolite activities in rice [5,6], with a shortening crop growth period [6]. Drought stress also alters the leaf phenotypic traits based on chlorophyll fluorescence parameters [7]. Moreover, studies have shown that root system development and lodging-resistance capability can be induced by drought stress [8–11]; it is better to remobilize carbon stores from the shoot to grain, resulting in the improvement of the absorption capacity of moisture and nutrition [8,11] and ultimately enhancing grain yields [10,12]. On the other hand, flooding stress affects crops in a way that cannot be ignored over the years. There is enhanced oxygen and carbon dioxide into acclimated leaves, so new aquatic-type leaves are formed with improving photosynthesis in water under extended-duration flooding [13]. However, flooding can increase heavy metal accumulation in roots and grains [14]. Rice roots endure anoxic stress with vitality decreasing; additionally, their abilities are reduced in regard to absorbing nutrients, and water decreases due to the tissue damage by peroxidation [15,16]. Waterlogging stress eventually reduces the effective panicle number, resulting in decreased yield [17]. Furthermore, drought and flood stress have a trend of deterioration resulting from the global climate, which is continuing to intensify and change irregularly. Extreme weather is becoming more frequent, with worsening drought or waterlogging disasters such as heavy drought or extraordinary rainstorms [18]; especially drought immediately followed by flood disasters, which are considered "abrupt drought–flood alternation" events [19,20]. Production loss has increased after abrupt drought–flood stress [20,21]; after a long flooding period to drainage, soil may be polluted because of the potential presence of toxic concentrations for a period of time after rice harvest [22]. In order to reduce negative influences on yield under drought, flooding or abrupt drought–flood alternation, control measures are used, such as gene regulation, which has made a great contribution to yield and quality [20,23–25], especially drought/salt/cold/lodging resistance cultivars and techniques [26–28].

Accordingly, the works of literature related to rice research are increasing year by year, so it is necessary to analyze rice literature to obtain the trends of research topics. Bibliometric methods can objectively and quantitatively interpret the research topics in a certain research field and can be used to predict future trends [29]. At present, they have been widely used in various research fields, with many analyses relating to the number of articles and keywords. For example, they have been used to conduct a bibliometric assessment of the number of documents, journals and keywords on the cluster of wheat and barley through the Scopus database [30]. Bibliometric analysis of remote sensing research uncovered the relationship between high-frequency keywords and emerging hot topics [31], and the publication distribution from journals, countries and institutions, as well as keywords regarding deoxyribonucleic acid (DNA) damage repair in the plants system, has also been analyzed. [32]. Meanwhile, bibliometric methods also were applied to soil nutrients [33], hydrology journals [34], global urbanization [35], carbon emissions [36] and glyphosate toxicology [37]. It implies that expanding analysis areas have overwhelmingly started using bibliometric methods, which has become increasingly popular in analyzing the number of papers, keywords and citations. In addition, there were relatively metrological analyses in rice research fields such as rice research and technological development [38], trends of plant research through molecular markers [39], the relationship between research priorities of rice and demands [40] and rice husks gasification [41]. These studies have revealed the rice research topics and could provide relatively useful information for the latter research in the rice field. However, there is still a blank regarding the bibliometric analysis of rice research under drought, flooding or both stresses. The purpose of this paper is to review this field using the bibliometric methods, which will provide overall information on the research topics and tendencies, and thus give cooperation strategies for the novice and experienced scholars.

2. Material and Methods

2.1. Data Source

The data were searched from the Science Citation Index Expanded (SCI-EXPANDED, since 1992) and the Social Sciences Citation Index (SSCI, since 2004) of the Web of Science Core Collection (WoSCC). Web of Science is a high-quality database that favorable to bibliometric analysis due to its covering period, data coverage and friendly interface [42]. In this research—encompassing documents published between the beginning on 1 January 1992 and the ending on 31 December 2021—the search was based on the title, abstract, author keywords and keywords plus of the documents. The advanced search mode was adopted: TS = ("drought" OR "drought stress" OR "water stress" OR "drought disaster" OR "waterlog*" OR "waterlogging stress" OR "waterlogging disaster" OR "drought–flood abrupt alternation" OR "sudden turn of drought and flood" OR "occurrence of droughts and floods" OR "sudden changing from drought to waterlogging") and TS = ("paddy" OR "paddies" OR "rice" OR "oryza"). Document types include "articles", "review articles", "book chapters", "notes", "letters", "data papers" or "book reviews". Publications with text files were exported, which then returned 8287 publications. Because the data are continually updated in Web of Science, the results may be different; however, any differences are likely to be small for analyses calculated over similar time windows [34].

2.2. Analysis Software

The software of VOSviewer 1.6.15 was developed by Nees Jan van Eck and Ludo Waltman from Leiden University (https://www.vosviewer.com/).VOSviewer and HistCite have been used for bibliometric analysis in a specific area. VOSviewer has been used for constructing large bibliometric maps. In our study, authors, organizations, countries and keywords were assigned by a clustering technique using VOSviewer, with the clustering giving a straightforward interpretation for these subjects [43]. The co-authorship of authors, organizations and countries, and the cluster density of keywords, were analyzed in this study by the VOSviewer, which is used to obtain an overview of the items' assignment and the general structure while showing the most critical areas in a map or table. This paper used the counting method by the default way of the VOSviewer. Histcite is a software system which generates chronological maps of bibliographic collections resulting from journal and institution searches from the Web of Science, and generates chronological historiography, highlighting the most-cited works in the retrieved collection [43,44]. However, there is no updated version of the official supporting HistCite, and HistCite Pro is a modified version based on HistCite. It could be used for classing the leading categories and journals depending on the number of publications and local/global citations [33]. In addition, figures were also produced in this study by Origin 2021 and Arc GIS 10.8. Excel 2019 was used for data analysis.

2.3. Assessment Criteria

In this research, as mentioned above, 8287 articles were obtained from WoSCC. When these papers were imported into HistCite Pro, 8228 publications were returned from this software. There were analysis of 8228 records in regard to their specific characteristics. The scientometric criteria indicators from VOSviewer and HistCite Pro, and consideration of analysis content in this study are: publication year, contributed categories and journals, contributed authors/institutions/countries, highly-cited publications and keywords. The evaluation parameters of bibliometric analysis in this paper include: (1) total number of publications (TN), the higher the total representing the greater the contribution to productivity from a research unit (e.g., an author, a research group, an institution, a country or a journal) [45] in the field of rice research under drought, flooding or abrupt drought–flood alternation stress; (2) total global citations (TGC), indicating the total of all citations in the global context based on WoSCC, which will indicate greater influence if the TGC has higher value [46]; (3) total local citations (TLC), which represents the total number of citations of a publication cited by other papers—in our case, of 8228 publications—meaning the TLC of a research unit is defined as the number of citations of all publications in the same research field [43], and the higher the TLC the more of an accurate impact on this field it has. The higher the TLC of a paper, the greater the possibility of it being a pioneering work [47]; (4) citations (total global citations) per paper (TGC/TN), representing the average quality articles of a research unit [48]; and (5) local citation score (LCSe), indicating the local citation score in the end, which could uncover trending publications and predict topics in the future based on these trending publications [49].

3. Results and Discussion

3.1. Analysis of Annual Publication Trend

A total of 8228 publications were analyzed over the years (Figure 1). The number of publications shows an increasing trend from 1992 to 2021, with a slight fluctuation, from 19 publications in 1992 to 932 in 2021. Especially after 2011, it increased rapidly and has reached higher values in the last two years. A rising number of papers is expected shortly.

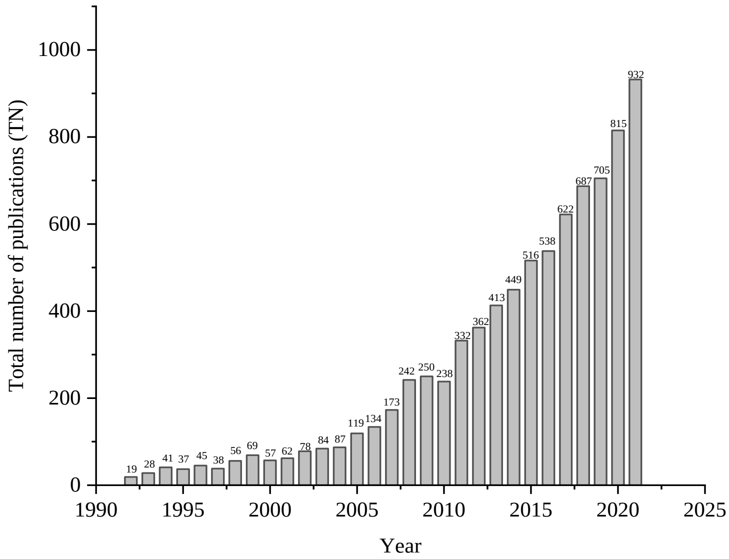

Figure 1. Annual publications in the field of rice research under drought, waterlogging or abrupt drought–flood alternation stress from 1992 to 2021.

3.2. Analysis of Main Categories and Journals

Categories' analysis of classified papers were published on the topics of rice research in a state of drought, waterlogging or abrupt drought–flood alternation stress depending on their specific attributes from the WoSCC database. There are 121 categories in the documents.

Table 1 shows the top 10 productive subject categories; the top three are plant sciences (3859 publications), agronomy (1607 publications) and biochemistry molecular biology (1005 publications), accounting for 46.6%, 19.4% and 12.1%, respectively. It is noted that there is a big gap in the number of publications between plant sciences and the others. There is a small gap between genetics heredity (688 publications), environmental sciences (678 publications), biotechnology applied microbiology (546 publications) and multidisciplinary sciences (503 publications). This is followed by agriculture multidisciplinary (406 publications), soil science (311 publications) and horticulture (292 publications), which each only occupy about 4–8%.

Table 1. Top 10 productive categories in the field of rice research under drought, waterlogging or abrupt drought–flood alternation stress from 1992 to 2021.

Rank	Categories	TN	TN(%)
1	Plant Sciences	3859	46.6
2	Agronomy	1607	19.4
3	Biochemistry Molecular Biology	1005	12.1
4	Genetics Heredity	688	8.3
5	Environmental Sciences	678	8.2
6	Biotechnology Applied Microbiology	546	6.6
7	Multidisciplinary Sciences	503	6.1
8	Agriculture Multidisciplinary	406	4.9
9	Soil Science	311	3.8
10	Horticulture	292	3.5

A total of 914 journals appeared in the documents. *Frontiers in Plant Science* (322 publications) obtained the top contribution to the number of publications. This was followed by *Field Crops Research* (241 publications), *PLoS One* (207 publications), *Journal of Experimental Botany* (170 publications), *International Journal of Molecular Sciences* (159 publications), *Plant Physiology and Biochemistry* (154 publications), *Plant Science* (152 publications), *Scientific*

Reports (144 publications), *Plant Molecular Biology* (114 publications) and *BMC Plant Biology* (108 publications) in Table 2. The ten journals occupy for 21.4% of the total number of publications (data not shown).

Table 2. Top 10 journals of total number of publications (TN), total local citations (TLC), total global citations (TGC) and citations per article (TGC/TN) in the field of rice research under drought, waterlogging or abrupt drought–flood alternation stress from 1992 to 2021.

Journals	Label	NO. (TN)	NO. (TLC)	TGC	NO. (TGC/TN)
Frontiers in Plant Science	FPC	1(322)	/(2)	10,168	/(31.6)
Field Crops Research	FCR	2(241)	1(4121)	12,438	/(51.6)
PLoS One	PO	3(207)	/(31)	7014	/(33.9)
Journal of Experimental Botany	JEB	4(170)	2(2959)	16,697	5(98.2)
International Journal of Molecular Sciences	IJMC	5(159)	/(97)	2515	/(15.8)
Plant Physiology and Biochemistry	PPB	6(154)	/(410)	3500	/(22.7)
Plant Science	PS	7(152)	7(1201)	7727	/(50.8)
Scientific Reports	SR	8(144)	/(0)	3627	/(25.2)
Plant Molecular Biology	PMB	9(114)	5(2014)	8033	10(70.5)
BMC Plant Biology	BPB	10(108)	/(0)	3432	/(31.8)
Plant Physiology	PP	/(97)	3(2917)	11,770	3(121.3)
Planta	Pla	/(92)	12(809)	3968	/(43.1)
Theoretical and Applied Genetics	TAG	/(85)	4(2180)	6415	9(75.5)
Plant and Cell Physiology	PCP	/(68)	11(849)	4351	/(64)
Crop Science	CS	/(66)	9(930)	2471	/(37.4)
Plant Biotechnology Journal	PBJ	/(62)	10(854)	3957	/(63.8)
Plant Journal	PJ	/(55)	6(1307)	5841	4(106.2)
Annals of Botany	AB	/(32)	/(354)	2853	6(89.2)
PNASUSA	PNA	/(24)	8(1051)	6522	1(271.8)
Proteomics	Pro	/(22)	/(293)	1916	8(87.1)
Plant Cell	PCe	/(20)	/(549)	3771	2(188.6)
Molecular Plant	MP	/(20)	/(350)	1751	7(87.6)

Note: The numbers in parentheses represent the total number of publications (TN), total local citations (TLC) and citations per article (TGC/TN); the numbers outside the parentheses represent the respective rankings, and slash (/) represents no ranking. PNASUSA: Proceedings of the Nation Academy of Sciences of the United States of America.

The journal of *Field Crops Research* is ranked first by total local citations (TLC), with 4121 beyond other journals (Table 2). There is no significant difference between the *Journal of Experimental Botany* (2959 TLC) and *Plant Physiology* (2917 TLC). In addition, the three journals have higher values concerning total global citations (TGC). It indicates that these journals could become the most influential leaders in this field of rice research under drought, waterlogging or abrupt drought–flood alternation stress. However, the journal of *Field Crops Research* has lower citations per article (51.6 TGC/TN), which means that the average quality of papers might need to be improved. The journals of *Plant Physiology* and *Journals of Experimental Botany* have a higher TGC/TN, with 121.3 ranked 3rd and 98.2 ranked 5th, respectively. It is noteworthy that these journals, including *PNASUSA* with 271.8 TGC/TN ranked 1st, *Plant Cell* with 188.6 TGC/TN ranked 2nd and *Plant Journal* with 106.2 TGC/TN ranked 4th, acquire a higher quality of publications on average, but only with fewer publications. These are followed by the *Annals of Botany* (89.2 TGC/TN), *Molecular Plant* (87.6 TGC/TN), *Proteomics* (87.1 TGC/TN), *Theoretical and Applied Genetics* (75.5 TGC/TN), and *Plant Molecular Biology* (70.5 TGC/TN), which rank from 6th to 10th.

To further investigate journals regarding relationships between output and total local citations, the total number of papers is considered as a proxy for output and the total local citations is counted as the effect of the field of rice research in a state of drought, waterlogging or abrupt drought–flood alternation stress. Figure 2 shows a two-by-two matrix, with the *X*-axis representing the total local citations and the *Y*-axis representing the total number of articles. The mean values (TN = 62; TLC = 386) of the two variables were calculated by the number of 20 as the threshold, depending on publications in 914 journals. Journals that met this threshold could be divided into four main groups: quadrant A, representing high production and high impact; quadrant B, representing low production and high impact; quadrant C, representing low production and low impact; and quadrant D, representing high production and low impact. A total of 87 journals met the requirements: 16 journals are in quadrant A, which means higher than average output and influence. From the 70 journals located in quadrants B, C and D, these journals are below the average production, with a TN of 62 and/or less than the average effect with a TLC of 386. One journal is located on the *X*-axis, meaning an equal to average output. A total of 22 of the journals are above the average impact, according to their locations in quadrants A and B, and 33 journals are above the average production, depending on quadrants A and D.

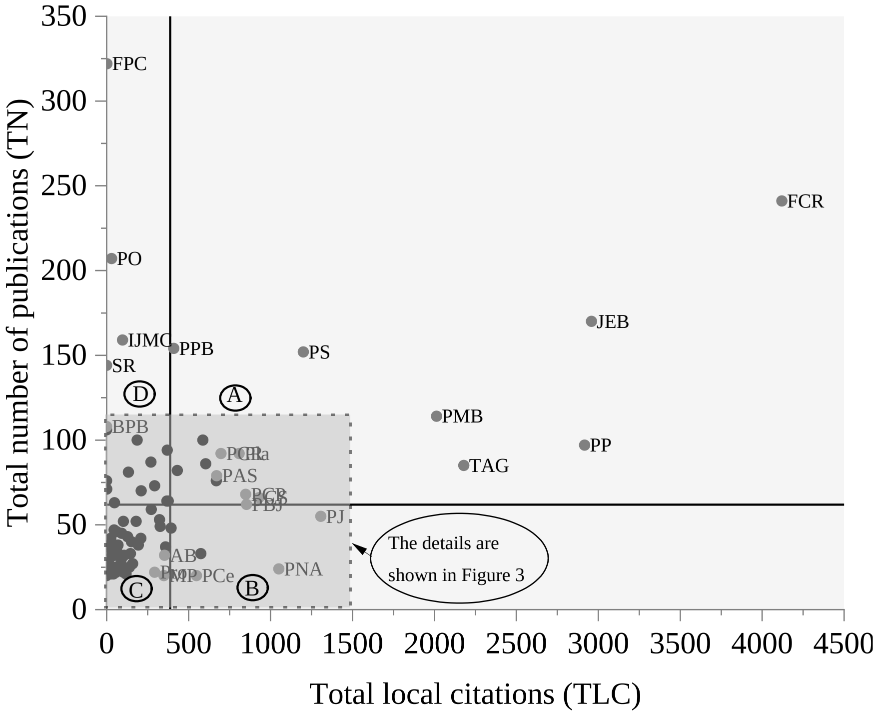

Figure 2. The number of publications in the field of rice research under drought, waterlogging or abrupt drought–flood alternation stress from 1992 to 2021. The gray circle represents 22 journals according to the rank of total number of publications (TN), total local citations (TLC) and citations per paper (TGC/TN) in Table 2; the black circle indicates other journals that met the requirements of the 20 publications, as the threshold. The abbreviation of the journals are shown in Table 2.

As can be seen in Figure 2, some journals overlapped, which is not conducive to illustrating distances regarding the impact of journals and concentrating on the number of outputs. To illustrate more clearlythe details for the reader, Figure 3 shows the details of the journals located near the axes of quadrants A, B, C and D. In addition to the ranked journals in Table 3, there are 12 journals in quadrant A, including FCR, JEB, PP, TAG, PMB, PS, PPB, PCR, Pla, PAS, PCP and CS in Table 3, Figures 2 and 3. Four other journals make a great contribution, and are highly influential and productive, because of their location in quadrant A, such as the *Journal of Plant Physiology*, *Plant Production Science*, *Plant Growth Regulation* and *Plant Cell and Environment*. There are 5 journals in quadrant B, and three journals of PJ, PNA and PCe are shown in Table 3, Figures 2 and 3. The rest of the journals, *New Phytologist* and *Molecular Genetics and Genomics*, contribute with a high impact on this field.

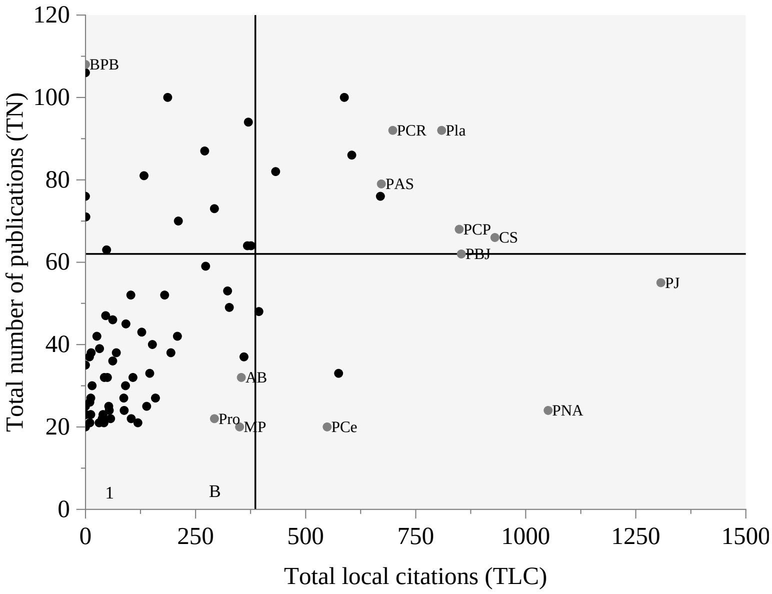

Figure 3. The number of publications in the field of rice research under drought, waterlogging or abrupt drought–flood alternation stress from 1992 to 2021. The gray circle represents 22 journals in Table 2, and the abbreviation of the journals are shown in Table 2; the black circle represents other journals that met the requirements of the 20 publications, as the threshold (the details of Figure 2 form the enclosed area).

Table 3. Top 10 productive authors, institutions and countries in the field of rice research under drought, waterlogging or abrupt drought–flood alternation stress from 1992 to 2021.

Rank	Items	TN	TN(%)	TGC	TGC/TN
	Top 10 authors				
1	Kumar, Arvind (National Rice Research Institute, Philippines)	88	1.07	3783	43.0
2	Xiong, Lizhong (Huazhong Agricultural University, China)	63	0.77	7782	123.5
3	Henry, Amelia (National Rice Research Institute, Philippines)	42	0.51	1564	37.2
4	Zhang, Jianhua (Chinese University Hong Kong, China)	41	0.50	1680	41.0
5	Kim, Ju-kon (Seoul National University, South Korea)	38	0.46	2591	68.2
6	Luo, Lijun (Shanghai Agrobiol Gene Center, China)	37	0.45	1389	37.5
7	Dixit, Shalabh (National Rice Research Institutet, Philippines)	35	0.43	1617	46.2
7	Li, Zhikang (Chinese Academy of Agricultural Sciences, China)	35	0.43	747	21.3
7	Yamauchi, Akira 9 (Nagoya University, Japan)	35	0.43	1169	33.4
8	Chen, Liang (Shanghai Agrobiol Gene Centerr, China)	31	0.38	627	20.2
9	Kato, Yoichiro (University Tokyo, Japan)	29	0.35	709	24.4
10	Serraj, Rachid (National Rice Research Institute, Philippines)	28	0.34	2044	73.0
	Top 10 institutions				
1	Chinese Academy of Sciences (China)	494	6.0	24,544	49.7
2	International Rice Research Institute (Philippines)	405	4.9	21,142	52.2
3	Chinese Academy of Agricultural Sciences (China)	334	4.0	9304	27.9
4	Huazhong Agricultural University (China)	277	3.3	15,823	57.1
5	Nanjing Agricultural University (China)	235	2.8	6899	29.4
6	China Agricultural University (China)	172	2.1	6996	40.7
7	Zhejiang University (China)	154	1.9	5046	32.8
8	University Tokyo (Japan)	140	1.7	9938	71.0
9	Northwest Agriculture and Forestry University (China)	137	1.7	4196	30.6
10	University of Western Australia (Australia)	115	1.4	5294	46.0
	Top 10 Countries				
1	China	3209	38.8	101,277	31.6
2	India	1375	16.6	39,294	28.6
3	USA	1011	12.2	45,168	44.7
4	Japan	700	8.5	35,550	50.8
5	Australia	484	5.8	20,722	42.8
6	Philippines	459	5.5	20,258	44.1
7	South Korea	439	5.3	14,707	33.5
8	Pakistan	307	3.7	9695	31.6
9	Germany	276	3.3	15,038	54.5
10	UK	270	3.3	15,694	58.1

3.3. Analysis of Authors, Institutions and Countries

Table 3 shows the top 10 authors, institutions and countries in regard to the number of publications. The top two productive scholars are Kumar Arvind (from Int Rice Res Inst, Philippines), with 88 publications accounting for 1.07%, and Lizhong Xiong (from Huazhong Agr Univ, China), with 63 publications accounting for 0.77%. There are no significant differences among the rest of the researchers from, Amelia Henry, who ranked 4th, to Rachid Serraj, who ranked 10th, ranging from 0.34% to 0.51%. It is noticed that the authors Lizhong Xiong, Ju-kon Kim and Rachid Serraj have considerable impacts on the field of rice research in a state of drought, waterlogging or abrupt drought–flood alternation stress, due to their higher total global citations (TGC) and citations per paper (TGC/TN). Especially the author Lizhong Xiong, who's publications are cited 7782 times—each article is cited 123.5 times, which is greatly higher than the others.

China produces the highest output of the number of articles, with 3209 papers, occupying 38.8%, which is higher than the other countries. Following China is India with 1375 papers and the USA with 1011 publications. The three countries might have greatly influenced the field due to their higher total global citations, but citations per paper are lower than Japan with 50.8 TGC/TN, Germany with 54.5 TGC/TN and the UK with 58.1TGC/TN. It means that the countries of Japan, Germany and UK have obtained a higher quality of publications on an average than the others. Furthermore, there is a small gap between Japan, with 700 publications and ranked 4th, and the UK, with 270 articles and ranked 10th.

It is noted that 494 articles were published by the Chinese Academy of Sciences (China), accounting for 6.0% of the total publications; followed by the International Rice Research Institute (Philippines), with 405 publications and accounting for 4.9%; the Chinese Academy of Agricultural Sciences (China), with 334 publications and accounting for 4.0%; and Huazhong Agricultural University (China), with 277 publications and accounting for 3.3% (Table 3). This means that these institutions make more contributions to output in this field. In addition, the Chinese Academy of Sciences and International Rice Research Institute have a higher TGC, with 24,544 and 21,142, respectively, which are relatively higher than other organizations. Meanwhile, the two institutions acquired advancing citations per publication, ranked 4th with 49.7 and 3rd with 52.2, respectively. It is noteworthy that University Tokyo (Japan) has higher citations per publication with 71.0, which is far more than other institutions.

In order to clarify the distribution of institutions, 20 publications were used as the threshold. Figure 4 is constructed, which involves 162 organizations. Citations per article of these institutions are shown in Figure 4B. Natural Beaks (Jenks) of Arc Gis 10.8 was adopted in the classification of number of publications in Figure 4A, which was divided into five grades: the first level (20–38), the second level (38–66), the third level (66–154), the fourth level (154–277) and the fifth level (277–494), meaning the higher the rating, the more articles published by the organizations. Citations per publication also was divided into five levels, from the first to the fifth level: 6.5–21.7, 21.7–35.2, 35.2–52.6, 52.6–90.7 and 90.7–216.3. The level get higher, institutions will obtain greater effects of publications on an average in this field.

The clusters of institutions with 20 articles as the threshold are mainly located in East Asia and South Asia (Figure 4A), where major institutions are distinguished from the third level to the fifth level. This was followed by locations in North America and Western Europe, where the dominating clusters of institutions obtained a higher grade of citations per paper, but only fewer publications (Figure 4A,B). Moreover, some scattered institutions are located in other parts of the world. The distribution characteristics of these institutions may be related to local rice cultivation, such as in the case of China, Japan and South Korea in East Asia, where rice is used as the main food crop, and thus more institutions may be attracted to the rice field and could consequently offer more contributions to the number of articles. This is especially in the case of China, where 7 of the top 10 institutions in number of publications belong, as seen in Table 3. There are 52 institutions in total, with 162 accounting for 32%, which means Chinese institutions are leading in terms of the number of articles in Figure 4A. However, the quality of publications of institutions in China is below the average according to citations per paper (Table 3 and Figure 4B). Eleven of these institutions meet the highest level with 90.7–216.3, among which the USA has the largest number of institutions with 6 and accounting for 55% (Figure 4B); these institutions include *Purdue University*, *University Calif Riverside*, *Clemson University*, *Texas A&M University*, *University Illinois* and *Cornell University*. Four institutions are located in Japan and occupy 27%, which include in *RIkagaku KENkyusho/Institute of Physical and Chemical Research* (*RIKEN)*, *Japan International Research Center for Agricultural Sciences (JIRCAS)* and *National InstituteAagrobiology Sciences*. The remaining two institutions are *Commonwealth Scientific and Industrial Research Organization-Plant Industry (CSIRO Plant Ind)* in Australia and *Myongji University* in South Korea (Figure 4B).

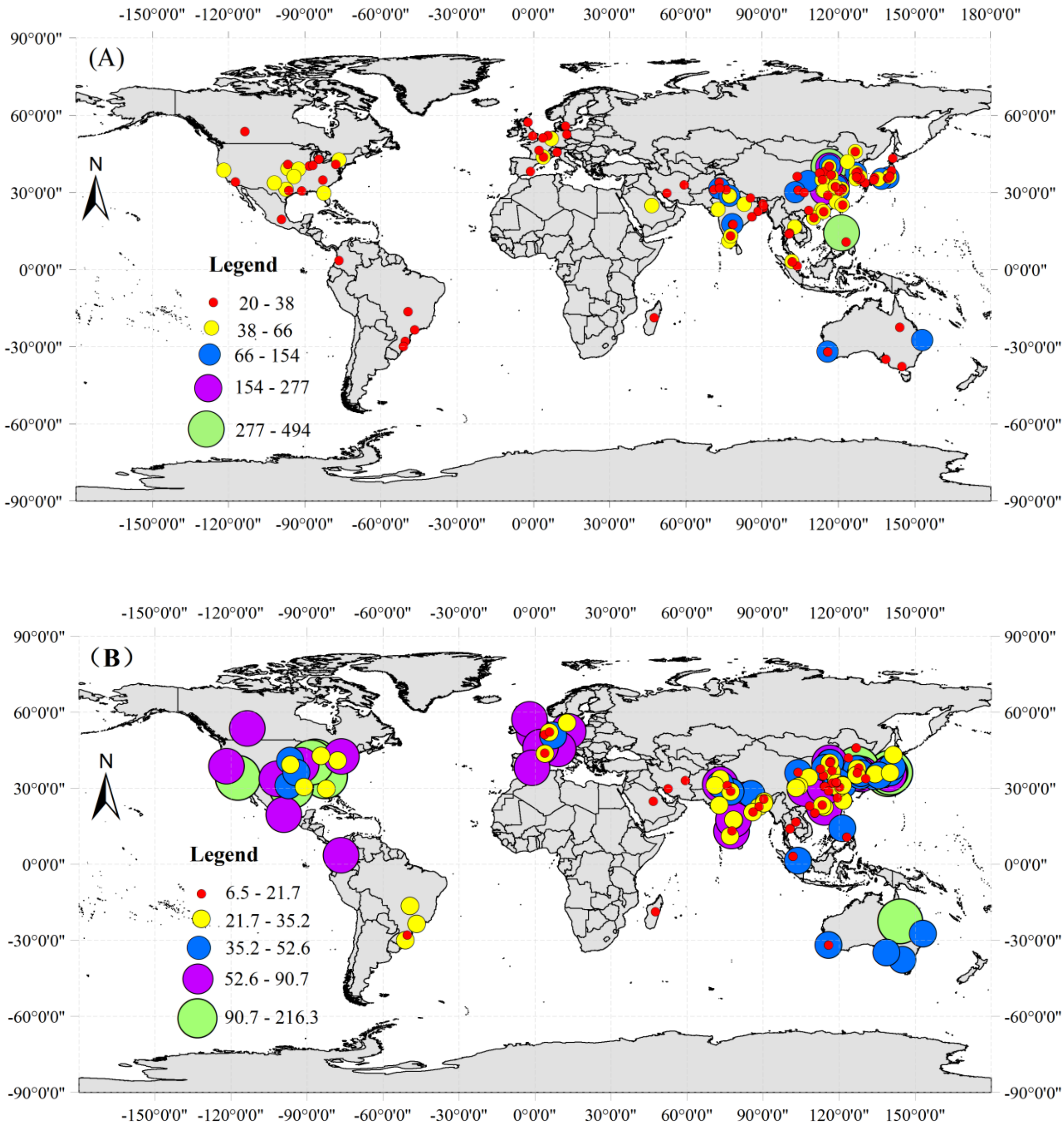

Figure 4. The distribution map regarding the number of publications of institutions, in which 20 publications were set as the threshold in (**A**); the distribution map regarding citations per article of institutions, in which 20 publications were set as the threshold in (**B**).

3.4. Analysis of Highly Cited Papers in Total Local Citations

Table 4 shows the top 10 highly cited publications of total local citations. To address the question of which articles are the most cited in the field of rice research in a state of drought, waterlogging or abrupt drought–flood alternation stress, this table shows the total local citations (TLC), the total local citations received per year (TLC/t), the total global citations (TGC) and the corresponding yearly average (TGC/t). The ranking of these indexes demonstrates that all articles listed can be considered highly influential in shaping this research field [49]. The article written by Emilyn G, Dubouzet et al. in 2003 was ranked first with 404 TLC, followed by the publication with 345 written by Honghong, Hu et al. in 2006. There is no gap between the article (Kazuo, Shinozaki et al., 2007) ranked 3rd and the article (Kazuo, Nakashima et al., 2007) ranked 5th. Meanwhile, the top three publications not only obtain higher TGC and also get advancing TGC/t, but the article by Yusaku, Uga et al. (2013) has obtained the highest TLC/t with 22.3 and the top LCSe with 67. It is demonstrable that these articles play an important role in the field of the rice research.

LCSe indicates the local citation score in the end, which could uncover trending publications. It could be better to grasp the general direction of research hot spots when obtaining the research themes of these papers listed, except for the three articles ranked 6th, 7th and 9th in Table 4. Higher LCSe can identify emerging topics. Specific gene expression/regulon/networks enhance drought resistance and salt tolerance [50–56] and could improve rice yield [53,57]; this may become hot research in the future. Now, there must be a discussion of the keywords, to acquire more details on the research field, and thus to predict future research topics.

Table 4. Top 10 highly cited papers in total local citations between 1992 and 2021.

Rank	Authors (year)	TLC	TGC	TLC/t	TGC/t	No. (LCSe)
1	Dubouzet, Emilyn G. 2003 [50]	404	1097	21.3	57.7	2(57)
2	Hu, Honghong. 2006 [58]	345	945	21.6	59.1	3(53)
3	Shinozaki, Kazuo. 2007 [52]	235	1498	15.7	99.9	9(33)
4	Jeong, Jin Seo. 2010 [53]	234	461	19.5	38.4	4(50)
5	Nakashima, Kazuo. 2007 [54]	231	683	15.4	45.5	5(42)
6	Fukai S. 1995 [58]	218	364	8.1	13.5	/
7	Rabbani, M. Ashiq. 2003 [59]	213	712	11.2	37.5	/
8	Xiang, Yong. 2008 [55]	210	386	15.0	27.6	6(38)
9	Ito Yusuke. 2006 [60]	209	572	13.1	35.8	/
10	Uga Yusaku. 2013 [56]	201	675	22.3	75.0	1(67)

Note: The numbers in parentheses represent LCSe, indicating the local citation score in the end; the numbers outside the parentheses represent LCSe rankings; slash(/) represents no ranking.

3.5. Analysis of Keywords

The visualization of the cluster density of co-occurrence keywords is shown in Figure 5. The full counting method was adopted by the counting method using VOSviewer, in which a minimum number of occurrences of a keyword, with 100 as a threshold, was applied; some 129 met the threshold out of a total of 23,020 keywords, including author keywords and keywords plus. A total of 129 keywords could be distinguished as three dominant clusters, and different clusters are indicated by the three kinds of colors: red, green and blue. In addition, these colors and font sizes represent total link strength (TLS), and the darker the background color of a keyword and the larger the font size, the more it is associated with other keywords. Meanwhile, the distance among the keywords indicates the relevance to these research topics [61].

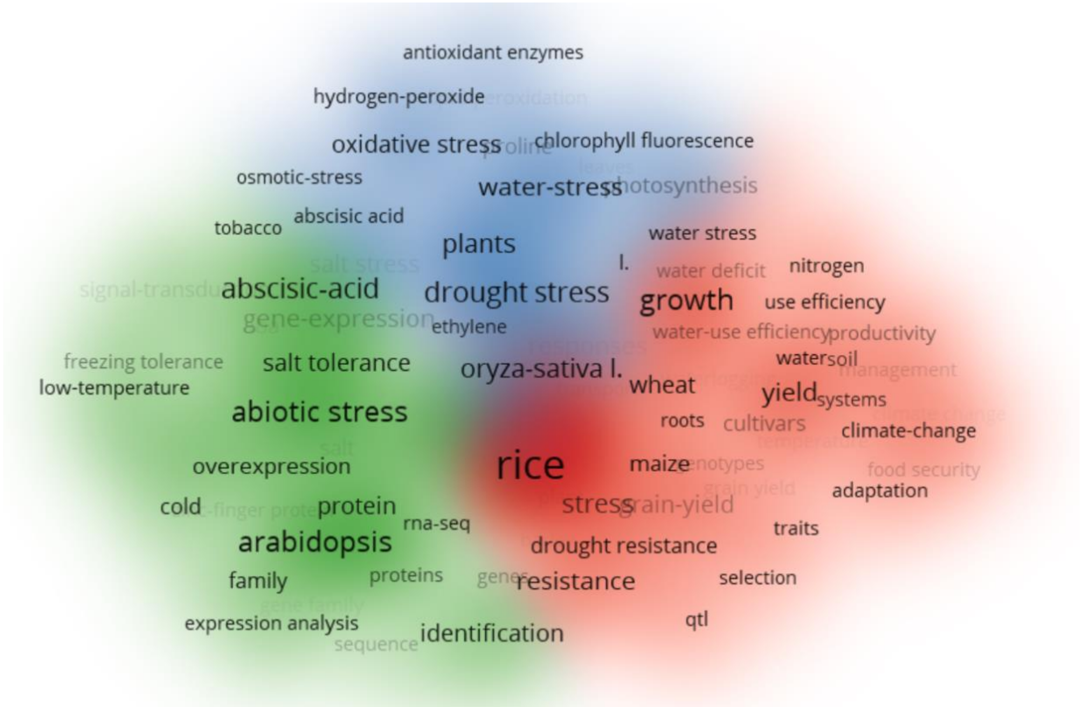

Figure 5. Visualization of cluster density of co-occurrence keywords, with 100 as a threshold, from 1992 to 2021.

The red cluster: the dominating research topics have included plants or yield (e.g., rice, growth, yield, maize, wheat, grain yield, roots, cultivars, productivity), water (water deficit, water-use efficiency, drought resistance, productivity) and other topics (soil, traits, management, nitrogen, climate change). Crop growth and yield are greatly affected by water stress [62], and scholars have been concerned with research on improving water-use efficiency [63,64], increasing soil fertility [65,66] and the effect of water deficit on yield compensation [67,68]. The keywords "rice", "growth" and "yield" reveal higher occurrences in the documents with higher TLS, which means that these research topics in the red cluster could interweave with other topics, such as gene regulation and physiological effects. The green cluster: the regulation of gene expression has emerged in the documents (e.g., overexpression, gene expression, signal transduction, identification and gene family) and scholars have also focused on the subject of abiotic stress (with freezing tolerance, cold, salt tolerance, low temperature). The blue cluster: the research direction mainly involves physiological studies (e.g., photosynthesis, chlorophyll fluorescence, oxidative stress, antioxidant enzymes, proline, abscisic acid, ethylene, lipid peroxidation and osmotic stress) and other topics (e.g., drought stress and plants).

These researchers Arvind Kumar, Lizhong Xiong, Ju-kon Kim, and Rachid Serraj may become the leaders in this field of rice research in a state of drought, waterlogging or abrupt drought–flood alternation, as stressed in Table 3. It may be beneficial to obtain the research orientation to follow the articles published by these authors, especially highly cited papers and the latest papers. The published articles—on the topic of the potential use of transgenic methods in the development of new rice varieties with resistance to abiotic stress and increasing rice productivity [69]—have been followed; such are these authors' highly cited papers [51,69–71] and recently published papers [72–77]. These papers verified that gene regulation could become the dominant area in the immediate future. From the introduction of highly cited papers of total local citations, especially the LCSe score in Table 4, it can also be found that gene research of rice has highly concerned scholars. It proves that gene regulation has always been a hot topic in this research field of rice research under drought, waterlogging or abrupt drought–flood alternation stress. With the development of research technologies and means, research hotspots are becoming more and more in-depth, and the research topics of rice cultivars, irrigation, water-use efficiency and soil fertility may gradually shift to intertwining with the themes of genomics and abiotic/biotic resistance with climate change.

4. Conclusions

In this study, articles published regarding rice research under drought, waterlogging or abrupt drought–flood alternation stress from the database of the Web of Science were analyzed based on bibliometric methods. The overall analysis of journals, authors, institutions, countries and keywords showed the number of publications and citations. (1) Output of publications: the output of papers showed an increasing trend, with a slight fluctuation, and dramatically improved after 2011. (2) Main subject categories and journals: The plant sciences category occupied about half of the number of publications. A total of 12 journals had a high output and highly local citations. Meanwhile, the three journals of *Field Crops Research*, *Journal of Experimental Botany* and *Plant Physiology* could be the most influentially leading in this field. There was a higher average quality of papers by the journals of *Proceedings of the Nation Academy of Sciences of the United States of America*, *Plant Cell*, *Plant Physiology*, *Plant Journal* and *Journals of Experimental Botany.* (3) Authors, institutions and countries: the author Arvind Kumar had the highest contribution to the output of articles, and Lizhong Xiong, Ju-kon Kim and Rachid Serraj have a great impact on the field, especially the author of Lizhong Xiong. China, and Chinese institutions, have become the leaders in terms of the number of articles. However, institutions in the USA and Japan had a higher quality of publications on average; Japan, Germany and the UK also had high quality articles on average. (4) Research trend: the use of transgenic methods to improve rice productivity with increasing abiotic stress (freezing tolerance, salt tolerance, drought tolerance) becomes research-oriented.

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