Worldwide rapeseed (*Brassica napus* L.) research: A bibliometric analysis during 2011–2021

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ABSTRACT

Rapeseed (*Brassica napus* L.) is the world's second produced oilseed and accounts for nearly 12% of world major vegetable oil production. For the last 10 years, the production, planting area, and yield of rapeseed have been stable, with improvement of seed quality and especially seed oil content. This paper presented the worldwide rapeseed research by using the bibliometric analysis of papers published during the period 2011–2021. In total, 7617 articles and reviews were included in this analysis. Our results showed that the global publication on rapeseed increased substantially in the past 11 years, and the number of publications of China grew significantly in particular. China was the largest contributor to rapeseed research with higher H-index value and number of citations compared to the other countries. China also had the largest number of leading universities and institutions, of which Huazhong Agricultural University was the most productive. The scientific mapping including co-authorship network of countries/regions and authors, and co-occurrence network of author keywords were analyzed using VOSviewer software. The most common rapeseed research topics included *oil*, *rapeseed meal*, *yield*, *biodiesel*, *fatty acids*, *salt stress*, and *proteins*, while the current research focused on topics such as: *abiotic stress*, *evolution*, *expression analysis*, *phylogenetic analysis*, *heterosis*, *polyploidy*, and *transcriptomics*. This paper depicts the knowledge structure of current global rapeseed research that may help direct the future studies for relevant researchers.

1. Introduction

Brassica napus L., commonly known as rapeseed or oilseed rape, is one of the most important oil crops providing not only cooking oil for humans, but also protein-rich fodder for animals, and renewable materials for biodiesel and industrial applications (Raboanatahiry et al., 2021). It is an allotetraploid that was generated about 7500 years ago by hybridization between ancestors of turnip (*Brassica rapa*) and Mediterranean cabbage (*Brassica oleracea*), followed by chromosome doubling and rearrangement (Chalhoub et al., 2014).

With the application of advanced breeding and cultivation technology, the production of rapeseed and oil quality has been greatly increased since 1994. Till 2020, rapeseed was grown in more than 66 countries and the total growth area worldwide reached 35 million hectares (Faostat, 2022). Over the last ten years, the global production of rapeseed has increased by 12.5 million tonnes or 20.9% to about 72.3 million tonnes and the production of rapeseed oil has risen by 15.3%–26.3 million tonnes, accounting for about 35.9% of the total rapeseed production.

Oilseed rape is now the second-highest yielding oil crop worldwide and accounted for 12.1% of world major vegetable oil in 2021 (Faostat, 2022). As one of the world's largest rapeseed producers, China produced approximately one fifth (11.9 million tonnes) of the world rapeseed production and imported 2.5 million tonnes of rapeseed oil from other countries (Oliveira and Yu, 2022).

Rapeseed oil is one of the oldest vegetable oil, however, it was consumed in limited quantities due to its high erucic acid in the oil and glucosinolates in the meal which might cause health problems (Kramer et al., 1990; Mawson et al., 1994). By 1974, the first low glucosinolate, low erucic acid (also called double low) rapeseed cultivar was developed from classical breeding methods in Canada (Stefansson and Kondra, 1975). A new name, canola (Canada oil low acid), was coined to distinguish low glucosinolate, low erucic acid rapeseed cultivars from other ones produced around the world. As an international standard, canola is used to specifically identify rapeseed varieties with less than 30 μmol glucosinolates per gram in the meal fraction and less than 2% erucic acid in the fatty acid profile which is considered benefit for human health
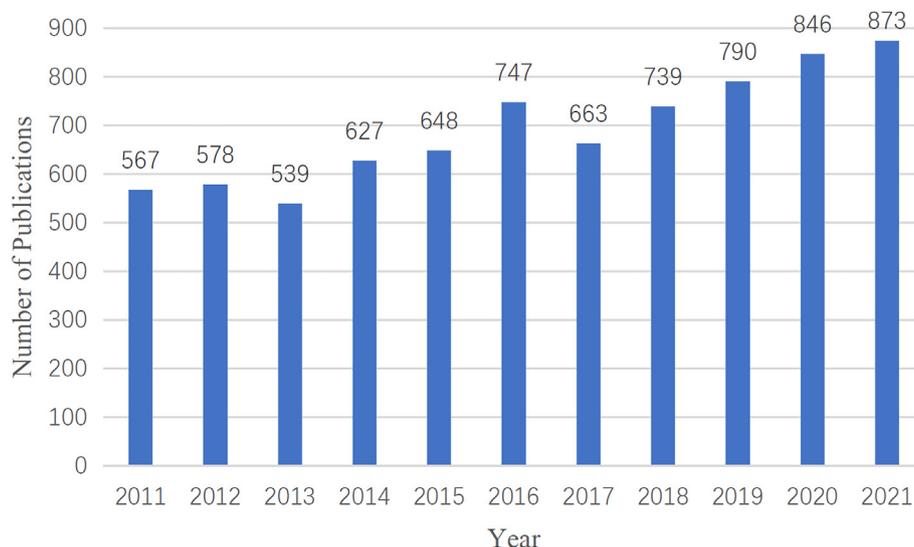
Fig. 1. Annual publications on *Brassica napus* research.

Table 1
The most productive subject categories.

Rank	WoS categories	No. of papers	% Total of all papers
1	Plant Sciences	2074	27.2
2	Agronomy	1342	17.6
3	Food Science Technology	993	13
4	Environmental Sciences	603	7.9
5	Agriculture Multidisciplinary	561	7.4
6	Agriculture Dairy Animal Science	515	6.8
7	Biotechnology Applied Microbiology	469	6.2
8	Engineering Chemical	411	5.4
9	Genetics Heredity	403	5.3
10	Biochemistry Molecular Biology	400	5.3
11	Energy Fuels	395	5.2
12	Chemistry Applied	393	5.2
13	Multidisciplinary Sciences	295	3.9
14	Horticulture	279	3.7
15	Soil Science	244	3.2
16	Chemistry Multidisciplinary	228	3
17	Nutrition Dietetics	227	3
18	Agricultural Engineering	218	2.9
19	Entomology	179	2.4
20	Ecology	127	1.7

(Canola Council of Canada, 2022).

On the other hand, the non-edible rapeseed oil is considered suitable for biodiesel usage which accounted for 50%–70% of European biodiesel production (Gupta et al., 2022). In addition, rapeseed cultivars with high erucic acid rapeseed oil is widely used for industrial applications such as cosmetics and lubricants. Rapeseed plants are widely adapted to the temperate zones and tolerant to high salinity. Rapeseed also produce 1.0–2.0 tons of dry matter per acre in a single season used as a winter forage (Tofanica, 2019). Like soybean, rapeseed contains both high oil content as well as high protein content. It contains about 45% oil and 23% protein compared to 20% and 40%, respectively, for soybean. When the oil is crushed out, it leaves a high quality, high protein (37%) feed concentrate which is highly palatable to livestock (Matthaus et al., 2016).

The high economic value and multifunctionality of rapeseed attract researchers worldwide to study various areas including breeding of new varieties, mechanic cultivation, high oil and quality, green energy, forage meal and industrial applications. Despite the fast-growing interests and research advancements in rapeseed applications in the last ten years, scientists have yet to determine the amount or quality of research conducted in this area. This limits research into rapeseed applications and justifies the need for the future study. Bibliometrics is a statistical method that uses mathematical and bibliographic counting statistical techniques to evaluate and quantify the contribution and productivity of a research field from massive academic literature (Broadus, 1987; Ellegaard and Wallin, 2015). Bibliometric studies have been widely used by scholars to present global research output, hot topics, scientific collaboration, and research trends in various research areas (Grace et al., 2021; Rey-Martí et al., 2016; Sugimoto et al., 2019). It may help scientists identify knowledge gap, optimize likelihood of publication, succeed in grant applications, and propose future research directions (Donthu et al., 2021; Ninkov et al., 2022). In agriculture, bibliometric analyses have been conducted to understand the research trends and hot spots of various fields, including molecular markers in plant research (Garrido-Cardenas et al., 2018), plant phenotyping (Costa et al., 2019), unmanned aerial vehicles and artificial intelligence in agriculture (Rejeb et al., 2022; Ruiz-Real et al., 2020), worldwide research trends on wheat and barley (Giraldo et al., 2019), cotton molecular breeding (He et al., 2019), and rice physiology and management in China (Peng, 2017). To the best of our knowledge, no bibliometric analysis has been reported recently on worldwide rapeseed research.

In order to provide a better understanding of the global trends and hot topics on rapeseed research, a bibliometric analysis was carried out using Web of Science Core Collection database in this study. Our bibliometric analysis combined performance analysis and scientific mapping. The performance analysis was based on the analysis of productivity and citations, such as counting the publications by publish year, subject categories, journals, countries/regions, affiliations, and authors. The scientific mapping including co-authorship network of countries/regions and authors, and co-occurrence network of author keywords were analyzed using VOSviewer software.

2. Materials and methods

2.1. Data collection

The data used in this study were obtained from the Science Citation Index-Expanded (SCIE) and Social Sciences Citation Index (SSCI) of Web of Science (WoS) core collection on March 16, 2022. To achieve greater accuracy in the results, the search was performed in the Title field as in (Aleixandre et al., 2013; Zakaria et al., 2021), using ("*Brassica napus*" or "*B. napus*" or "rapeseed"or "oilseed rape" or canola or colza) as the query for a period from 2011 to 2021. Only articles and reviews were retained.

Table 2
Top 20 journals in oilseed rape research.

No.	Journal	TP	Ratio	TC	AC	H-index	IF	5YIF	QC
1	Frontiers in Plant Science	211	2.8	3425	16.2	33	6.627	7.255	Q1
2	PLoS ONE	152	2.0	3280	21.6	32	3.752	4.069	Q2
3	Industrial Crops and Products	103	1.4	2414	23.4	29	6.449	6.508	Q1
4	Theoretical and Applied Genetics	93	1.2	2365	25.4	28	5.574	5.662	Q1
5	Scientific Reports	88	1.2	1661	18.9	24	4.996	5.516	Q2
6	BMC Plant Biology	81	1.1	1192	14.7	20	5.26	5.761	Q1
7	Euphytica	77	1.0	701	9.1	15	2.185	2.387	Q2
8	Crop Pasture Science	76	1.0	1125	14.8	20	2.249	2.541	Q2
9	Journal of Agricultural and Food Chemistry	74	1.0	1302	17.6	23	5.895	6.048	Q1
10	Agronomy Basel	73	1.0	248	3.4	9	3.949	4.117	Q1
11	European Journal of Lipid Science and Technology	73	1.0	987	13.5	18	3.196	2.852	Q3
12	Journal of the American Oil Chemists Society	73	1.0	895	12.3	16	1.952	2.346	Q3
13	Field Crops Research	71	0.9	1363	19.2	24	6.145	7.234	Q1
14	Fuel	69	0.9	1876	27.2	28	8.035	7.621	Q1
15	International Journal of Molecular Sciences	69	0.9	579	8.4	14	6.208	6.628	Q1
16	Animal Feed Science and Technology	64	0.8	894	14.0	18	3.313	3.914	Q1
17	Canadian Journal of Plant Science	64	0.8	633	9.9	15	1.375	1.524	Q3
18	Plants Basel	62	0.8	366	5.9	10	4.658	4.827	Q1
19	Food Chemistry	61	0.8	1559	25.6	23	9.231	8.795	Q1
20	BMC Genomics	58	0.8	1570	27.1	25	4.547	4.931	Q2

TP: Total publications; Ratio: Ratio proportion of 7617 (%); TC: Total number of citations; AC: Average number of citations; IF: Journal impact factor in 2021; IF 5 year: Journal impact factor after 5 years; QC: Quartile in Category.

Table 3
The most publishing countries/regions.

No.	Country	TP	Ratio	TC	AC	H-index
1	PRC (China)	2306	30.3	36,724	16	70
2	Canada	915	12.0	17,500	19	54
3	USA	621	8.2	11,261	18	49
4	Poland	573	7.5	5862	10	33
5	Germany	569	7.5	10,946	19	46
6	Iran	552	7.2	5952	11	33
7	Australia	464	6.1	8955	19	42
8	France	366	4.8	8869	24	43
9	Pakistan	316	4.1	5030	16	35
10	England	282	3.7	6488	23	39
11	South Korea	171	2.2	3975	23	32
12	Spain	160	2.1	3475	22	35
13	Brazil	156	2.0	1684	11	21
14	India	156	2.0	2181	14	28
15	Czech Republic	154	2.0	1595	10	22
16	Turkey	153	2.0	2546	17	28
17	Japan	144	1.9	3144	22	31
18	Denmark	104	1.4	1599	15	23
19	Egypt	88	1.2	1188	14	19
20	Italy	88	1.2	1469	17	21
21	Netherlands	86	1.1	1530	18	22
22	Belgium	76	1.0	1751	23	22
23	Sweden	74	1.0	1274	17	20
24	Lithuania	69	0.9	449	7	10
25	Saudi Arabia	60	0.8	807	13	17
26	Scotland	60	0.8	873	15	16
27	Russia	59	0.8	540	9	14
28	Malaysia	58	0.8	644	11	14
29	Mexico	56	0.7	697	12	12
30	Norway	56	0.7	667	12	14

TP: Total publications; Ratio: Ratio proportion of 7617 (%); TC: Total number of citations; AC: Average number of citations.

The full records of the refined documents were downloaded in the tab-delimited format for bibliometric analysis. 34 documents labeled as Highly Cited Papers according to Essential Science Indicators (ESI) database were selected for further analysis. ESI is an analytical database used to identify top-performing research in Web of Science Core Collection (Chuang et al., 2011; Liao et al., 2019). According to Clarivate (2022), Highly Cited Paper is defined as "a paper that belongs to the top 1% of papers in a research field published in a specified year". The ESI database for this study was updated as of March 10, 2022 to cover an 11-year period, 2011–December 2021.

2.2. Bibliometric analysis

The general profile and research performance of the retrieved papers were analyzed using Microsoft Office Excel 2016 and the Analyze Results tool of WoS database. The Hirsch index (H-index), proposed by Hirsch (2005), is defined as the number of h papers that have received at least h citations. Journal impact factors (IFs) and 5 year IFs were taken from the Journal Citation Reports (JCR) published in 2021. The co-authorship network and keywords analysis were visualized using the VOSviewer (version 1.6.17).

3. Results

3.1. Scientific production

A total of 7617 records on rapeseed research were obtained from the WoS core collection from 2011 to 2021. Of which, 7504 (98.5%) are articles and 113 (1.5%) are reviews. The main type of communication language is English, comprising 98.6% of the total publication, while the other 1.4% include nine different languages such as Polish, Portuguese, German, et al. Fig. 1 shows an increasing trend of the annual publications from 2011 to 2021. The total number of publications increased steadily from 567 in 2011 to 873 in 2021, with mild annual fluctuations in 2013 and in 2016, respectively.

3.2. Subject categories

One of the major goals of scientometric analysis is to classify the scientific literature into specific subjects (Leydesdorff and Rafols, 2009; Zhang et al., 2022). Each journal and book indexed by the WoS core collection belongs to one or more subject categories. In our study, the papers on rapeseed research were published in 135 different subject categories according to the WoS database. Table 1 shows the top 20 WoS categories and the most productive journals in each subject. The largest numbers of papers were published in journals in the area of Plant Sciences, comprising 27.2% of all publication. This was followed by Agronomy (17.6%) and Food Science Technology (13.0%). It is notable that about half of all papers were published in these three categories. In addition, the table shows that different subject categories, such as Environmental Sciences, Engineering Chemical and Energy Fuels, were involved as well, suggesting the rapeseed research is multidisciplinary.
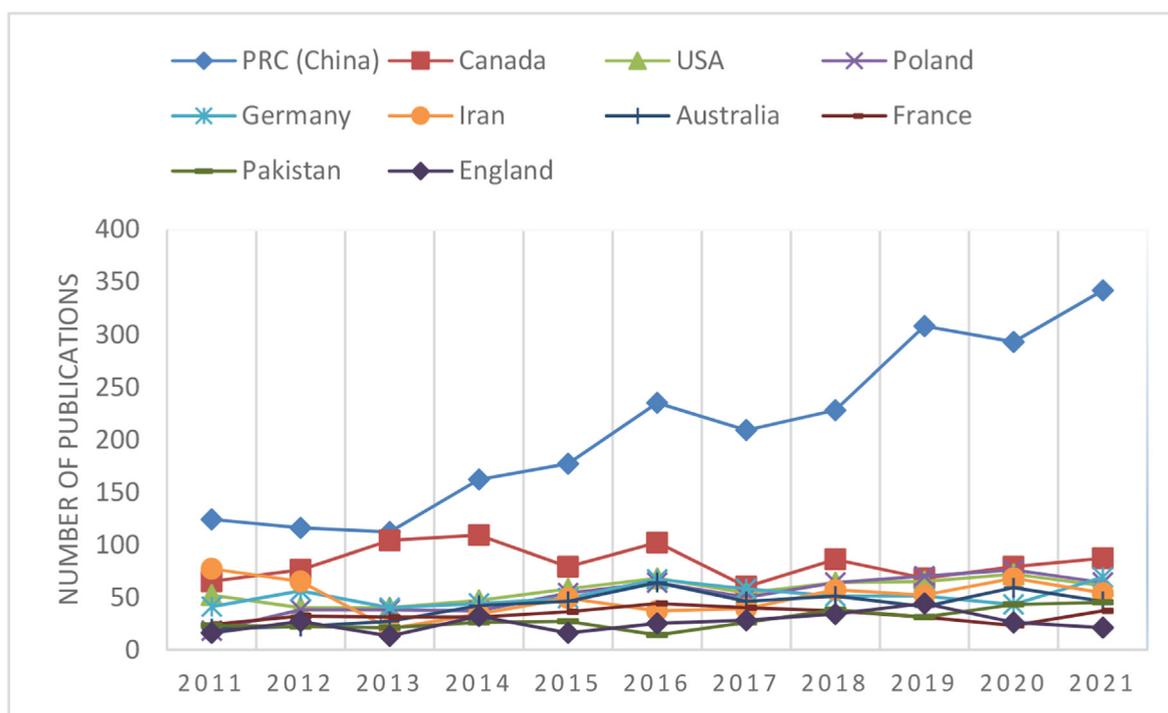
Fig. 2. Yearly trends of top 10 countries.

Table 4
The most publishing institutions.

No.	Organization	TP	TC	AC	H-index	Country
1	Huazhong Agricultural University	546	10,503	19.2	44	China
2	Oil Crops Research Institute CAAS	315	6447	20.5	37	China
3	Agriculture & Agri-Food Canada	285	6198	21.7	38	Canada
4	Inrae	243	6392	26.3	40	France
5	University of Alberta	210	3756	17.9	32	Canada
6	Zhejiang University	194	4476	23.1	40	China
7	University of Saskatchewan	193	3309	17.1	31	Canada
8	University of Manitoba	184	3319	18.0	30	Canada
9	Southwest University China	176	2852	16.2	27	China
10	Chinese Academy of Sciences	149	2799	18.8	30	China
11	Islamic Azad University	148	926	6.3	17	Iran
12	Northwest A&F University China	121	1719	14.2	26	China
13	Polish Academy of Sciences	112	1471	13.1	21	Poland
14	University of Agriculture Faisalabad	111	1211	10.9	20	Pakistan
15	Poznan University of Life Sciences	105	1182	11.3	19	Poland
16	United States Department of Agriculture	102	1531	15.0	21	USA
17	University of Western Australia	99	2917	29.5	24	Australia
18	Commonwealth Scientific Industrial Research Organization	98	1829	18.7	26	Australia
19	Hunan Agricultural University	98	2176	22.2	17	China
20	Justus Liebig University Giessen	93	3684	39.6	31	Germany

TP: Total publications; TC: Total number of citations; AC: Average number of citations.

3.3. The most publishing Journals

All the 7617 papers during 2011–2021 were published in 1187 different journals. The top 20 most publishing journals are listed in Table 2 with citations, H-index, IF in 2021, IF 5 year and Quartile in Category (QC). *Frontiers in Plant Science* was the most productive journal with 211 papers contributing to 2.8% of the total publication, followed by *PloS ONE* (152 Papers, 2.0%), *Industrial Crops and Products* (103 papers, 1.4%), *Theoretical and Applied Genetics* (93 papers, 1.2%), Scientific Reports (88 papers, 1.2%), *BMC Plant Biology* (81 papers, 1.1%), *Euphytica* (77 papers, 1.0%), *Crop Pasture Science* (76 papers, 1.0%) and *Journal of Agricultural and Food Chemistry* (74 papers, 1.0%). According to the JCR in 2021, the impact factors (IFs) of *Frontiers in Plant Science*, *PloS ONE*, and *Industrial Crops and Products* are 6.627, 3.752 and 6.449 respectively. Comparatively, the journals with higher IFs, such as *Food Chemistry* (9.231) and *Fuel* (8.035), published obviously less papers. Moreover, twelve of the top 20 journals are in Quartile 1.

3.4. The most publishing countries/regions

To investigate the global distribution on rapeseed research, the information of countries/regions was analyzed. The academic documents on rapeseed research originated from 113 countries/regions. Table 3 shows that the most publishing country on the rapeseed research was PRC (China) with 2306 papers, comprising 30.3% of all publications, followed by Canada (915 papers, 12.0%), USA (621 papers, 8.2%), Poland (573 papers, 7.5%), Germany (569 papers, 7.5%), Iran (552 papers, 7.2%), Australia (464 papers, 6.1%), France (366 papers, 4.8%), Pakistan (316 papers, 4.1%), England (282 papers, 3.7%). China also had the highest number of citations and H-index. The yearly trend of the top 10 countries is presented in Fig. 2. It shows that China have played a major role in oilseed rape research with the highest publications in the last 11 years.

Fig. 3. The country collaboration network visualization using VOSviewer. The country collaboration network visualization using VOSviewer. Countries/regions conducting rapeseed research with a minimum of 20 documents were analyzed. The size of the node is proportional to the number of publications. The link between the nodes represents that two countries have a relationship of co-authorship. The thicker the link, the higher the frequency of collaboration between countries. A cluster is made up of the countries that have frequently co-authored research publications.

3.5. The most publishing institutions

Table 4 shows the most publishing 20 research institutions across the world working on oilseed rape, contributing to 40.5% of the world publication. As we can see, Huazhong Agricultural University was the most publishing institution with 546 papers, followed by Oil Crops Research Institute of the Chinese Academy of Agricultural Sciences (CAAS) with 315 papers, and then Agriculture Agri Food Canada (285), Inrae (243), University of Alberta (210), Zhejiang University (194), University of Saskatchewan (193), University of Manitoba (184), Southwest University China (176) and Chinese Academy of Sciences (149).

3.6. Country/region co-authorship network

VOSviewer software was used to analyze the co-authorship network among countries/regions conducting rapeseed research with a minimum of 20 documents (Fig. 3). In a country co-authorship network, each node represents a country. According to VOSviewer manuscript (van Eck and Waltman, 2021), the size of the node is proportional to the number of publications. The link between the nodes represents that two countries have a relationship of co-authorship. The thicker the link, the higher the frequency of collaboration between countries. A cluster is made up of the countries that have frequently co-authored research publications. Fig. 3 shows 47 countries distributed in six different clusters. China, being the

most publishing country, had the highest international collaboration (links = 36, total link strength = 825). The top five collaborating countries with China were the USA (link strength = 163), Canada (link strength = 121), Pakistan (link strength = 118), Australia (link strength = 108) and German (link strength = 79). The number of China publications has been greatly promoted by the international cooperation. In addition to cooperating with China, the USA also had a close cooperative relationship with Canada (link strength = 68). China, USA and Canada were in the same cluster.

3.7. Author co-authorship analysis

A total of 24,072 authors were identified from the 7617 documents published from 2011 to 2021. The network of authorship was constructed using the fractional method of counting (Fig. 4). The influence of documents with many authors could be reduced by the fractional counting (Guleria and Kaur, 2021). Of the 24,072 authors, 327 authors had at least 10 publications. Authors in the same cluster usually tend to work in the same research team or have close cooperation. For instance, the cluster in red in the middle area of the visualization consists of 8 researchers from Huazhong Agricultural University working on rapeseed breeding with Fu Tingdong as the team lead. Some clusters without any links are located further away from each other in the surrounding area, which tend to be less cooperative and less related (van Eck and Waltman, 2017). To identify the leading researchers in each cluster and better

Fig. 4. The author collaboration network visualization. Authors with at least 10 publications on rapeseed research were analyzed. The size of the node is proportional to the number of publications. The link between the nodes represents that two authors have a relationship of co-authorship. The thicker the link, the higher the frequency of collaboration between authors. A cluster is made up of the authors that have frequently co-authored research publications.

understand the co-authorship network, the authors published at least 20 papers as corresponding author for 7617 documents are listed in Table 5. Based on our statistics, 26 authors with the minimum productivity of 20 documents are from 17 different institutes and 5 different countries.

3.8. Co-occurrence network analysis of author keywords

Co-occurrence analysis of keywords presents scholars' interests and indicates the research trends. Fig. 5 shows the co-occurrence network map of author keywords with at least 15 occurrences. Of the 15,398 keywords, 194 met the threshold. The size of the node represents the number of times that the keyword occurs. The link between the keywords indicates the co-occurrence between them. The top 10 keywords with

high frequency were rapeseed, oil, rapeseed meal, yield, biodiesel, fatty acids, salt stress, and proteins.

A total of 10 clusters that represent different research themes are identified in the network. The author keywords of each cluster are listed respectively from high to low occurrences in Table S1. The first cluster, colored by red, is the biggest with 40 keywords including *oil, fatty acids, proteins, vegetable oil*. This cluster represents the oil and fatty acid analysis, which have been the leading research area on rapeseed. Cluster 2 (green) has 27 keywords related to physiological research of rapeseed, such as salt stress, photosynthesis and seed germination. Cluster 3 (blue) focuses on the cultivation and yield of rapeseed, including the keywords such as *nitrogen use efficiency, crop rotation* and *oil yield*. Cluster 4 (yellow), Cluster 5 (purple), Cluster 6 (cyan), Cluster 7 (orange), and Cluster 8

Table 5
Authors who published at least 20 papers as the corresponding author in 7617 documents on rapeseed research.

Author	No. of papers	Institution	Country
Zhou Weijun	46	Zhejiang University	China
Xu Fangsen	40	Huazhong Agricultural University	China
Li Maoteng	37	Huazhong University of Science & Technology	China
Lu Jianwei	36	Huazhong Agricultural University	China
Li Jiana	33	Southwest University	China
Hwang Sheau-Fang	32	University of Alberta	Canada
Qian Wei	28	Southwest University	China
Rahman Habigur	27	University of Alberta	Canada
Wang Hanzhong	26	Oil Crops Research Institute CAAS	China
Tan Xiaoli	26	Jiangsu University	China
Wang Youping	26	Yangzhou University	China
Liu Liezhao	24	Southwest University	China
Huang Fenghong	23	Oil Crops Research Institute CAAS	China
Kim Tae-Hwan	22	Chonnam National University	South Korea
Liu Kede	22	Huazhong Agricultural University	China
Dalai Ajay K.	22	University of Saskatchewan	Canada
Barbetti Martin J.	22	University of Western Australia	Australia
Hua Wei	21	Oil Crops Research Institute CAAS	China
Szydlowska-Czerniak, Aleksandra	21	Nicolaus Copernicus University	Poland
Strelkov Stephen E.	21	University of Alberta	Canada
Fernando W. G. Dilantha	21	University of Manitoba	Canada
Wu Xiaoming	20	Oil Crops Research Institute CAAS	China
Tu Jinxing	20	Huazhong Agricultural University	China
Jiang Yuanqing	20	Northwest A&F University	China
Yu Peiqiang	20	University of Saskatchewan	Canada
Zijlstra Ruurd T.	20	University of Alberta	Canada

(brown) are involved in phytoremediation, animal feed, genetic diversity, disease resistance, and biofuel research, respectively. Cluster 9 represents technologies used for identification of candidate genes and genetic improvement of rapeseed with the keywords like *QTL*, *RNA-seq*, *GWAS*, *SNP*, and *transcriptomics*. The last cluster (grey) is the smallest with only 6 keywords, which are separated and scattered in other clusters. This cluster may be related to seed quality and secondary metabolites, but it is hard to tell which specific research area it belongs to.

To comprehend the research trend on rapeseed, the co-occurrence overlay visualization of author keywords was conducted (Fig. 6). In the overlay visualization, the color indicates the average publication year of the documents in which a keyword occurs. The most recent keywords are marked in yellow in Fig. 6. Most of them are from cluster 6 and cluster 9 in Fig. 5, including *abiotic stress*, *evolution*, *expression analysis*, *phylogenetic analysis*, *expression pattern*, and *heterosis* in cluster 6 and *RNA-seq*, *GWAS*, *candidate genes*, *flowering time*, *polyploidy*, and *transcriptomics* in cluster 9. Comparatively, the keywords signaled by blue color represent the research areas intensively studied in the earlier years. As it is shown in Fig. 6, the keywords from cluster 8 are indicated mostly by blue or turquoise.

3.9. Highly cited papers

Citations are used as a measure of influence. If an article is heavily cited, it is considered important (Zupic and čater, 2015). Of the 7617 articles and reviews on rapeseed research, 34 (0.45%) documents are Highly Cited Papers according to ESI database (updated as of March 10, 2022). Table S2 lists the 34 Highly Cited Papers, including 31 articles and 3 reviews. The paper with the highest number of citations (1172), titled "Early allopolyploid evolution in the post-Neolithic *Brassica napus* oilseed genome", was finished by more than 80 authors from 8 different countries/regions published in *Science* in 2014 (Chalhoub et al., 2014). Of the 34 Highly Cited Papers, 14 papers (41.18%) are published by the unique country.

4. Discussion

This study presented a bibliometric overview of the academic research on rapeseed during the period 2011–2021. The data for bibliometric analysis were obtained from WoS Core Collection database, which is widely recognized among researchers for providing standardized and high-quality academic publication information. A total of 7617 documents from 113 countries/regions around the world were collected and analyzed.

Our results showed that the global publication on rapeseed research increased considerably during the last 11 years. Based on the number of publications, China was the largest contributor to rapeseed research, followed by Canada. China also had the largest number of leading universities and institutions, in which Huazhong Agricultural University was the most productive.

Moreover, we found that the papers on oilseed rape research were published in many journals that classified to different subject categories. Comparatively, *Frontiers in Plant Science* was the most publishing journal, and the largest numbers of papers were published in the subject category of Plant Sciences. Based on ESI database, 34 highly cited paper were presented, which represented the most influential paper.

Furthermore, co-authorship analysis and keyword co-occurrence analysis were conducted using VOSviewer. The country co-authorship analysis showed that the most strong-link country was China, suggesting that China has the highest international collaboration. The keyword co-occurrence analysis indicated that *rapeseed*, *oil*, *rapeseed meal*, *yield*, *biodiesel*, *fatty acids*, *salt stress*, and *proteins* had the highest frequency. The co-occurrence overlay visualization of author keywords showed that current research on rapeseed focused on topics such as: *abiotic stress*, *evolution*, *expression analysis*, *phylogenetic analysis*, *heterosis*, *polyploidy*, and *transcriptomics*.

China is among the leading countries in rapeseed genomic research internationally, having jointly with other countries accomplished the whole genome sequencing of rapeseed and its two parental species, *Brassica oleracea* and *Brassica rapa*. With the application of advanced breeding and production technologies, in the near future, the oil yield and quality of rapeseed varieties will be greatly increased, and more varieties with desirable traits, especially early maturation, high yield, high resistance to biotic and abiotic stress, and suitability for mechanized harvesting will be developed.

This work is useful for understanding the research trends on rapeseed and providing support for further research in this area. However, there were several limitations in this study. First, the data presented were limited to the WoS Core Collection database. The publications indexed in the other databases might not be considered. Second, some papers on rapeseed might be excluded using our defined search query. Third, there

Fig. 5. Co-occurrence network analysis of author keyword. Author keywords with at least 15 occurrences were analyzed. The size of the node represents the number of times that the keyword occurs. The link between the keywords indicates the co-occurrence between them.

Fig. 6. Co-occurrence overlay visualization of author keyword. The color indicates the average publication year of the documents in which a keyword occurs. The most recent keywords are marked in yellow.

could be the other indicators and measures that we did not take into account to analyze the research impact.

Declaration of competing interest

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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocsci.2022.11.004.

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