Bibliometric Analysis of Cucumber (*Cucumis sativus* L.) Research Publications from Horticulture Category Based on the Web of Science

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Additional index words. bibliometric analysis, cucumber, *Cucumis sativus*, horticulture category, VOSviewer, Web of Science

Abstract. Cucumber (*Cucumis sativus* L.) is an economically important vegetable crop that is cultivated worldwide. The current study aimed to identify and analyze the 2030 articles and review article about cucumber research from the horticulture category of the VOS viewer Web of Science. Bibliometric data were analyzed by bibliometric science mapping and visualization tools. Articles mainly written in English (1884; 92.81%) were from 5630 authors, 80 countries or territories, and 1094 organizations; they were published in 46 journals and book series. The top five core journals are *Scientia Horticulturae* (337; 16.60%), *HortScience* (265; 13.05%), *Journal of the American Society for Horticultural Science* (239; 11.77%), *European Journal of Plant Pathology* (195; 9.61%), and *Horticulture Journal (Journal of the Japanese Society for Horticultural Science)* (157; 7.73%). These journals each published more than 157 articles. The top five countries and regions were the United States, People's Republic of China, Japan, South Korea, and India. The top five organizations were the University of Wisconsin, North Carolina State University, U.S. Department of Agriculture–Agricultural Research Service, Michigan State University, and Nanjing Agricultural University. The top five authors are Todd C. Wehner (Wehner, TC), Jack E. Staub (Staub, JE), Yiqun Weng, R.L. Lower, and S. Tachibana; each published more than 24 articles. All keywords used for cucumber research in the horticulture category were separated into eight clusters for different research topics. Visualizations offer exploratory information regarding the current state in a scientific field or discipline as well as indicate possible developments in the future. This review could be a valuable guide for designing future studies.

The cucumber (*Cucumis sativus* L.), which belongs to the Cucurbitaceae family, is a commonly consumed vegetable. It is an economically important crop that is widely cultivated throughout the world. Cucumber plants often experience biotic and abiotic stresses during its developmental life cycle, thus leading to reductions in yield and quality (Wang et al., 2015). Cucumber plants suffer from several

diseases, such as downy mildew, powdery mildew (PM), anthracnose, and cucumber mosaic virus, which limit crop production. Developing resistance to these diseases is a major subject of cucumber plant breeding. Cucumber is a potential model plant candidate for the Cucurbitaceae family and would provide new scientific knowledge through molecular analysis (Nanasato and Tabei, 2020). PM is a destructive foliar disease with wide distribution and rapid spread that causes substantial yield losses. The long-term planting and variable adaptability of pathogens have led to the gradual decline in plant resistance. Consequently, the cultivation of durable and resistant cultivars is clearly the most economical and environmentally friendly method of controlling PM diseases during cucumber breeding (Chen et al., 2021). High yield can be achieved by improving cultural practices and by

developing genetically superior cultivars. High-yielding cultivars, precision farming systems, increased use of chemicals for fertilization and weed and disease control, and proper training of the local farmers allowed for significant changes in agriculture (Gusmini and Wehner, 2008).

Cucumber is a popular vegetable worldwide. The total cucumber production (including gherkins) in 2018 was 75.2 million tons from 1.984 million cultivated hectares (FAOSTAT, 2020). China is one of the main countries producing cucumbers. The total cucumber production (including gherkins) in China in 2018 was 56.24 million tons from 1.044 million hectares, which accounted for 52.7% and 74.8% of the corresponding world totals, respectively. Cucumber (*Cucumis sativus*, L.) is widely grown in greenhouses in China as an off-season vegetable because of its high yield and economic benefits (Liu et al., 2021).

Cucumber (*Cucumis sativus* L.) is a major vegetable crop with important economic and biological value, and it serves as a model plant for studying several important biological processes (Che and Zhang, 2019). Cucumber was the first among major horticulture crops with a publicly available draft genome. Its relatively small, diploid genome, short life cycle, and self-compatible mating system offer advantages for genetic studies (Wang et al., 2020). The hypocotyl is an important agronomic trait of cucumber, and transplanting seedlings with a short hypocotyl is an effective method of increasing cucumber yield (Zhang et al., 2021). Cucumber is a potential model plant candidate for the Cucurbitaceae family and would provide new scientific knowledge through molecular analysis (Nanasato and Tabei, 2020).

The category of horticulture includes resources concerning the cultivation of flowers, fruits, vegetables, or ornamental plants in gardens, orchards, or nurseries (InCites Journal Citation Reports; Clarivate, 2021). Searching the publications by the topic keywords of “Cucumber” OR “*Cucumis sativus* L.” and all the years published for article or review article types in the Web of Science, the top three Web of Science categories are Plant Sciences, Horticulture, and Agronomy. In this paper, publications that focused on the horticulture category were collected.

Bibliometric indicators have been frequently used to analyze scientific and technological production in different fields of knowledge. Bibliometric techniques have been adopted in some research, such as essential oil-bearing plants exposed to water stress (Kulak et al., 2019), grafting in horticultural plants (Belmonte-Ureña et al., 2020), scientific research about fungus *Phakopsora pachyrhizi* Sydow and Sydow affecting soybean [*Glycine max* (L.) Merrill] (Meira et al., 2020), highly cited articles in the Science Citation Index Expanded (subject category: horticulture) (Kolle et al., 2017), the research, innovation, and development of *Corylus avellana* (Raparelli and Lolletti, 2020), the berries on the top (Yeung et al., 2019), bibliometric analysis of French National Institute for Agricultural Research (INRA) publications

Received for publication 23 June 2021.
Accepted for publication 2 Aug. 2021.
Published online 21 October 2021.

This work was supported by Hubei Provincial Natural Science Foundation of China (2019CFA017). B.-Z.Y. and Z.-L.B. are the corresponding authors. E-mail: yuanbz@mail.hzau.edu.cn or biezl@mail.hzau.edu.cn.

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Table 1. Document type and language of the publication about cucumber research from the horticulture category of the Web of Science.

Rank	Document type	Records	% of 2030	Language	Records	% of 2030
1	Article	1999	98.47	English	1884	92.81
2	Review	31	1.53	Japanese	58	2.86
3	Proceedings paper	18	0.89	Korean	24	1.18
4	Early access	4	0.20	German	23	1.13
5	Book chapter	1	0.05	Russian	17	0.84
6				Portuguese	14	0.69
7				Spanish	6	0.30
8				Chinese	2	0.10
9				Swedish	2	0.10

Fig. 1. Number of published articles about cucumber research from the horticulture category based on the Web of Science from 1946 to 2021.

about fruits and vegetables produced between 2002 and 2006 (Tatry et al., 2011), tree fruit growing in Germany (Dalla Via and Baric, 2012), trends in mango research (Kolle et al., 2018), and wine research and its relationship with wine production (Jamali et al., 2020). Others have researched soil and water conservation in the Loess Tableland-Gully region of China (Wang et al., 2019), advances in water use efficiency in agriculture, and sustainable water use in agriculture (Velasco-Muñoz et al., 2018a, 2018b). Rice with fertilizer has been analyzed based on Citespace (Sun and Yuan, 2019), the top articles about world rice research (Sun and Yuan, 2020a), library and information science (Sun and Yuan, 2020b), water resources (Sun and Yuan, 2020c), the agronomy category (Sun and Yuan, 2021), green and sustainable science and technology (Yuan and Sun, 2019), scientific research of maize or corn (Yuan and Sun, 2020a, 2020b), and

global research of muskmelon (*Cucumis melo* L.) (Yuan et al., 2021).

Research is the way to the truth; therefore, innovations are important to finding something new or a new understanding to approach the truth. It is not helpful for researchers to duplicate the same problem without improving their research. It is the responsibility of the authors, reviewers, and editors to stop publishing such problems in journals. The aim of this study was to assess publications of research and review articles about cucumber (*Cucumis sativus* L.) from the horticulture category during all years using bibliometric science mapping and visualization tools. We assess the scattering of publications in citation databases, classification of topics, and progress over the years. Country input and author collaboration (coauthorship) are addressed. Special attention is dedicated to research topics and research fronts.

Data and Methodology

Web of Science. The Clarivate Analytics Web of Science (WoS) is the world's leading scientific citation search and analytical information platform and one of the world's largest and most comprehensive academic information resources covering more than 12,000 core academic journals. The numbers of publications in the WoS Core Collection were derived from the following databases: The Science Citation Index–Expanded (SCIE), 1900 to present; Social Science Citation Index (SSCI), 1900 to present; Conference Proceeding Citation Index–Science (CPCI-S), 2015 to present; Conference Proceedings Citation Index–Social Science & Humanities (CPCI-SSH), 2015 to present; Current Chemical Reactions (CCR-EXPANDED), 1985 to present; and Index Chemicus (IC), 1993 to present.

Data collection and analysis. This study surveyed articles from the WoS Core Collection (1900–present) (data retrieval last performed on 29 Mar. 2021). We used the following keyword query:

Topic: (“Cucumber” or “*Cucumis sativus* L.”)

Then, the results were refined by the document type (article or review) and Web of Science category (horticulture).

There were 2030 articles from WoS Core Collection. Full records and cited references of the included articles were extracted using other reference software file formats and imported into VOSviewer (version 1.6.16; 2020; Leiden University, Leiden, the Netherlands) for further citation analysis. The impact factors (IFs; IF 2020 and IF 5-year) were taken from the Journal Citation Report (JCR) 2020, which was published in 2021 and had the latest data available.

VOSviewer. Visualizations (network and overlay) using VOSviewer were conducted for WoS data to determine the co-occurrence and clusters of connected publications, country input, and author collaboration (coauthorship), as well as clusters of inter-related research topics. We used VOSviewer to show the international collaboration between the authors, organizations, and countries, and the research trends through all keywords (Van Eck and Waltman, 2010). Default parameter values of the VOSviewer were usually used in the analysis. Items were represented by a label and a circle. The sizes of the circles reflect the weight of

Table 2. All Web of Science (WoS) categories and research areas for cucumber research from the horticulture category.

Rank	WoS categories	TP	Ratio (%)	Research Areas	TP	Ratio (%)
1	Horticulture	2030	100	Agriculture	2030	100
2	Agronomy	566	27.88	Plant Sciences	544	26.80
3	Plant Sciences	544	26.80	Genetics Heredity	164	8.08
4	Genetics Heredity	164	8.08	Food Science Technology	69	3.40
5	Food Science Technology	69	3.40	Biotechnology Applied Microbiology	1	0.05
6	Biotechnology Applied Microbiology	1	0.05	Forestry	1	0.05
7	Forestry	1	0.05	Nutrition Dietetics	1	0.05
8	Nutrition Dietetics	1	0.05	Virology	1	0.05
9	Virology	1	0.05			

Ratio refers to the percentage out of 2030.

TP = total publications.

Table 3. Top 20 journals about cucumber research from the horticulture category of the Web of Science.

Rank	Journal	TP	Ratio	IF 2020	IF 5-yr	QC	RC
1	Scientia Horticulturae	337	16.60	3.463	3.672	Q1	4
2	HortScience	265	13.05	1.455	1.617	Q2	18
3	Journal of the American Society for Horticultural Science (Proceedings of the American Society for Horticultural Science)	239	11.77	1.144	1.617	Q3	23
4	European Journal of Plant Pathology	195	9.61	1.907	2.022	Q2	11
5	Horticulture Journal (Journal of the Japanese Society for Horticultural Science)	157	7.73	0.959	1.115	Q3	25
6	Euphytica	111	5.47	1.895	2.181	Q2	12
7	Theoretical and Applied Genetics	104	5.12	5.699	5.565	Q1	2
8	Journal of Horticultural Science Biotechnology (Journal of Horticultural Science)	80	3.94	1.641	1.616	Q2	15
9	European Journal of Horticultural Science (Gartenbauwissenschaft)	62	3.05	1.482	1.503	Q2	17
10	Postharvest Biology and Technology	60	2.96	5.537	5.821	Q1	3
11	Horticultural Science Technology (Korean Journal of Horticultural Science Technology)	48	2.37	0.869	0.912	Q4	29
12	HortTechnology	41	2.02	1.087	1.059	Q3	24
13	Horticulture Environment and Biotechnology	37	1.82	1.842	2.083	Q2	14
14	Acta Scientiarum Polonorum Hortorum Cultus	35	1.72	0.673	0.811	Q4	33
15	Indian Journal of Horticulture	34	1.68	0.163	0.229	Q4	37
16	Molecular Breeding	34	1.68	2.589	2.75	Q1	7
17	Seed Science and Technology	26	1.28	0.905	0.996	Q3	27
18	Horticultura Brasileira	23	1.13	0.845	0.98	Q4	30
19	Horticulture Research	22	1.08	6.793	6.589	Q1	1
20	New Zealand Journal of Crop and Horticultural Science	17	0.84	1.154	1.424	Q3	22

Ratio refers to the percentage out of 2030.

IF = impact factor; QC = quartile in the category; RC = rank in the horticulture category; TP = total publications.

Data are from the 2020 edition of Journal Citation Reports.

an item. Some items were not displayed to avoid overlapping. The colors in the network visualization represented clusters of similar items as calculated by the program. The distance between the items indicated the strength of the relationships.

Results and Discussion

Document types and language of publication. Based on Clarivate Analytics WoS Index, the 2030 articles were from SCIE (2030), and some papers also belong to CPCI-S (18), SSCI (6), and Book Citation Index–Science (1). The document types and languages are displayed in the Table 1. Among the document types, there were 1999 articles (98.47%) and 31 reviews (1.53%), including 18 proceedings articles (0.89%), 4 early access articles (0.20%), and 1 book chapter (0.05%). The first article titled “The development of downy mildew-resistant cucumbers” (Barnes et al., 1946) was published in *Proceedings of the American Society for Horticultural Science* (47:357–360).

Almost all of the articles were published in English (1884; 92.81%); others were published in Japanese (58; 2.86%), Korean (24; 1.18%), German (23; 1.13%), Russian (17; 0.84%), Portuguese (14; 0.69%), Spanish (6; 0.30%), Chinese (2; 0.10%), and Swedish (2; 0.10%). English was the dominating language in the WoS. Scholars tend to publish their articles in English because they want them to be widely accepted. Most of the published documents were in the form of original research articles, and English was the most common language used (Khan et al., 2020).

Publication output. To determine the trend in cucumber research in the horticulture category of the WoS, a total of 2030 articles and reviews were obtained from the online version of the WoS database from 1946 to

2021 (Fig. 1). The most articles (91) were published in 2018. In the 1980s, 1990s, 2000s, and 2010s, the article publication rates were 93.15%, 82.86%, 63.30%, and 41.53%, respectively. The *h*-index was initially proposed as a measure of a researcher’s scientific output based on counting the number of publications (*N*) by that researcher cited *N* or more times (Hirsch, 2005). For the 2030 articles, the *h*-index was 66, and the average citation per item was 15.69.

Web of Science categories and research areas. For cucumber research from the horticulture category of the WoS, there are nine WoS subject categories in the science edition (total of 254 categories) and eight research areas. Table 2 shows the WoS categories and research areas regarding the subject of cucumber research from the horticulture category of the WoS. The top five WoS categories include Horticulture (2030; 100%), Agronomy (566; 27.88%), Plant Sciences (544; 26.80%), Genetics Heredity (164; 8.08%), and Food Science Technology (69; 3.40%). The top five research areas include Agriculture (2030; 100%), Plant Sciences (544; 26.80%), Genetics Heredity (164; 8.08%), Food Science Technology (69; 3.40%), and Biotechnology Applied Microbiology (1; 0.05%). The journals or articles may be classified as two or more categories in the WoS, which shows the multidisciplinary character of this research field (Elango and Ho, 2017, 2018). In the WoS, publications are also mapped to WoS categories, which are more detailed than areas (Stopar et al., 2021).

Core journals. Based on JCR 2020 data (published in 2021), there are 45 journals and one book series regarding cucumber research from the horticulture category of the WoS. The one book series is *Advances in Virus Research*. The top 20 core journals are

displayed in Table 3. Based on the JCR 2020, there are 37 journals in the horticulture category.

The top 5, top 10, top 15, and top 20 journals published 59.66%, 80.20%, 89.80%, and 95.81% of the total articles, respectively. *Scientia Horticulturae* was the most productive journal, with 337 articles (16.60%), followed by *HortScience* (265; 13.05%), *Journal of the American Society for Horticultural Science* (*Proceedings of the American Society for Horticultural Science*; 257; 12.66%), *European Journal of Plant Pathology* (195; 9.61%), and *Horticulture Journal* (*Journal of the Japanese Society for Horticultural Science*; 157; 7.73%). These journals each published more than 157 articles. Some journal names were changed; therefore, we combined these titles as the same journal; however, the total number of journals was calculated separately. Of the top 20 journals, there were 5 journals in quartile 1, 6 journals in quartile 2, 5 journals in quartile 3, and 4 journals in quartile 4 (Table 3). White-Gibson et al. (2019) demonstrated the importance of publishing in the English language and in a journal with a high IF. A citation analysis is not a measurement of scientific quality, but it is reflective of importance (White-Gibson et al., 2019).

According to the publication data regarding the citation of 45 journals, 33 journals met the thresholds of 5 publications and 32 journals were connected to each other. The network of citations in the field of cucumber research from the horticulture category of the WoS is shown as six clusters with different colors in Fig. 2. The sizes of the circles reflect the total number of journal publication records. If journals were in the same cluster, then it was suggested that they published articles with

Fig. 3. Network visualization maps of authors of cucumber research from the horticulture category of the Web of Science.

consisted of five countries and regions (yellow): Germany, Greece, Egypt, Nigeria, and Saudi Arabia. The fifth cluster consisted of four countries (violet): People's Republic of China, Canada, Turkey, and Pakistan. The

sixth cluster consisted of three countries (light blue): Spain, Mexico, and Australia. The seventh cluster consisted of two countries (orange): United States and South Africa. Taiwan, which is a region of China,

showed stronger research and collaboration in the field of cucumber research. It seems that greater cooperation brings more advanced achievements in scientific research. Therefore, geographical location is an important factor

Table 4. Top 19 most prolific authors who published articles in the field of cucumber research from the horticulture category of the Web of Science.

Rank	Author	Articles	Citations	Avg. citations	Organizations	Country
1	Todd C. Wehner (Wehner, TC)	81	1035	12.78	North Carolina State University	United States
2	Jack E. Staub (Staub, JE)	65	1454	22.37	University of Wisconsin	United States
3	Yiqun Weng	37	850	22.97	University of Wisconsin	United States
4	R.L. Lower	28	293	10.46	USDA-ARS	United States
5	S. Tachibana	24	327	13.63	Mie University	Japan
6	Rebecca Grumet (Grumet, R)	23	390	16.96	Michigan State University	United States
7	L.R. Baker	19	174	9.16	Michigan State University	United States
8	Jinfeng Chen (Chen, JF)	19	370	19.47	Nanjing Agricultural University	China
9	Toshio Shibuya	17	115	6.76	Osaka Prefecture University	Japan
10	Toshiki Asao (Asao, T)	16	332	20.75	Osaka Prefecture University	Japan
11	Shi-Rong Guo (Guo, Shirong)	14	155	11.07	Nanjing Agricultural University	China
12	Michael J. Havey (Havey, MJ)	14	315	22.50	University of Wisconsin	United States
13	Yoshiaki Kitaya	14	106	7.57	Osaka Prefecture University	Japan
14	C.E. Peterson	14	189	13.50	University of Wisconsin	United States
15	Ryosuke Endo	13	100	7.69	Osaka Prefecture University	Japan
16	Yuhong Li	13	290	22.31	Northwest A&F University	China
17	A.D. Munshi	13	62	4.77	ICAR Indian Agricultural Research Institute	India
18	T. Saito	12	32	2.67	Shizuoka University	Japan
19	M.E. Saltveit	12	219	18.25	University of California Davis	United States

Table 5. Top 20 countries/regions publishing articles in the field of cucumber research from the horticulture category of the Web of Science.

Rank	Countries/regions	Records	Cluster	Total link strength	Citations	Avg. citations
1	United States	466	7	136	8356	17.93
2	People's Republic of China	330	5	111	5495	16.65
3	Japan	172	2	22	2010	11.69
4	South Korea	109	2	28	957	8.78
5	India	81	1	31	924	11.41
6	Spain	64	6	23	1371	21.42
7	Poland	56	3	14	591	10.55
8	Canada	50	5	10	1209	24.18
9	Israel	40	3	20	1383	34.58
10	Netherlands	39	3	26	1199	30.74
11	Germany	39	4	13	894	22.92
12	Brazil	36	1	3	248	6.89
13	Italy	34	3	21	1289	37.91
14	Iran	31	2	7	413	13.32
15	Greece	30	4	7	603	20.10
16	France	29	1	26	846	29.17
17	Turkey	28	5	10	286	10.21
18	England	18	1	7	370	20.56
19	Norway	18	2	4	421	23.39
20	Mexico	17	6	2	281	16.53

that determines international cooperation. The increasing international exchanges have promoted academic communications (Tang et al., 2018).

Organization coauthorship analysis. According to the publication data, a total of 1094 organizations published 2030 publications. The organization coauthorship analysis reflected the degree of communication between institutions as well as the influential institutions in this field (Reyes-Gonzalez et al., 2016). Table 6 lists the top 22 organizations and institutions that had more than 16 publications. These organizations are mainly focused in China (eight organizations), the United States (seven organizations), Japan (two organizations), Israel (one

organization), Canada (one organization), India (one organization), South Korea (one organization), and Greece (one organization). The University of Wisconsin, North Carolina State University, U.S. Department of Agriculture–Agricultural Research Service (USDA–ARS), Michigan State University, and Nanjing Agricultural University are the top five organizations that have had articles published. The organizations of Agriculture Research Organization, Shandong Agricultural University, Agricultural University of Athens, University of Wisconsin, and Cornell University had the highest average number of citations per article.

Of the 1094 organizations, there were 119 organizations that met the minimum

threshold of five; however, 88 organizations were connected to each other (Fig. 5). The VOSviewer software divided these 88 institutions into 11 clusters using different colors. Geographical localization is an important factor for partnership and joint ventures.

All keywords co-occurrence analysis. Of the 6672 keywords, there were only 621 keywords that met the threshold more than five times. These were separated into eight main cluster viewpoints of cucumber research from the horticulture category of the WoS (Fig. 6). The top 20 co-occurrence keywords (occurring more than 55 times) were cucumber, *cucumis sativus*, growth, plants, tomato,

Fig. 4. The country coauthorship network of cucumber research from the horticulture category of the Web of Science with 38 nodes and seven clusters.

Table 6. Top 22 organizations publishing articles in the field of cucumber research from the horticulture category of the Web of Science.

Rank	Organizations	Records	TLS	Citations	Avg. C	Country
1	University of Wisconsin	103	128	2318	22.50	United States
2	North Carolina State University	76	22	936	12.32	United States
3	USDA-ARS (ARS)	64	108	1380	21.56	United States
4	Michigan State University	53	24	1111	20.96	United States
5	Nanjing Agricultural University	48	40	691	14.40	China
6	Shandong Agricultural University	33	22	872	26.42	China
7	China Agricultural University	31	32	629	20.29	China
8	Northwest Agriculture and Forest University	31	61	463	14.94	China
9	Chinese Academy of Agricultural Sciences	30	36	622	20.73	China
10	Cornell University	25	17	557	22.28	United States
11	University of Florida	25	12	385	15.40	United States
12	Shanghai Jiao Tong University	24	30	352	14.67	China
13	Agricultural Research Organization	22	11	1002	45.55	Israel
14	Osaka Prefecture University	20	1	122	6.10	Japan
15	Agriculture and Agri-Food Canada	19	5	327	17.21	Canada
16	Indian Agricultural Research Institute	18	10	145	8.06	India
17	Shimane University	18	6	357	19.83	Japan
18	Zhejiang University	18	6	361	20.06	China
19	University of Georgia	17	11	230	13.53	United States
20	Agricultural University of Athens	16	5	396	24.75	Greece
21	Seoul National University	16	15	216	13.50	South Korea
22	Yangzhou University	16	14	112	7.00	China

Avg. C = average citations; TC = total citations.

yield, resistance, quality, expression, identification, photosynthesis, temperature, tolerance, leaves, disease resistance, stress, inheritance, fruit, Arabidopsis, and genome.

The same data were arranged by the period of cucumber research from the horticulture category of the WoS (Fig. 7). According to the manual for VOSviewer version 1.6.16 (Van Eck and Waltman, 2020), blue colors indicate older research topics, and yellow and green colors indicate more recent topics of interest. When blue is used for topics, it does not mean that the topic is no longer researched; instead, blue usually indicates that, on average, the topic was intensely investigated previously, but now more attention has shifted toward other topics.

Visualizations of large datasets (big data) offer exploratory information regarding the current state of a scientific field or discipline as well as indicate possible developments in the future. The top 20 keywords are listed and ranked in each cluster in Fig. 6.

The first cluster (red) focused on inheritance analyses and gene expression. It included keywords such as expression, identification, inheritance, arabidopsis, genome, gene, cucurbitaceae,

markers, genes, quantitative trait loci, sativus, sativus L., map, QTL analysis, loci, DNA, evolution, linkage, diversity, and genetic diversity.

The second cluster (green) focused on the metabolism and tolerance to stress of the plant. The keywords were ranked as tolerance, leaves, stress, fruit, *cucumis sativus* L., accumulation, light, seedlings, oxidative stress, storage, arabidopsis-thaliana, Cl, gene-expression, injury, metabolism, acid, ethylene, hydrogen-peroxide, chlorophyll fluorescence, and abscisic-acid.

The third cluster (blue) focused on plant growth and fruit quality. It included keywords such as growth, tomato, yield, quality, photosynthesis, temperature, responses, salinity, soil, greenhouse, management, nitrogen, crops, grafting, lettuce, leaf, salt tolerance, soilless culture, fruit-quality, and efficiency.

The fourth cluster (yellow) focused on cucumber disease resistance and biocontrol management. The keywords included cucumber, disease resistance, induction, powdery mildew, biological-control, disease, salicylic-acid, vegetable breeding, plant growth, infection, biological control, biocontrol, damping-off, induced resistance, cucurbits, root, systemic acquired-resistance, systemic

resistance, downy mildew, and induced systemic resistance.

The fifth cluster (violet) focused on cucumber grafting cultivars. It included keywords such as *cucumis sativus*, *cucumis-sativus*, watermelon, *sativus* L., *cucumis-sativus* L., cultivars, rootstock, water, vegetables, citrullus lanatus, maize, transformation, culture, pickling cucumber, plant-regeneration, fruits, toxicity, cytokinins, higher plants, pollination, and pumpkin.

The sixth cluster (light blue) focused on cucumber mosaic virus and disease resistance. It included keywords such as resistance, melon, protein, tobacco, cucumber mosaic virus, pepper, *cucumis melo*, plant, cmv, cucumber mosaic-virus, muskmelon, sequence, squash, field, lycopersicon-esculentum, potyvirus, virus resistance, coat protein, cucumber-mosaic-virus, capsicum annum, and diseases.

The seventh cluster (orange) focused on cucumber nutrient solution and cucumber allelopathy. The keywords included hydroponics, rice, cucumber *cucumis-sativus*, nutrient solution, germination, vegetable crops, proteins, autotoxicity, systems, root exudates, allelopathy, cucumber (*cucumis*

Fig. 5. The organization coauthorship network of cucumber research from the horticulture category of the Web of Science.

Fig. 6. VOSviewer co-occurrence network visualization mapping of the most frequent keywords (minimum of five occurrences) for cucumber research from the horticulture category of the Web of Science.

sativus L.), corn substances, activated-charcoal, bell pepper, hydroponic culture, activated charcoal, allelochemicals, and bioassay.

The eighth cluster (brown) focused on plants nutrition. The keywords included plants, nutrition, nitrate, susceptibility, assimilation, nitrate reductase, amino-acids, ammonium, greenhouses, nutrient, podosphaera xanthii, zinc, availability, biomass, elevated CO₂, pH, and podosphaera-xanthii.

Top articles based on Essential Science Indicators. The top articles are the sum of hot articles and highly cited articles based on the Clarivate Analytics Essential Science Indicators (ESI). A highly cited article is an article that belongs to the top 1% of articles in a research field published during a specified year. A hot article is an article published within the past 2 years that was cited a number of times during the most recent 2-month period, thus placing it in the top 0.1% of articles in the same field. The Essential Science Indicators database includes a period of more than 11 years (1 Jan. 2010–31 Dec. 2020).

Based on the ESI database, these top articles are six highly cited articles (Table 7) that have been published in *Scientia Horticulturae* (Ahmed et al., 2020; Schwarz et al.,

2010; Z.W. Zhang et al., 2020; T.G. Zhang et al., 2020) and *Theoretical and Applied Genetics* (Lu et al., 2014; Pan et al., 2020) (Table 7).

The most frequently cited articles. A citation analysis has been performed to provide a supplementary index to determine the impact of scientific studies and identify studies, researchers, and the most renowned institutions focusing on the theme. Although several articles have been published, a relatively small number of individuals account for a large proportion of the citations within the period. The total number of citations of the eight most frequently cited articles is more than 150 (Fig. 8). These eight articles have been published in the following four journals: *HortScience* (Lee, 1994), *Scientia Horticulturae* (Carmen Martinez-Ballesta et al., 2010; Colla et al., 2010; Feng et al., 2010; Schwarz et al., 2010), *Postharvest Biology and Technology* (Qin and Lu, 2008), and *European Journal of Plant Pathology* (De Meyer et al., 1998; Zehnder et al., 2001). The citations of these articles increased every year until 2020, but their rates of increase are different (Fig. 8). The most cited article (blue line) was

published in *HortScience* (Lee, 1994). An article published in *Scientia Horticulturae* (Schwarz et al., 2010) had highest number of citations per year (22.08; red line); it was also the most highly cited article based on ESI (Table 7). The number of times that an article is cited is considered a good quantitative measure of the impact of an article.

Conclusions

This study analyzed 2030 articles and review articles of cucumber research from the horticulture category of the WoS. These articles were mainly written in English (92.81%) and were from 5630 authors, 80 countries/territories, and 1094 organizations, and they were published in 46 journals and book series. The top five core journals were ranked as *Scientia Horticulturae*, *HortScience*, *Journal of the American Society for Horticultural Science*, *European Journal of Plant Pathology*, and *Horticulture Journal* (*Journal of the Japanese Society for Horticultural Science*). The top five countries and regions were the United States, People's Republic of China, Japan, South Korea, and India. The top five

Fig. 7. VOSviewer co-occurrence overlay visualization mapping of most frequent keywords (minimum of five occurrences) for cucumber research from the horticulture category of the Web of Science.

organizations were the University of Wisconsin, North Carolina State University, USDA-ARS, Michigan State University, and Nanjing Agricultural University. The top five authors were Todd C. Wehner (Wehner, TC), Jack E. Staub (Staub, JE), Yiqun Weng, R.L. Lower, and S. Tachibana. All keywords of the cucumber research from the horticulture category

Table 7. Top 6 highly cited articles according to the ESI.

Rank	References	TC	ACPY
1	Schwarz, Dietmar; Rouphael, Youssef; Colla, Giuseppe; Venema, Jan Henk, 2010. Grafting as a tool to improve tolerance of vegetables to abiotic stresses: Thermal stress, water stress and organic pollutants. <i>Scientia Horticulturae</i> 127(2 SI):162–171. https://doi.org/10.1016/j.scienta.2010.09.016 .	265	22.08
2	Lu, Hongfeng; Lin, Tao; Klein, Joel; Wang, Shenao; Qi, Jianjian; Zhou, Qian; Sun, Jinjing; Zhang, Zhonghua; Weng, Yiqun; Huang, Sanwen, 2014. QTL-seq identifies an early flowering QTL located near Flowering Locus T in cucumber. <i>Theoretical and Applied Genetics</i> 127(7):1491–1499. https://doi.org/10.1007/s00122-014-2313-z .	127	15.88
3	Ahmed, Golam Jalal; Wu, Meijuan; Wang, Yaqi; Yan, Yaru; Mao, Qi; Ren, Jingjing; Ma, Ronghui; Liu, Airon; Chen, Shuangchen, 2020. Melatonin alleviates iron stress by improving iron homeostasis, antioxidant defense and secondary metabolism in cucumber. <i>Scientia Horticulturae</i> 265:109205. https://doi.org/10.1016/j.scienta.2020.109205 .	33	16.5
4	Zhang, Zhengwei; Wu, Pei; Zhang, Wenbo; Yang, Zhifeng; Liu, Huiying; Ahmed, Golam Jalal; Cui, Jinxia, 2020. Calcium is involved in exogenous NO-induced enhancement of photosynthesis in cucumber (<i>Cucumis sativus</i> L.) seedlings under low temperature. <i>Scientia Horticulturae</i> 261:108953. https://doi.org/10.1016/j.scienta.2019.108953 .	18	9
5	Pan, Yupeng; Wang, Yuhui; McGregor, Cecilia; Liu, Shi; Luan, Feishi; Gao, Meiling; Weng, Yiqun, 2020. Genetic architecture of fruit size and shape variation in cucurbits: a comparative perspective. <i>Theoretical and Applied Genetics</i> 133(1):1–21. https://doi.org/10.1007/s00122-019-03481-3 .	15	7.5
6	Zhang, Tengguo; Shi, Zhongfei; Zhang, Xiaohua; Zheng, Sheng; Wang, Juan; Mo, Jiangnan, 2020. Alleviating effects of exogenous melatonin on salt stress in cucumber. <i>Scientia Horticulturae</i> 262:109070. https://doi.org/10.1016/j.scienta.2019.109070 .	11	5.5

ACPY = average citations per year; ESI = Essential Science Indicators database; TC = total citations.

Fig. 8. Comparison of the citations per year of the eight most cited articles and their initial publications until 29 Mar. 2021.

were separated into eight clusters of different research topics. The analyses and visualizations reported herein offer exploratory information regarding the current status of a scientific field or discipline as well as indicate possible developments in the future.

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