Bibliometric and visual analysis of planthopper research between 1980 and 2017

*Chaoxing Hu and Lingzhen Cao**

Planthoppers are highly destructive pests of rice. We carried out a bibliometric analysis of planthopper research from 1980 to 2017, to retrospect planthopper research progress in recent decades. We found that China leads planthopper research, and that the possible research frontiers are rice resistance or defence to planthoppers, mechanisms controlling planthopper winged morphs, resistance mechanism of planthopper to insecticide imidacloprid, Southern rice black-streaked dwarf virus vectored by planthopper, and molecular and genetic methods in planthopper research (dsRNA, RNAi and genomics).

Keywords: Bibliometric and visual analysis, planthoppers, rice viruses.

PLANTHOPPERS belonging to the family Delphacidae (Hemiptera) mainly include the brown planthopper (*Nilaparvatalugens* (Stål)), white-backed planthopper (*Sogatella furcifera* (Horváth)) and the small brown planthopper (*Laodelphax striatellus* (Fallén))[1], which are some of the most devastating agricultural pests on rice in Asia[1]. These insects damage rice by sucking the sap, and also by transmitting various rice viruses, such as rice black-streaked dwarf virus (RBSDV), Southern rice black-streaked dwarf virus (SRBSDV) and rice ragged stunt virus (RRSV)[2]. Since the 1960s, frequent outbreaks of planthoppers have resulted in huge losses in rice production worldwide. For example, approximately 1 million tonnes of rice is lost annually in China because of planthoppers[3].

Extensive studies have been carried out to develop control programmes to reduce damage by planthoppers. Previous reviews have summarized specific aspects of planthopper research, such as the feeding physiology of brown planthoppers[4], population biology of planthoppers[1], threat of brown planthoppers to high-yielding rice production in tropical Asia[5], rice resistance to planthoppers and leafhoppers[6], and the use of genetics and molecular breeding to improve the resistance of rice to brown planthoppers[7]. These literature surveys, typically prepared by specific domain experts, provide valuable insights into some aspects of planthopper research. However, an overview of planthopper research as a whole is lacking, which would be of benefit to those working in the area.

Therefore, here we provide a scientometric review of the literature related to planthopper research. Scientometrics is mainly concerned with the quantitative characteristics of scientific research and can enable scientists to quickly outline a clear framework for a specific topic[8]. Scientometric literature reviews only provide an additional point of reference; and they are not intended to and cannot replace expert-led reviews.

Based on our scientometric review of the literature, we reveal the intellectual landscape of planthopper research, identifying landmark articles and highlighting emerging research trends. This article provides a broader view of trends in planthopper research and will also benefit researchers in this field to distinguish key papers and essential points of reference from among the vast resources available.

Chaoxing Hu and Lingzhen Cao are in the College of Life Science, Jiangxi Normal University, 330022, Nanchang, China.
*For correspondence. (e-mail: clzclz1011@163.com)

Data and methods

Data collection

This study surveyed papers in the SCIE (Scientific Citation Index Expanded) database of the Web of Science (WoS) published from January 1980 to July 2017 (retrieval date 14 January 2018). We used the keywords 'planthoppers or planthopper' to search the database. The document types used were articles and reviews, and the language was restricted to English. In fact, a large number of articles have been published in other languages like Chinese, Japanese, Thai and Malay, or in local journals. Considering that articles published in SCIE journals could represent the highest research level in this field, some bias in our analysis is acceptable.

CiteSpace

CiteSpace (version 5.1.R2.SE), freely available at http://cluster.cis.drexel.edu/~cchen/citespace/, was used to analyse and visualize patterns and trends in planthopper research. CiteSpace systematically identifies developments in a specific knowledge domain[9]. The intellectual landscape of a scientific field is represented by a network of different entities in CiteSpace, such as countries, authors, keywords and cited references. In a constructed network, these entities are displayed in terms of nodes of different sizes and colours. Citation tree-rings represent the citation history of an article. The colour of a citation ring indicates the time-frame of a corresponding citation. The thickness of a ring is proportional to the number of citations in a given time-period[9].

We used CiteSpace to investigate (i) the structure of the planthopper research base and (ii) research trends in this field. To display the structure of the research base, individual nodes in the network were aggregated into groups based on their interconnectivity. Each group represented a distinct specialty or a thematic concentration. In addition, landmarks nodes, generally with a high frequency count or high betweenness centrality (BC), were used to reveal focus topics in planthopper research. The BC value of a node in a network measures the extent to which the node is part of paths that connect an arbitrary pair of nodes in the network[10]. A node of high BC is usually one that connects two or more large groups of nodes. To reveal the possible research trend(s), CiteSpace identifies emerging topics in terms of entities with high citation burst, such as articles and keywords. Citation burst is an indicator of an active area of research. The citation burst of an entity over time indicates a specific duration in which an abrupt change in frequency occurs (i.e. that the publication has attracted an extraordinary amount of attention from the scientific community). The burst detection in CiteSpace is based on Kleinberg's algorithm[11].

Parameter design

In this study, we set the research period to 1980–2017 and the years per slice to 1. The term source selected were 'title', 'abstract', 'author keywords' and 'keywords plus'. For the selection criterion, we chose the *g*-index, which is an improvement of the *h*-index of Hirsch to measure the global citation performance of a set of articles[12]. In CiteSpace, the *g*-index was modified by introducing a scaling factor, *k* that assisted in controlling the overall size of the resultant network in accordance with our particular needs. *k* can be any positive number and its value is proportional to the size of the resultant network. In this study, we set *k* from 4 to 8 for each time slice. In addition, we chose 'pathfinder' to prune the constructed networks.

Results

Publication output analysis

In total, 2767 articles on planthoppers were indexed from 1980 to 2017. The number of publications on planthoppers remained at <50 from 1980 to 2001, but then showed a yearly increase (Figure 1). The gradual increase in the number of journals could partly explain this uptrend. Especially, four of the top 10 journals with most publications were established after 2000 – *Zootaxa*, *PLOS ONE*, *Scientific Reports* and *Pest Management Science*. This considerable increase in the number of annual publications could also indicate that planthopper research has received increasing attention from the research community.

Co-country analysis

Table 1 shows the top 10 most productive countries in terms of planthopper research from 1980 to 2017. Together, they resulted in 2501 papers, accounting for 90.38% of all published papers. China had the most publications (1058, 38.24%), followed by the USA (432, 15.61%) and Japan (293, 10.59%). China is much ahead of other countries in this research field. These top three countries published more than half (64.44%) of the total number of publications, indicating their leading roles in planthopper research. Given that planthoppers mainly devastate crops grown in Asia, it is not unexpected that half of the top 10 countries are in this continent (China, Japan, India, The Philippines and South Korea). Figure 2 shows 90 country nodes with 333 links. Based on the

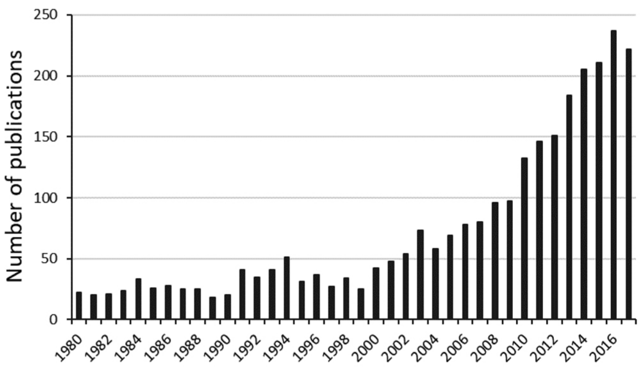

Figure 1. Number of publications in the field of planthopper research (1980–2017).

Table 1. Top 10 most productive countries

Ranking	Frequency	Betweenness centrality	Country
1	1058	0.13	Peoples' R China
2	432	0.18	USA
3	293	0.16	Japan
4	148	0.13	England
5	117	0	India
6	115	0.69	The Philippines
7	95	0.16	Australia
8	85	0.15	France
9	81	0.16	Germany
10	77	0.12	South Korea

number of links with nodes, we can infer that collaboration is active at the country level.

Co-institution analysis

Table 2 lists the top 10 most productive institutions. Together, they resulted in 898 papers, accounting for 32.45% of the total number of papers. Of the top ten most productive institutions, nine are in China, and one, i.e. the International Rice Research Institute (IRRI); ranked 3 in the Philippines. This is consistent with the country results described above, indicating that China is leading in planthopper-related research. The BC values of each of the top 10 institutions are relatively small, which suggests that no research institution has played a central role in any specific research aspect.

As shown by the co-institution network from 1980 to 2017 (Figure 3), there were 303 nodes with 487 links. The links between institutions are relatively few, which suggests less cooperation among them. To more effectively control planthoppers, cooperation between institutions should be encouraged and strengthened in the future.

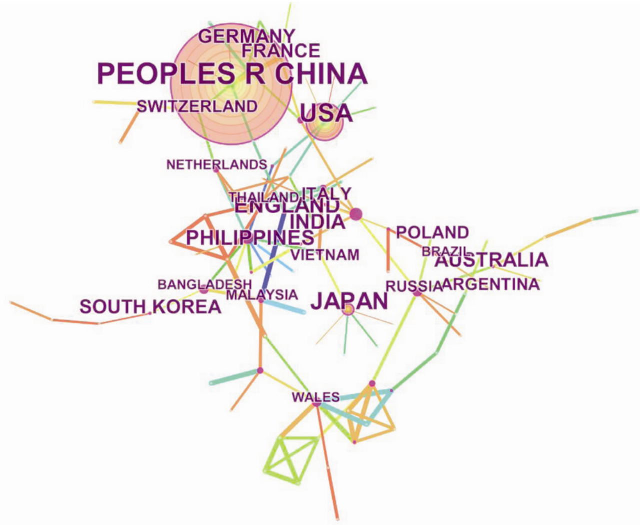

Figure 2. Co-country network in the field of planthopper research from 1980 to 2017 (95 nodes and 371 links).

Figure 3. Co-institution network of planthopper research from 1980 to 2017 (303 nodes and 487 links).

Co-author analysis

The top 10 most productive authors, i.e. those who have contributed the most publications on planthopper research, were identified from the co-authorship network (Table 3). The number of publications by these authors ranged from 33 to 54, but with little difference between them, indicating that there is no obvious leading researcher in this field. Of these ten scientists, nine are from China, highlighting the dominance of the country in this research field.

There were 435 nodes and 734 links in the co-authorship network (Figure 4), which contains all the primary authors of the literature included in the dataset. In the network, the ratio of links by nodes was small, and authors were divided into groups with no obvious links between the groups. This might be because these authors are engaged in different subtopics of planthopper research, or that willingness to cooperate is low. The low BC values in Table 3 reflect, to some extent, this loose network structure (Figure 4).

Co-keywords analysis

The keywords of an article provide information about its core content, and also help us gain an understanding of the development of research topics over time. Therefore, keyword analysis can be used to identify evolving research frontiers relating to a knowledge domain. During our analysis, keywords with the same meaning were combined, such as '*Nilaparvata lugens*' and 'brown planthopper', as well as '*Sogatella furcifera*' and 'white-backed planthopper'.

Table 4 lists the top 20 keywords and Figure 5 displays the co-keywords network of planthopper research. The most cited keyword was '*Nilaparvata lugens*', indicating that this species is the main focus of research, mainly because it causes the most damage to rice crops. Two other important planthoppers, *Laodelphax striatellus* and *Sogatella furcifera*, are also listed in Table 4. Keywords relating to planthopper taxonomy, such as 'insect', 'Hemiptera', 'Delphacidae', 'Fulgoroidea', 'Auchenorrhyncha', 'identification' and 'taxonomy' also appear in Table 4. The inclusion of the keywords 'gene',

Table 2. Top 10 most productive institutions from 1980 to 2017

Ranking	Frequency	BC	Institution	Country
1	182	0.22	Nanjing Agricultural University	China
2	145	0.21	Zhejiang University	China
3	99	0.12	Int Rice Research Institute	The Philippines
4	97	0.12	Chinese Academy Science	China
5	85	0.02	Chinese Academic Agricultural Science	China
6	71	0.21	Yangzhou University	China
7	58	0.01	Wuhan University	China
8	54	0.02	Guizhou University	China
9	54	0.07	Sun Yat Sen University	China
10	53	0	Huazhong Agricultural University	China

Table 3. Top 10 productive authors in the field of planthopper research from 1980 to 2017

Frequency	BC	Author	Current working organization	Country
54	0.12	Wu, J. C.	Yangzhou University	China
49	0.01	He, G. C.	Wuhan University	China
43	0.19	Zhu, L. L.	Wuhan University	China
42	0.03	Matsumura, M.	NARO Kyushu Okinawa Agricultural Research Center	Japan
42	0.11	Zhang, C. X.	Zhejiang University	China
39	0.04	Cheng, J. A.	Zhejiang University	China
39	0.06	Liu, Z. W.	Nanjing Agricultural University	China
39	0	Chen, X. S.	Guizhou University	China
35	0.01	Liang, A. P.	Chinese Academy of Sciences	China
33	0	Lou, Y. G.	Zhejiang University	China

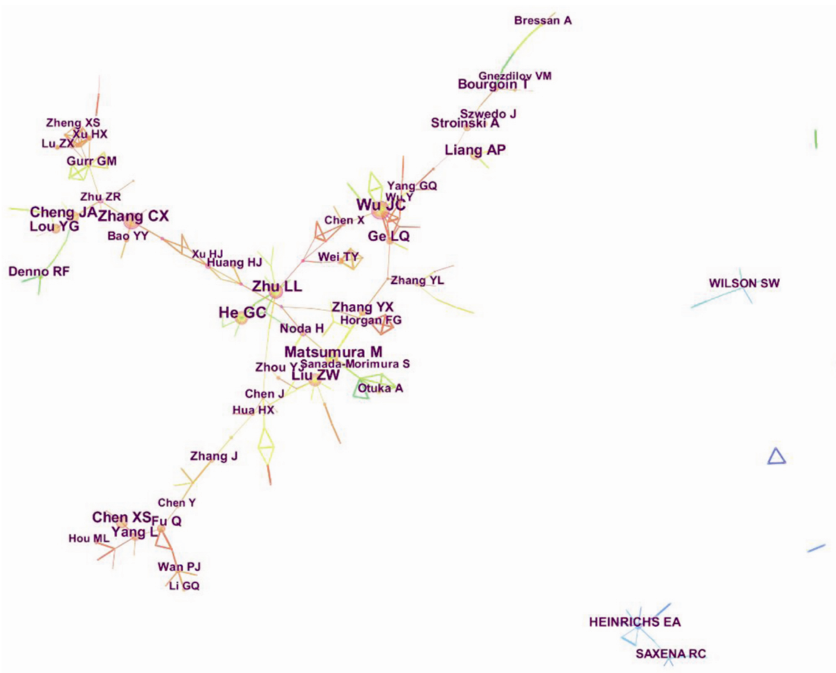

Figure 4. Co-authorship network from 1980 to 2017 (435 nodes and 734 links).

'expression', 'identification' and '*Drosophila melanogaster*' implies the use of molecular techniques in planthopper research. The keywords 'resistance' and 'insecticide' reflect a focus of research on the resistance of planthoppers to some insecticides, whereas 'population' primarily indicates studies relating to planthopper population dynamics. The keywords 'rice', 'plant' and 'resistance' reflect the interaction of planthoppers with their host plant (mainly rice), and the research of rice resistance to planthoppers. Keyword 'China', the only country name, again

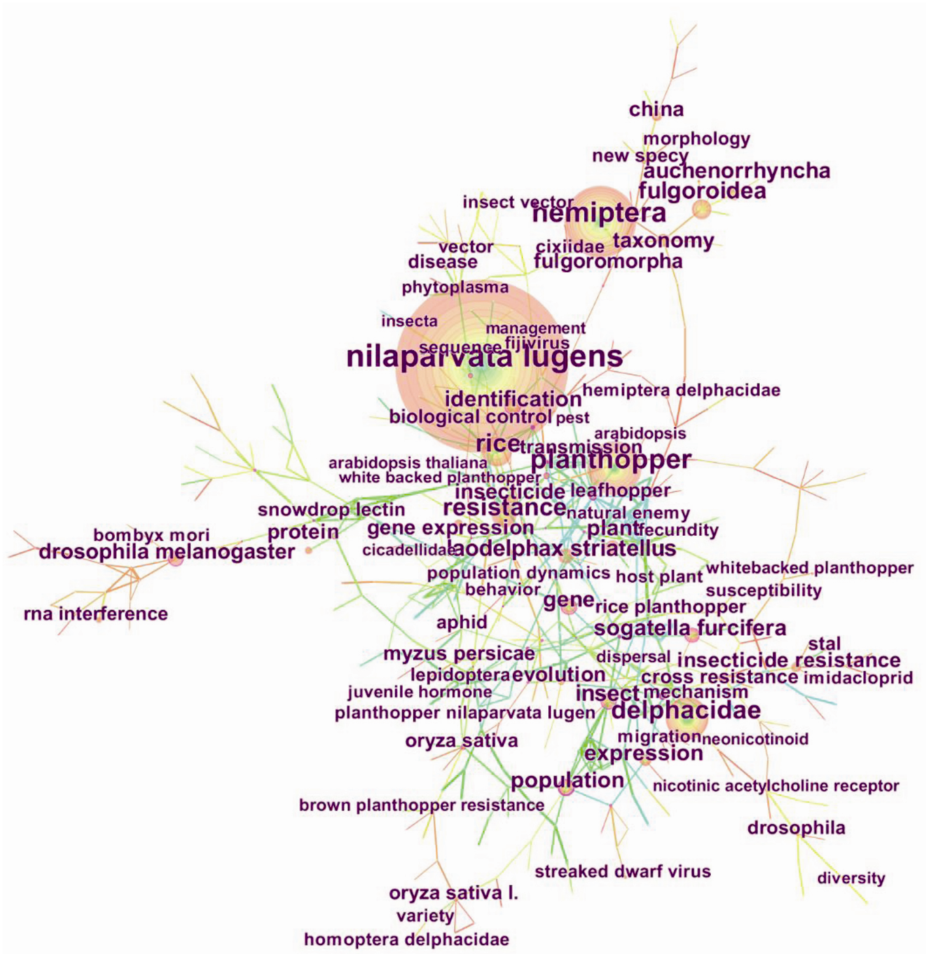

Figure 5. Co-keywords network of planthopper research from 1980 to 2017 (475 nodes and 2239 links).

Table 4. The 20 most frequently used keywords in articles related to planthopper research published from 1980 to 2017

Ranking	Frequency	Keywords	Ranking	Frequency	Keywords
1	1086	*Nilaparvata lugens*	11	136	plant
2	483	Hemiptera	12	134	identification
3	402	planthopper	13	130	population
4	305	Delphacidae	14	129	*Sogatella furcifera*
5	265	rice	15	123	expression
6	221	resistance	16	116	Auchenorrhyncha
7	164	Fulgoroidea	17	107	taxonomy
8	153	*Laodelphax striatellus*	18	104	*Drosophila melanogaster*
9	144	insect	19	103	insecticide
10	139	gene	20	96	China

demonstrates the leading role of China in planthopper research, which is consistent with the results discussed above.

Detecting keywords with strong bursts provides clues to possible new research frontiers (i.e. emerging trends and abrupt changes that occur in a timely manner). Here, 12 keywords with the strongest citation bursts during the study period have been obtained (Table 5). Six of these keywords (‘marker assisted selection’, ‘*drosophila melanogaster*’, ‘genome’, ‘rna interference’, ‘transcriptome’ and ‘molecular characterization’) were related to molecular research methods, indicating the use of biotechnology in planthopper research. Other keywords reflected other trends, such as rice defence to planthoppers research (‘defense’ and ‘marker assisted selection’), population reproduction (‘reproduction’ and ‘genitalia’), environmental effect and adaptation (‘adaptation’ and ‘temperature’).

Figure 6. Co-cited reference network of planthopper research from 1980 to 2017 (538 nodes and 1499 links).

Table 5. Keywords with the strongest citation bursts until 2017

Keywords	Strength	Starting year	Ending year
temperature	3.7263	2012	2017
marker assisted selection	3.7263	2012	2017
Drosophila melanogaster	6.6359	2013	2017
genome	4.9303	2013	2017
RNA interference	8.0648	2013	2017
Hemiptera delphacidae	11.2258	2014	2017
transcriptome	4.1455	2014	2017
fenitalia	6.1261	2014	2017
reproduction	4.2358	2014	2017
adaptation	4.8727	2015	2017
defense	3.9022	2015	2017
molecular characterization	5.7356	2015	2017

Co-cited reference analysis

Co-cited reference analysis is a good means of illustrating the relationships between the source articles in our dataset and the corresponding cited articles in external reference records. The co-cited reference network, containing 538 nodes and 1499 links, displays the main landmark papers and the network structure between them (Figure 6). The most cited articles are usually regarded as landmark papers because of their ground-breaking contributions. The ten most cited articles and their main findings are discussed below (also see Table 6).

(1) In 'identification and characterization of *Bph14*, a gene conferring resistance to brown planthopper in rice', Du *et al.*[13] reported the cloning a gene of rice, which confers resistance to brown planthopper.

(2) In 'resurrecting the ghost of green revolutions past: the brown planthopper as a recurring threat to high-yielding rice production in tropical Asia', Bottrell and Schoenly[5] reviewed factors that contribute to serious outbreaks of brown planthoppers.

(3) In 'southern rice black-streaked dwarf virus: a new proposed Fijivirus species in the family Reoviridae', Zhou *et al.*[14] revealed a novel dwarf disease transmitted by planthoppers in southern China.

(4) In 'genomes of the rice pest brown planthopper and its endosymbionts reveal complex complementary contributions for host adaptation', Xue *et al.*[15] obtained and described genomes of the brown planthopper and its two endosymbionts, and found a series of complex adaptation mechanisms in this species.

(5) In 'feeding-based RNA interference of a trehalose phosphate synthase gene in the brown planthopper, *Nilaparvata lugens*', Chen *et al.*[16] suggested that RNA interference could be useful for controlling brown planthoppers.

(6) In 'insect vector interactions with persistently transmitted viruses', Hogenhout *et al.*[17] reviewed the progress in understanding vector (mainly Hemiptera, such as planthoppers) interactions with the more than 200 plant viruses that they transmit.

(7) In 'Expression of snowdrop lectin (GNA) in transgenic rice plants confers resistance to rice brown planthopper', Rao *et al.*[18] successfully constructed transgenic rice plants containing the Snowdrop lectin (*Galanthus-nivalis* agglutinin) gene, and found that the transgenic rice decreased the survival and overall fecundity of brown planthoppers.

(8) In 'MEGA5: molecular evolutionary genetics analysis using maximum likelihood, evolutionary distance, and maximum parsimony methods', Tamura *et al.*[19] described an evolutionary genetics analysis tool that is commonly used in molecular mechanism analysis. This software is now widely used in planthopper research.

Table 6. Top 10 most cited references related to planthopper research during 1980–2017

ID	Frequency	Year	Reference
1	91	2009	13
2	67	2012	5
3	64	2008	14
4	62	2014	15
5	60	2010	16
6	56	2008	17
7	56	1998	18
8	55	2011	19
9	53	2010	20
10	51	2010	21

Table 7. References with strong citation burst more than 9 until 2017

ID	Reference	Strength	Starting year	Ending year
1	17	11.8242	2010	2017
2	13	9.9681	2012	2017
3	19	12.0443	2012	2017
4	14	18.1461	2012	2017
5	5	13.6364	2013	2017
6	20	10.6046	2013	2017
7	16	10.71	2013	2017
8	22	9.5206	2014	2017
9	6	10.651	2014	2017
10	23	10.934	2014	2017
11	24	9.5206	2014	2017
12	25	15.7074	2015	2017
13	15	22.2333	2015	2017
14	26	12.1073	2015	2017
15	27	9.2576	2015	2017
16	28	10.3681	2015	2017

(9) In 'gene knockdown by intro-thoracic injection of double-stranded RNA in the brown planthopper, *Nilaparvata lugens*', Liu *et al.*[20] successfully used gene knockdown technique in planthoppers, which is essential for their post-genomic investigations.

(10) In 'transcriptome analysis of the brown planthopper *Nilaparvata lugens*', Xue *et al.*[21] assembled the first *de novo* transcriptome of the brown plant hopper and performed the corresponding gene expression analyses.

These ten articles reflect the hot topics of planthopper research. Most of these topics, such as resistance to pesticides, plant virus transmission, and interaction mechanisms with host plants involve the use of molecular techniques, indicating the increasing importance of these approaches in planthopper research.

Articles with strong citation bursts are pioneer studies in a specific research area. Among the references with citation bursts strength more than 9 (Table 7), eight also appear in the list of the most cited references (ID1-7, 13; Table 6), which suggests that they have inspired a significant amount of additional research. Based on analyses of these burst citation articles, we arrived at the following possible research frontiers: (1) virus vectored by planthoppers, especially focused on SRBSDV (ID1, 4, 8, 11); (2) rice resistance or defence to planthoppers (ID 2 and 9); (3) threat of planthoppers to rice production in Asia (ID5); (4) Molecular and genetic methods in planthopper research, such as RNAi (ID 6 and 7) and genome analysis (ID 13); (5) mechanisms of interaction between planthopper and its host rice (ID10); (6) mechanisms controlling wing dimorphism of planthopper (ID12); (7) planthopper identification (ID14), and (8) resistance mechanism of planthopper to insecticide imidacloprid (ID15 and 16).

Conclusion

In summary, a comprehensive bibliometric analysis of literature related to planthopper research from 1980 to 2017 has been made using CiteSpace and WoS. Based on our analysis, we conclude that: (i) a total of 2767 articles were indexed from 1980 to 2017, with an increasing trend each year since 2001; (ii) China was the leading country in planthopper research, followed by USA and Japan, which was supported by the number of the most productive research institutions and authors; (iii) the main research topics were resistance to insecticides, population dynamics, interactions with host plant, and utilization of molecular methods; (iv) the possible research frontiers are rice resistance or defence to planthoppers, mechanisms controlling planthopper winged morphs, resistance mechanism of planthopper to insecticide imidacloprid, SRBSDV vectored by planthopper, and molecular and genetic methods in planthopper research (dsRNA, RNAi and genomics). Thus, our analysis will provide useful information and references for researchers in the field.

1. Denno, R. F. and Roderick, G. K., Population biology of planthoppers. *Annu. Rev. Entomol.*, 1990, **35**(1), 489–520.
2. Otuka, A., Migration of rice planthoppers and their vectored re-emerging and novel rice viruses in East Asia. *Front. Microbiol.*, 2013, **4**(6), 309.
3. Heong, K. L. and Hardy, B., Rice planthopper problems and relevant causes in China, in Planthoppers: new threats to the sustainability of intensive rice production systems in Asia, International Rice Research Institute, Los Baños (Philippines), 2009, pp. 157–178.
4. Sōgawa, K., The rice brown planthopper: Feeding physiology and host plant interactions. *Annu. Rev. Entomol.*, 1982, **27**(1), 49–73.
5. Bottrell, D. G. and Schoenly, K. G., Resurrecting the ghost of green revolutions past: The brown planthopper as a recurring threat to high-yielding rice production in tropical Asia. *J. Asia-Pac. Entomol.*, 2012, **15**(1), 122–140.
6. Fujita, D., Kohli, A. and Horgan, F. G., Rice resistance to planthoppers and leafhoppers. *Crit. Rev. Plant. Sci.*, 2013, **32**(3), 162–191.
7. Hu, J., Xiao, C. and He, Y., Recent progress on the genetics and molecular breeding of brown planthopper resistance in rice. *Rice*, 2016, **9**(1), 30.
8. Hood, W. W. and Wilson, C. S., The Literature of Bibliometrics, Scientometrics, and Informetrics. *Scientometrics*, 2001, **52**(2), 291.

9. Chen, C., CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. *J. Assoc. Inf. Sci. Tech*., 2006, **57**(3), 359–377.
10. Ulrik, B., A faster algorithm for Betweenness Centrality. *J. Math. Sociol*., 2001, **25**(2), 163–177.
11. Kleinberg, J., Bursty and hierarchical structure in streams. In Eighth ACM SIGKDD International Conference on Knowledge Discovery and Data Mining, Edmonton, AB, Canada, 2002, vol. 7, pp. 91–101.
12. Egghe, L., Theory and practise of the *g*-index. *Scientometrics*, 2006, **69**(1), 131–152.
13. Du, B. *et al.*, Identification and characterization of Bph14, a gene conferring resistance to brown planthopper in rice. *Proc. Natl. Acad. Sci. USA*, 2009, **106**(52), 22163–22168.
14. Zhou, G. H., Wen, J. J., Cai, D. J., Li, P., Xu, D. L. and Zhang, S. G., Southern rice black-streaked dwarf virus: A new proposed Fijivirus species in the family Reoviridae. *Chinese Sci. Bull.*, 2008, **53**(23), 3677–3685.
15. Xue, J. *et al.*, 'Genomes of the rice pest brown planthopper and its endosymbionts reveal complex complementary contributions for host adaptation. *Genome Biol.*, 2014, **15**(12), 521.
16. Chen, J. *et al.*, Feeding-based RNA interference of a trehalose phosphate synthase gene in the brown planthopper, Nilaparvata lugens. *Insect Mol. Biol.*, 2010, **19**(6), 777–786.
17. Hogenhout, S. A., Ammar, E. D., Whitfield, A. E. and Redinbaugh, M. G., Insect vector interactions with persistently transmitted viruses. *Annu. Rev. Phytopathol.*, 2008, **46**(1), 327.
18. Rao, K. V. *et al.*, Expression of snowdrop lectin (GNA) in transgenic rice plants confers resistance to rice brown planthopper. *Plant J.*, 1998, **15**(4), 469–477.
19. Tamura, K., Peterson, D., Peterson, N., Stecher, G., Nei, M. and Kumar, S., MEGA5: Molecular evolutionary genetics analysis using maximum likelihood, evolutionary distance, and maximum Parsimony methods. *Mol. Biol. Evol.*, 2011, **28**(10), 2731–2739.
20. Liu, S., Ding, H. Z. P., Zhang, C. W., Yang, B. J. and Liu, Z. W., Gene knockdown by intro-thoracic injection of double-stranded RNA in the brown planthopper, Nilaparvata lugens. *Insect Biochem. Mol. Biol.*, 2010, **40**(9), 666–671.
21. Xue, J. *et al.*, Transcriptome analysis of the brown planthopper nilaparvata lugens. *PLoS One*, 2010, **5**(12), e14233.
22. Zhou, G., Xu, D., Xu, D. and Zhang, M., Southern rice black-streaked dwarf virus: a white-backed planthopper-transmitted fijivirus threatening rice production in Asia. *Front. Microbiol.*, 2013, **4**(4), 270.
23. Cheng, X., Zhu, L. and He, G., Towards understanding of molecular interactions between rice and the brown planthopper. *Mol. Plant*, 2013, **6**(3), 621–634.
24. Pu, L., Xie, G., Ji, C., Ling, B., Zhang, M., Xu, D. and Zhou, G., Transmission characteristics of Southern rice black-streaked dwarf virus by rice planthoppers. *Crop Protection*, 2012, **41**(6), 71–76.
25. Xu, H. J. *et al.*, Two insulin receptors determine alternative wing morphs in planthoppers. *Nature*, 2015, **519**(7544), 464.
26. Bourgoin, T. *et al.*, From micropterism to hyperpterism: recognition strategy and standardized homology-driven terminology of the forewing venation patterns in planthoppers (Hemiptera: Fulgoromorpha). *Zoomorphology*, 2015, **134**(1), 63.
27. Ding, Z., Wen, Y., Yang, B., Zhang, Y., Liu, S., Liu, Z. and Han, Z., Biochemical mechanisms of imidacloprid resistance in Nilaparvata lugens: over-expression of cytochrome P450 CYP6AY1. *Insect Biochem. Mol. Biol.*, 2013, **43**(11), 1021–1027.
28. Bass, C. *et al.*, Overexpression of a cytochrome P450 monooxygenase, CYP6ER1, is associated with resistance to imidacloprid in the brown planthopper, Nilaparvata lugens. *Insect Mol. Biol.*, 2011, **20**(6), 763–773.

ACKNOWLEDGEMENTS. This study was supported by the National Natural Science Funds (No. 31460489) and Jiangxi Provincial Education Department Fund (No. GJJ150333), China.

Received 1 December 2017; revised accepted 29 January 2018

doi: 10.18520/cs/v114/i12/2445-2452