

Trend and impact of plant cell publications: a bibliometric analysis of global research output from 1992 to 2016

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Abstract: The objective of this writing was to conduct a bibliometric analysis of all plant cell publications during the period from 1992 to 2016 by using the Science Citation Index Expanded (SCI-EXPANDED) in the Clarivate Analytics Web of Science database. Basic analysis includes document types, languages, journals, Web of Science categories, distribution by countries and institutes. Indicators such as total, independent, collaborative, first author, corresponding author, and single author publications were applied to compare publication performances by specific countries and institutions of the top ranking. The G7 dominated most of the high impact publications in plant cell research. The high-ranked contributing institutions were non-universities from France, China, Russia, Spain, and USA. University of Tokyo in Japan was the most productive university single out on the top. Plant cell articles were published mainly in Web of Science of plant sciences. *Plant Physiology*, *Plant Journal*, and *Plant Cell* were the top three productive journals on this subject. In addition, top cited and the high impact articles in recent years were also compared. Distributions of words in title, author keywords, and *KeyWords Plus* in different periods were used for searching research focuses.

Keywords: plant cells; citations per publication; publication trends; Web of Science core collection; front page

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1 Introduction

Plants are unique among the eukaryotic organisms whose cells have membrane-enclosed nucleus and organelles (Adl et al., 2012). Plant cells are the basic unit of life in organisms of the Kingdom Plantae (Cavalier-Smith, 2009) and they are characteristic eukaryotic cells or cells with membrane bound nucleus (Pollard and Cooper, 2009). Plant cells are the basic building block and carry out all of the functions necessary for survival of the whole plant (Morant et al., 2007). The most important distinctive structure of plant cells is the presence of the cell wall outside the cell membrane (Cosgrove, 2005). Plant cells contain large central vacuoles (Neuhaus and Rogers, 1998). Vacuoles are related to lysosomes, which have specialized functions in assisting plant growth and playing an important structural role for the plant (Boller and Kende, 1979). Plant cells also contain chlorophyll, giving plants the green color and allows them to perform photosynthesis (van Kooten and Snel, 1990). Photosynthesis, the making of food from harvesting light as an energy, carbon dioxide, and water, occurs in the chloroplasts of the cell (Raghavendra et al., 1994).

Plant cells are relatively large and can differ considerably within a plant (Jin and Martin, 1999). There is a large diversity of different types of cells found through stems, leaves

and roots (Stals and Inzé, 2001). They are separated into different types with different functions:

(1) Parenchyma cells, the majority of cells in a plant, are found in leaves and carry out photosynthesis and cellular respiration, along with other metabolic processes (Gunning and Pate, 1969).

(2) Collenchyma cells provide support to growing parts of a plant, they have thick cell walls, grow and change shape as a plant grows (Jones et al., 1997).

(3) Sclerenchyma cells, hard and tough, also have support function but in the areas of a plant that have ceased growing (Zhong and Zheng, 2007)

(4) Xylem cells transport mostly water and a few nutrients throughout a plant from the roots to the stem and leaves (Zwieniecki et al., 2001).

(5) Phloem cells transport nutrients made during photosynthesis to all parts of a plant. They transport sap, which is a watery solution high in sugars (Karley et al., 2002).

The history of plant cell researches is long but there were some important stages (Thorpe, 2007). In 1756, Henri-Louis Duhamel du Monceau pioneered the experiments on wound healing in plants through spontaneous callus formation on decorticated region of elm plants (Grasso, 1993). Prior to 1839, the science of cell and tissue culture was advanced after proposing the cell theory by Schleiden and Schwann

(Vasil, 2008). In 1908, Simon successfully regenerated a bulky callus, buds, roots from a poplar trees on the surface of medium containing indolic acetic acid (IAA), which plays regulatory role in cell division (Gautheret, 1983). From 1940 to 1970, suitable nutrient media were developed for culturing plant cells, tissue, protoplasts, anthers, roots tips and embryos (Thorpe, 2007). Based on the success of plant cell culturing techniques, many recent advances had been made in the area of micropropagation, production of secondary metabolites and pathogen-free plants, genetic manipulation (Hussain et al., 2012). Plant cell and tissue culture are applied in medical, cultivation, food, biochemistry and others (Burton and Fincher, 2014; Mitani et al., 2017).

This data analysis was designed to determine the trends in articles devoted to plant cell from 1992 to 2016. The bibliometric research data were based on those available from Science Citation Index Expanded (SCI-EXPANDED). Trends in journals analysis, Web of Science category, nationally collaborative publication and author's keywords.

2 Materials and Methods

The data reported in this study were retrieved from the online version of Science Citation Index Expanded (SCI-EXPANDED), the Clarivate Analytics Web of Science Core Collection database (updated on October 30, 2017). Keywords “plant cells”, “plant cell”, “plant cellwalls”, and “plant celle” were searched in terms of topic (including title, abstract, author keywords, and *KeyWords Plus*) within the publication years from 1992 to 2016. *KeyWords Plus* supplies additional search terms extracted from the titles of articles cited by authors in their bibliographies and footnotes in the ISI (now Clarivate Analytics) database, and substantially augments title-word and author-keyword indexing (Garfield, 1990a, b). This yielded 22,591 documents as plant cells-related publications for further analysis. Those documents can only be found in by *KeyWords Plus* are more likely to be unrelated to the “plant cells”. In recent years, Ho's group firstly proposed the “front page” filter (Fu et al., 2012; Fu and Ho, 2014; Ho and Fu, 2016) - which covers only documents with searching keywords in their “front page”, including only the title, abstract, and author keywords - might avoid introducing unrelated publications for analysis (Fu et al., 2012). Finally, 16,972 documents were defined as plant cells-related research publications. The full record of SCI-EXPANDED and the number of citations in each year for each document were downloaded into Microsoft Excel 2013 and additional coding manually performed (Li and Ho, 2008; Ho and Fu, 2016). The journal impact factors (IF_{2016}) were taken from the Journal Citation Reports (JCR) published in 2016.

Affiliations of authors in England, Scotland, Northern Ireland, and Wales were re-grouped as one group by the United Kingdom (UK). Hong Kong before 1997 were included under the heading of China (Fu and Ho, 2013). Yugoslavia were checked and re-classified to Serbia (Wambu et al., 2017), Croatia, or Slovenia. USSR (the Union of Soviet Socialist Republics) were checked and re-classified as Russia (Ho et al., 2016), Ukraine (Wambu et al., 2017), Belarus, Tatarstan, Azerbaijan, or Latvia. Czechoslovakia were checked and re-classified to either Slovakia or Czech Republic (Lin and Ho, 2015). Similarly, Acad Sci USSR was checked and re-classified as being the Russian Acad Sci (Russian Academy of Sciences) and the Tatarstan Acad Sci (Tatarstan Academy of Sciences). Czechoslovak Acad Sci was checked and re-classified as being the Czech Acad

Sci. Minist Publ Hlth USSR was checked and reclassified as being the Minist Publ Hlth Russia.

Contributions of different institutions and countries were estimated by the affiliation of at least one author to the articles (Wang et al., 2010). Collaboration type was determined by the affiliations of the different authors, where the term ‘single country article’ (SP) was assigned if all authors were from the same country. The term ‘internationally collaborative article’ (CP) was designated to those articles that were co-authored by researchers from multiple countries. The term ‘single institute article’ (SI) was assigned if the address of all authors was from a single institute. The term ‘inter-institutionally collaborative article’ (CPI) was assigned if authors were from different institutes.

To investigate the citations received by plant cell-related publications, indicators such as C_{2016} , TC_{2016} , and CPP_{2016} were applied. The impact of papers in the most recent years is considered as the number of citations from Web of Science Core Collection of a paper in 2016 only, C_{2016} (Ho, 2012); citations of papers are considered as the total number of citations since publication to the end of 2016 was referred to as TC_{2016} (Wang et al., 2011; Chuang et al., 2011); and CPP_{2016} , citations per publication ($CPP_{2016} = TC_{2016}/TP$) (Ho, 2012; Chuang and Ho, 2015).

3 Results and Discussion

3.1 Document Type and Language of Publication

During the period examined, there were 16,972 plant cell-related documents from 20 document types found. Article was the most-frequently used document type with 13,517 entries comprising 80% of the total publications. Distribution of document type about plant cell is shown in Table 1. Similar with other fields, review had CPP_{2016} (citation per publication; $CPP_{2016} = TC_{2016}/TP$) higher than article (Ho and Fu, 2016; Wambu and Ho, 2016) because the former emphasizes on major development for each research topic and, as a result readers can read as well as understand easily for the contents for wide citations (Guimarães and Garlini, 2004). The results also recorded that document type of ‘retracted publication’ had highest citation per publication with CPP_{2016} of 221, indicating the attractiveness of the research topic and issue in these publications. The retracted publication entitled “An enhanced transient expression system in plants based on suppression of gene silencing by the p19 protein of tomato bushy stunt virus” (Voinnet et al., 2003) with TC_{2016} of 995 is one of a good example to reach the highest CPP_{2016} in retracted publication in SCI-EXPANDED. This retracted publication was also corrected subsequently two times by the authors (Voinnet, 2015; Voinnet et al., 2015).

Journal articles were used for further analysis because they represented the majority of document types that also included whole the research hypothesis, methods and results (Ho et al., 2010). Thirteen languages were found and only one article was published in a multi-language journal. English (13,306 articles; 98% of 13,517; $CPP_{2016} = 34$) was the most used language, followed distantly by Russian (60; 0.44%; $CPP_{2016} = 1.8$), Chinese (33; 0.24%; $CPP_{2016} =$

Table 1. Distribution of document type

| Document type | TP (%) | TP* | AU | APP | TC ₂₀₁₆ | CPP ₂₀₁₆ |
|--------------------------|-------------|--------|--------|-----|--------------------|---------------------|
| Article | 13,517 (80) | 13,507 | 67,350 | 5 | 446,702 | 33 |
| Review | 2,611 (15) | 2,611 | 7,715 | 3 | 168,041 | 64 |
| Proceedings paper | 631 (3.7) | 631 | 2,400 | 3.8 | 23,479 | 37 |
| Meeting abstract | 448 (2.6) | 443 | 1,827 | 4.1 | 81 | 0.18 |
| Editorial material | 217 (1.3) | 214 | 396 | 1.9 | 4,531 | 21 |
| Book chapter | 155 (0.91) | 155 | 486 | 3.1 | 11,548 | 75 |
| Note | 73 (0.43) | 73 | 265 | 3.6 | 1,634 | 22 |
| Correction | 33 (0.19) | 33 | 148 | 4.5 | 134 | 4.1 |
| Letter | 28 (0.16) | 28 | 79 | 2.8 | 691 | 25 |
| News item | 22 (0.13) | 14 | 17 | 1.2 | 152 | 6.9 |
| Addition correction | 6 (0.035) | 6 | 21 | 3.5 | 3 | 0.5 |
| Biographical-item | 5 (0.029) | 5 | 8 | 1.6 | 1 | 0.2 |
| Retracted publication | 5 (0.029) | 5 | 26 | 5.2 | 1,103 | 221 |
| Reprint | 4 (0.024) | 4 | 6 | 1.5 | 13 | 3.3 |
| Book review | 3 (0.018) | 3 | 3 | 1 | 0 | 0 |
| Discussion | 1 (0.0059) | 1 | 6 | 6 | 2 | 2 |
| Hardware review | 1 (0.0059) | 1 | 4 | 4 | 3 | 3 |
| Item about an individual | 1 (0.0059) | 1 | 1 | 1 | 0 | 0 |
| Retraction | 1 (0.0059) | 1 | 1 | 1 | 0 | 0 |
| Software review | 1 (0.0059) | 1 | 1 | 1 | 0 | 0 |

TP: total articles, TP*: total articles with authors' information in Web of Science; AU: number of authors, APP: number of publication; TC₂₀₁₆: total citations since publication to the end of 2016; CPP₂₀₁₆: citations per publication (TC₂₀₁₆/TP).

1.5), Polish (29; 0.21%; CPP₂₀₁₆ = 1.1), and German (17; 0.13%; CPP₂₀₁₆ = 2.6). Others languages also used in plant cell-related studies, such as French (16 articles), Japanese (16), Portuguese (15), Spanish (12), Czech (9), and one for each of Finnish, Hungarian, and Korean, respectively.

3.2 Characteristics of Publication Outputs

In recent years, Ho's group proposed a relationship between total number of articles in a year (TP) and their citations per publication ($CPP_{year} = TC_{year}/TP$) by the years in a research field as a unique indicator (Chuang et al., 2012; Chuang and Ho, 2015). The annual number of SCI-EXPANDED articles including searching keywords in "front page" for the period examination counted and is displayed in Figure 1. The number of articles was fluctuated with an increase from 324 articles in 1992 to 556 articles in 2008 and another sharply increased from 2008 to 2016. Articles published in the period 1992–2008 had the highest CPP₂₀₁₆. This is not surprising because newly published articles require time to accumulate citations (Picknett and Davis, 1999). The highest CPP₂₀₁₆ was 58 in 2003, this attributed to the four of the top ten articles (TC₂₀₁₆ > 840) such as articles by Khvorova et al. (2003) (TC₂₀₁₆ = 1,446; ranked 1st), Blokhina et al. (2003) (TC₂₀₁₆ = 1,393; ranked 2nd), Foreman et al. (2003), (TC₂₀₁₆ = 1,078; ranked 3rd), and Voinnet et al. (2003) (TC₂₀₁₆ = 995; ranked 5th). Based on Figure 1, it takes CPPs about a decade to reach a plateau. Similarly, highly cited articles in Taiwan (Chuang and Ho, 2015) and articles published in *Journal of Membrane Science* (Fu and Ho, 2015) also took about one decade to reach a plateau. It might be concluded

that to evaluate impact of papers, citations accumulated at least one decade is needed for a good assessment of their active life (Ho and Fu, 2016).

3.3 Journals and Web of Science Categories

In last decade, distribution of Web of Science categories and journals were investigated in research topics (Chiu and Ho, 2007). In total 13,517 plant cells-related articles were published in 1,557 journals in a range of 139 Web of Science categories in SCI-EXPANDED. Distribution of the top 11 productive journals, which published over 200 articles as listed in Table 2. *Plant Physiology* (IF₂₀₁₆ = 6.456) published the most articles with 612 articles (4.5% of 13,517 articles), while *Plant Journal* ranked second with 507 articles (3.8%). Eight of the eleven journals listed in the category of plant sciences. *Journal of Biological Chemistry* was the only one listed in category of biochemistry and molecular biology. *Proceedings of the National Academy of Sciences of the United States of America* and *PLoS One* were listed in category of multidisciplinary sciences. The percentages of leading journals with distribution of articles in plant cell research and other fields were not high (Zhang et al., 2010). Article entitled "Functional siRNAs and miRNAs exhibit strand bias" (Khvorova et al., 2003) published in *Cell* (IF₂₀₁₆ = 30.410) had the highest TC₂₀₁₆ = 1,446 and C₂₀₁₆ = 76 and become the most cited article in this field.

Plant science (5,734 articles), biochemistry and molecular biology (3,389), biotechnology and applied microbiology (1,843), cell biology (1,635), multidisciplinary sciences (877), and microbiology (584) were the top six most popular categories. Comparison of the growth trends of Web of Science categories in a research field is proposed as Figure 1 (Li et al., 2009b). Publishing trends of the six most productive Web of Science categories in plant cell research are shown in Figure 2. The number of publications in the category of microbiology showed a steady growth without any sharp changes, while categories of plant science, biotechnology and applied microbiology, and multidisciplinary sciences showed a period of rapid growth over the last decade. In addition, publications in the category of microbiology might catch up cell biology in the next year based on further extrapolation from the current trend.

3.4 Countries and Institutes

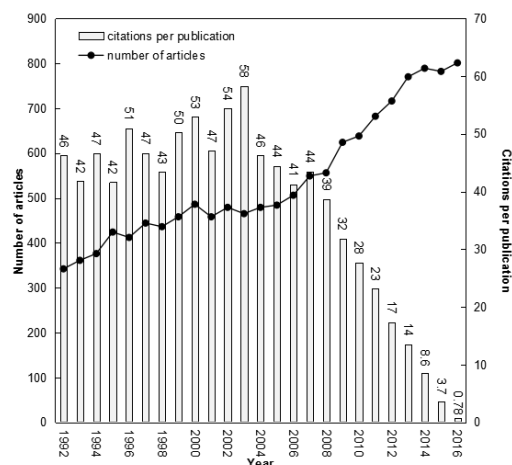
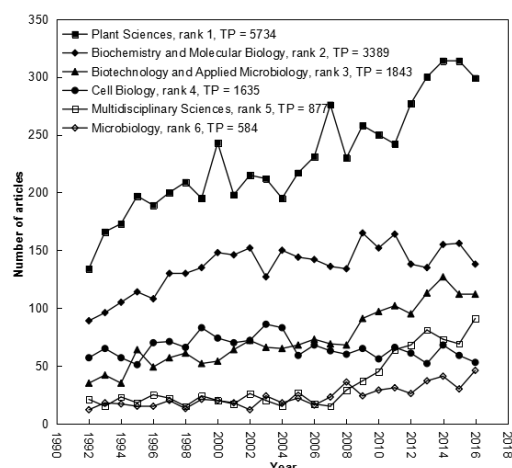
Excluding 47 articles (0.35% of 13,517 articles) without any affiliation information of authors in Web of Science, there were 13,470 articles with author information. Altogether, 10,026 (74% of 13,470 articles) were single country articles and 3,444 (26%) were internationally collaborative articles. The top ten countries, taking up 78% of the 13,470 articles, are listed in Table 3 with six indicators, such as total number of articles, single country articles, internationally collaborative articles, first author articles, corresponding author articles, and single author articles (Ho and Kahn, 2014) as well as CPP₂₀₁₆. The G7 (United States of America, UK,

Table 2. Top eleven productive journals.

| Journal | TP (%) | IF ₂₀₁₆ | Web of Science category |
|---|-----------|--------------------|--|
| Plant Physiology | 612 (4.5) | 6.456 | Plant Sciences |
| Plant Journal | 507 (3.8) | 5.901 | Plant Sciences |
| Plant Cell | 369 (2.7) | 8.688 | Biochemistry and Molecular Biology |
| | | | Plant Sciences |
| | | | Cell Biology |
| Proceedings of the National Academy of Sciences of the United States of America | 327 (2.4) | 9.661 | Multidisciplinary Sciences |
| PLoS One | 269 (2) | 2.806 | Multidisciplinary Sciences |
| Planta | 263 (1.9) | 3.361 | Plant Sciences |
| Journal of Experimental Botany | 258 (1.9) | 5.83 | Plant Sciences |
| Journal of Biological Chemistry | 254 (1.9) | 4.125 | Biochemistry and Molecular Biology |
| Plant and Cell Physiology | 239 (1.8) | 4.76 | Plant Sciences |
| | | | Cell Biology |
| Molecular Plant-Microbe Interactions | 224 (1.7) | 4.332 | Biochemistry and Molecular Biology |
| | | | Biotechnology and Applied Microbiology |
| | | | Plant Sciences |
| Plant Molecular Biology | 218 (1.6) | 3.356 | Biochemistry and Molecular Biology |
| | | | Plant Sciences |

TP (%): rank and the percentage of number of articles; IF₂₀₁₆: impact factor in 2016

Germany, Canada, France, Japan, and Italy), China, Australia, and Spain were ranked the top ten. USA was the most dominant country producing 3,506 articles and ranked top in all six indicators. Japan ranked 2nd for first author, and corresponding author articles separately while Germany ranked 2nd in internationally collaborative, and the UK ranked 2nd in single author articles. The G7 published 8,827 articles (66% of the 13,470 articles with author-affiliation information) with TC₂₀₁₆ of 355,040 (80% of 445,104 citations) and CPP₂₀₁₆ of 40. Domination in publication output by mainstream countries was not surprising because similar pattern has been reported in research on, for example, photosynthesis (Yu et al., 2012), drinking water (Fu et al., 2013), and proteomics (Tan et al., 2014). UK had the highest CPP₂₀₁₆ of 51, followed by USA (47) and Germany (42). China had much lower CPP₂₀₁₆ of 16. Figure 3 illustrates the annual number of articles from the six most productive countries during 1992-2016. USA ranked the first place, showing a slightly growth from 2006 to 2014, while China had a dramatic increasing from 2004 to 2015, number of articles published in this period was getting higher from 26 to 168 and even higher

**Figure 1.** Number of articles and citations per publication by year in the research field of plant cell between 1992 and 2016.**Figure 2.** The top six Web of Science categories during 1992-2016.

than any other countries singularly. This indicates that China has made great progress and developed rapidly in plant cell research in the last decade.

Of the 13,470 articles with author affiliations in Web of Science, 6,164 (46% of 13,470 articles) were single institution articles and 7,306 (54%) were inter-institutionally collaborative articles. Six indicators such as number of total, independent, collaborative, first-author, corresponding-author, and single-author articles were proposed to evaluate publications by institutions and countries (Ho and Kahn, 2014). The top ten productive institutions are listed in Table 4 with these six indicators. Five of the ten top institutions were government research institutions. A bias in institute analysis should be noted that the National Institute of Agricultural Research (INRA) in France (Ho, 2014), the National Center for Scientific Research (CNRS) in France, the Chinese Academy of Sciences in China (Li et al., 2009b), the Russian Academy of Sciences in Russia (Li et al., 2009a), and the Spanish National Research Council (CSIC) (Elango and Ho, 2017) have many branches in different cities. The articles of these five in-

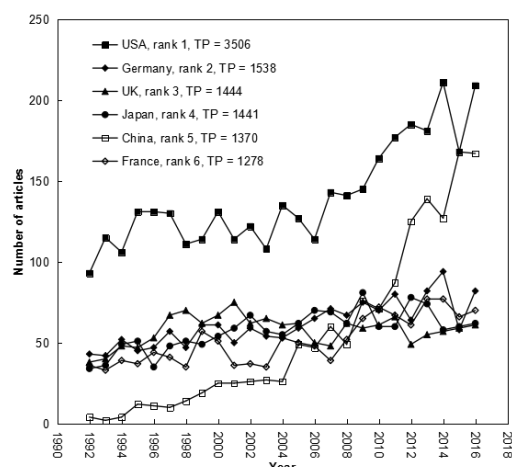


Figure 3. Trends of publications for the top six most productive countries in the research field of plant cell ($TP > 1,000$).

stitutes were pooled under one heading as mentioned in Web of Science respectively, but articles divided into branches would result in different rankings (Li et al., 2009b). INRA in France (303 articles; 2.2% of 13,470 articles) was the most productive institution, a public institute in French that dedicated to agricultural science. Five of the top ten institutes on plant cell research were universities such as University of Tokyo in Japan, Cornell University, Purdue University, University of California Berkeley, and University of Georgia in USA, respectively (Table 4). Similar, it was reported that four of the top ten institutes on photosynthesis research were universities and six were government research institutes (Yu et al., 2012). University of Tokyo in Japan and University of California Berkeley in USA ranked not only top ten on plant cell researches but also photosynthesis research (Yu et al., 2012).

3.5 Top Cited Articles

Ho (2012) proposed total number of citations since publication to the end of the most recent year (C_{year}) and number of citations in the most recent year (C_{year}) to compare with the top cited articles in the research fields. The top ten cited articles with TC_{2016} and C_{2016} in plant cell field is listed in Table 5. Cell ($IF_{2016} = 30.41$) was the only one journal published two highly cited articles. Other journals such as *Advanced Functional Materials* ($IF_{2016} = 12.124$), *Annals of Botany* ($IF_{2016} = 4.041$), *Nature* ($IF_{2016} = 40.137$), *Phytochemistry* ($IF_{2016} = 3.393$), *Plant Journal* ($IF_{2016} = 5.901$), *Science* ($IF_{2016} = 37.205$), *Current Biology* ($IF_{2016} = 8.851$), and *Journal of Experimental Botany* ($IF_{2016} = 5.830$) published only one of the top ten articles respectively. USA dominated publications in the highly cited articles (50%). Articles entitled “Engineered GFP as a vital reporter in plants” (Chiu et al., 1996) was the only one internationally collaborative article by USA and Japan. Six of the top ten highly cited articles (TC_{2016}) can also be found in the top ten high impact articles in the most recent year (C_{2016}). In pluripotent stem

cell research, six of the top ten articles in TC_{year} can be also found in the top ten in C_{year} (Lin and Ho, 2015). In top ten most cited articles, only two published in 1990s. The most cited articles was “Functional siRNAs and miRNAs exhibit strand bias” (Khvorova et al., 2003) with TC_{2016} of 1,446 and C_{2016} of 76 ranked in 13th while the most impact article in the most recent year entitled “Breaking the code of DNA binding specificity of TAL-Type III effectors” (Boch et al., 2009) with C_{2016} of 196 and TC_{2016} of 939 ranked in 6th. In this article, the authors showed how target DNA specificity of transcription activatorlike effectors from plant pathogenic is encoded and the new specificities of the modular protein architecture enabled the construction of artificial effectors (Boch et al., 2009).

A historical perspective of the eight highly cited articles with over 870 citations is shown in Figure 4. Two articles published in 1990s had a rapid increasing from the publishing year, but after several years, citation of these articles decreased and kept fluctuated to the end of the period examined in this analysis. Otherwise, two articles published in 2000s with the most citations in 2016 (C_{2016}) showed citations increased sharply and kept up to the end of period. It is clear from Figure 4 that the highly cited articles might not always maintain high impact or visibility after publication (Ho and Kahn, 2014).

3.6 Hot Issues

Word cluster which uses supporting words in title, abstract, author keywords, and *KeyWords Plus* to find the main research focuses and then research trends (Mao et al., 2010; Wang and Ho, 2016). This method can analyze the historical development of the science more completely and precisely, and more importantly, to discover the directions the science is taking (Chen and Ho, 2015; Zheng et al., 2017). Each word cluster was composed of several supporting words that include plural forms, abbreviations, and other transformations, as well as words with similar meaning from words in title, abstract, author keywords, and *KeyWords Plus* analysis results. Then the word cluster can also search combined words from abstract of the related publications. Finally, by analyzing the number of publications containing these “word clusters”, the overview of the research hotspots could be revealed. For example, “*Arabidopsis*”, “*Arabidopsis thaliana*”, “*Arabidopsis-thaliana*”, and “*thaliana*”, constitute a word cluster for a research focus on *Arabidopsis*, and another one is “wall”, “cell wall”, and “plant cell walls” were supported for plant cell wall to be hotspots. Figure 5 shows the research trends for the topics of “*Arabidopsis*” and “plant cell wall” with the most articles were classified respectively from 1992 to 2016. “Pectins: Structure, biosynthesis, and oligogalacturonide-related signaling” by Ridley et al. (2001) was the most frequently cited article in plant cell wall research with TC_{2016} of 876. Authors described new methods that may be useful to study localized pectin structure in the plant cell wall. Pectin is biosynthesized and reviewed the biological activities and possible modes of action of pectic

Table 3. Top 10 most productive countries

| Country | <i>TP</i> | <i>TPR</i> (%) | <i>IPR</i> (%) | <i>CPR</i> (%) | <i>FPR</i> (%) | <i>RPR</i> (%) | <i>SPR</i> (%) | <i>CPP</i> ₂₀₁₆ |
|-----------|-----------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|----------------------------|
| USA | 3,506 | 1 (26) | 1 (22) | 1 (38) | 1 (20) | 1 (20) | 1 (25) | 47 |
| Germany | 1,538 | 2 (11) | 4 (7.5) | 2 (23) | 4 (8.0) | 4 (8.0) | 3 (9.6) | 42 |
| UK | 1,444 | 3 (11) | 5 (6.6) | 3 (23) | 5 (7.4) | 5 (7.3) | 2 (12) | 51 |
| Japan | 1,441 | 4 (11) | 2 (11) | 6 (11) | 2 (9.4) | 2 (9.4) | 4 (8.3) | 32 |
| China | 1,370 | 5 (10) | 3 (10) | 5 (11) | 3 (9.1) | 3 (9.3) | 13 (1.5) | 16 |
| France | 1,278 | 6 (9.5) | 6 (6.3) | 4 (19) | 6 (6.8) | 6 (6.8) | 7 (4.6) | 39 |
| Canada | 556 | 7 (4.1) | 8 (2.9) | 7 (7.7) | 7 (2.9) | 7 (2.9) | 8 (3.9) | 32 |
| Australia | 470 | 8 (3.5) | 11 (2.3) | 9 (7.0) | 12 (2.4) | 12 (2.4) | 9 (2.4) | 32 |
| Spain | 462 | 9 (3.4) | 14 (2.0) | 8 (7.6) | 11 (2.5) | 11 (2.4) | 14 (1.3) | 32 |
| Italy | 454 | 10 (3.4) | 10 (2.6) | 12 (5.7) | 9 (2.6) | 9 (2.6) | 10 (1.8) | 29 |

TP: total articles, *TPR*(%): total number of articles and the percentage of total articles; *IPR*(%): rank and percentage of single country articles; *CPR*(%): rank and percentage of internationally collaborative articles; *FPR*(%): rank and the percentage of first author articles; *RPR*(%): rank and the percentage of the corresponding authored articles; *SPR*(%): rank and the percentage of the single authored articles; *CPP*₂₀₁₆: citations per publication (*TC*₂₀₁₆/*TP*).

Table 4. Top 10 productive institutions

| Institute | <i>TP</i> | <i>TPR</i> (%) | <i>IPR</i> (%) | <i>CPR</i> (%) | <i>FPR</i> (%) | <i>RPR</i> (%) |
|--|-----------|----------------|----------------|----------------|----------------|----------------|
| National Institute of Agricultural Research (INRA), France | 303 | 1 (2.2) | 7 (0.94) | 2 (3.4) | 2 (1.2) | 3 (1.2) |
| National Center for Scientific Research (CNRS), France | 287 | 2 (2.1) | 19 (0.63) | 1 (3.4) | 6 (0.83) | 6 (0.84) |
| Chinese Academy of Sciences, China | 266 | 3 (2.0) | 5 (1.0) | 3 (2.8) | 3 (1.2) | 2 (1.3) |
| Russian Academy of Sciences, Russia | 261 | 4 (1.9) | 1 (2.6) | 14 (1.4) | 1 (1.7) | 1 (1.7) |
| University of Tokyo, Japan | 230 | 5 (1.7) | 15 (0.68) | 4 (2.6) | 5 (0.93) | 4 (0.94) |
| Cornell University, USA | 191 | 6 (1.4) | 2 (1.3) | 9 (1.5) | 4 (1.0) | 5 (0.91) |
| Purdue University, USA | 177 | 7 (1.3) | 4 (1.0) | 6 (1.5) | 7 (0.82) | 8 (0.76) |
| University of California, Berkeley, USA | 170 | 8 (1.3) | 8 (0.92) | 6 (1.5) | 8 (0.79) | 7 (0.77) |
| University of Georgia, USA | 158 | 9 (1.2) | 9 (0.89) | 14 (1.4) | 11 (0.71) | 14 (0.64) |
| Spanish National Research Council (CSIC), Spain | 156 | 10 (1.2) | 17 (0.65) | 5 (1.6) | 9 (0.76) | 10 (0.70) |

TP: total articles, *TPR*(%): total number of articles and the percentage of total articles; *IPR*(%): rank and percentage of single institute articles; *CPR*(%): rank and percentage of inter-institutionally collaborative article; *FPR*(%): rank and the percentage of first author articles; *RPR*(%): rank and the percentage of the corresponding authored articles; *SPR*(%): rank and the percentage of the single authored articles.

oligosaccharides referred to as oligogalacturonides (Ridley et al., 2001). The top five plant cell wall articles published by Martinez et al. (2008), Torney et al. (2007), Martin et al. (2008), Kaku et al. (2006), and Abad et al. (2008), affected a sharply increasing on plant cell wall research from 2007 (Figure 5). In addition, article entitled “Reactive oxygen species produced by NADPH oxidase regulate plant cell growth” by Foreman et al. (2003) was the most frequently cited *Arabidopsis* article which ranked 3rd in both *TC*₂₀₁₆ and *C*₂₀₁₆ in plant cell research respectively. The number of articles related “*Arabidopsis*” had increased period from 1992 to 2004 and after that it showed fluctuated increase while studies on plant cell wall rose rapidly and have taken the lead in recent years especially from 2007 to 2016. Therefore, in next researches, “*Arabidopsis*” will become the topic that concerned by researchers.

4 Conclusion

In total 16,972 plant cells-related papers published from 1992 to 2006 with 20 document types were found in SCI-EXPANDED. English was the dominant language in these articles. Article was the most common document type considered. The citation history of selective articles showed that plant cell researches were given an increasing amount of attention over the period from 1992 to 2016. Articles published before 2003 had higher annual citations per publication and articles need about one decade to reach a plateau on their citations per publication. *Plant Physiology* was the most popular journal listed in Web of Science category of plant sciences, which dominated plant cells research. USA contributed the most articles, followed by Germany and United Kingdom. The Institut National de la Recherche Agronomique (INRA)

Table 5. Top 10 productive institutions

| Rank (<i>TC</i> ₂₀₁₆) | Rank (<i>C</i> ₂₀₁₆) | Articles |
|---------------------------------------|--------------------------------------|--|
| 1 (1,446) | 13 (76) | Khvorova, A., Reynolds, A. and Jayasena, S.D., 2003. Functional siRNAs and miRNAs exhibit strand bias. <i>Cell</i> , 115(2), 209-216. |
| 2 (1,393) | 2 (155) | Blokhina, O., Virolainen, E. and Fagerstedt, K.V., 2003. Antioxidants, oxidative damage and oxygen deprivation stress: a review. <i>Annals of Botany</i> , 91(2), 179-194. |
| 3 (1,078) | 3 (108) | Foreman, J., Demidchik, V., Bothwell, J.H.F., Mylona, P., Miedema, H., Torres, M.A., Linstead, P., Costa, S., Brownlee, C., Jones, J.D.G., Davies, J.M. and Dolan, L., 2003. Reactive oxygen species produced by NADPH oxidase regulate plant cell growth. <i>Nature</i> , 422(6930), 442-446. |
| 4 (1,005) | 98 (29) | Chiu, W.L., Niwa, Y., Zeng, W., Hirano, T., Kobayashi, H. and Sheen, J., 1996. Engineered GFP as a vital reporter in plants. <i>Current Biology</i> , 6(3), 325-330. |
| 5 (995) | 7 (93) | Voinnet, O., Rivas, S., Mestre, P. and Baulcombe, D., 2003. Retracted: An enhanced transient expression system in plants based on suppression of gene silencing by the p19 protein of tomato bushy stunt virus. <i>Plant Journal</i> , 33 (5), 949-956. |
| 6 (939) | 1 (196) | Boch, J., Scholze, H., Schornack, S., Landgraf, A., Hahn, S., Kay, S., Lahaye, T., Nickstadt, A. and Bonas, U., 2009. Breaking the code of DNA binding specificity of TAL-type III effectors. <i>Science</i> , 326(5959), 1509-1512. |
| 7 (876) | 14 (72) | Ridley, B.L., O'Neill, M.A. and Mohnen, D., 2001. Pectins: structure, biosynthesis, and oligogalacturonide-related signaling. <i>Phytochemistry</i> , 57(6), 929-967. |
| 8 (873) | 495 (13) | Bradley, D.J., Kjellbom, P. and Lamb, C.J., 1992. Elicitor-and wound-induced oxidative cross-linking of a proline-rich plant cell wall protein: a novel, rapid defense response. <i>Cell</i> , 70(1), 21-30. |
| 9 (856) | 5 (104) | Slowing, I.I., Trewyn, B.G., Giri, S. and Lin, V.S.Y., 2007. Mesoporous silica nanoparticles for drug delivery and biosensing applications. <i>Advanced Functional Materials</i> , 17(8), 1225-1236. |
| 10 (847) | 4 (106) | Alscher, R.G., Erturk, N. and Heath, L.S., 2002. Role of superoxide dismutases (SODs) in controlling oxidative stress in plants. <i>Journal of Experimental Botany</i> , 53(372), 1331-1341. |

*TC*₂₀₁₆: total citations since publication to the end of 2016; *C*₂₀₁₆: citations in 2016 only.

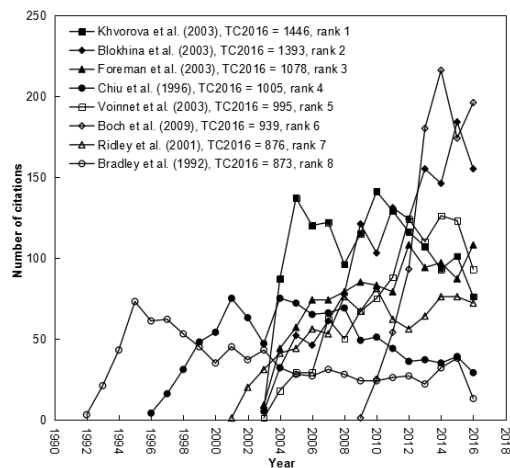


Figure 4. The top eight most frequently cited articles in the research field of plant cell.

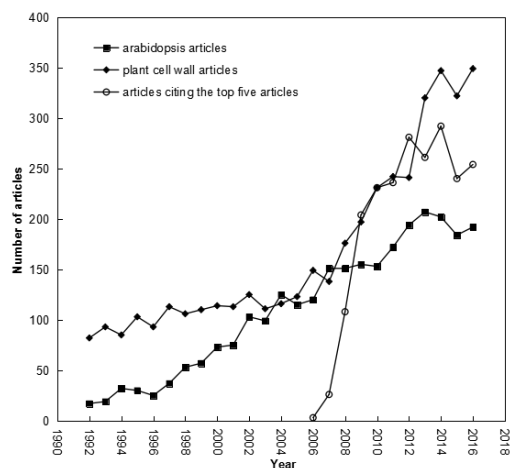


Figure 5. Comparison of the trends of plant cell related items.

in France was the most active in the plant cell research. University of Tokyo in Japan was the leading university in the world. Six of the top ten highly cited articles were also ranked in the top ten citations in the most recent year. Trends analysis showed that plant cell research mainly focuses on “*Arabidopsis*” and “plant cell wall”.

Conflict of Interest Statement

No conflict of interest was reported by the authors.

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