Worldwide trends on *Ophiocordyceps sinensis*: A bibliometric analysis (1970-2016)

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Abstract This study aims to examine the literature related to the *Ophiocordyceps sinensis* (*O. sinensis*) that are published from 1970 to 2016 through bibliometric methods based on databases of Web of Science™ Core Collection. Out of 811 retrieved publications, 82.8% were journal articles. The patterns of these articles such as countries, institutions, journals and authors, as well as subject categories, hot topics and the most highly cited articles were investigated. Visualized tool CiteSpace and traditional methods were employed. Results show a growth of publications related to *O. sinensis* with China being the leading country contributing the largest number of articles with the greatest influence. The Chinese Academy of Sciences is the leading institute in *O. sinensis* research, followed by the Hong Kong Polytechnic University. Most journal articles were related to polysaccharide, cell, extract, and antioxidant activity. Burst detection methods shows that environmental science, ecology, polymer science, multidisciplinary science, structural characterization and conservation are the prominent directions of future *O. sinensis* research. These findings identify hotspots in the *O. sinensis* research. Similarly, the present study provides policymakers useful information on subtopic selection and publication strategy in *O. sinensis* research.

Keywords: Bibliometric analysis· *Ophiocordyceps sinensis*· Traditional Chinese medicine· Future research directions

1. Introduction

Ophiocordyceps sinensis (Berk.) GH Sung et al. [=*Cordyceps sinensis* (Berk.) Sacc., anamorph: *Hirsutella sinensis* Liu, Guo, Yu & Zeng] (Ascomycota) is a tremendously rare and precious Traditional Chinese Medicine (TCM) that tonify the kidneys and lungs mainly used

to treat asthma, bronchitis, lung inflammation, night sweats, and other diseases (Hiyoshi, Fujiwara et al. 1996, Bucci 2000, Shao, Zhao et al. 2003, Hyde, Bahkali et al. 2010, Silva, Rapior et al. 2012, Zhang, Lin et al. 2014, Chen and Li 2015,Sung, Hywel-Jones et al. 2007). *O. sinensis* was recorded in the Chinese Pharmacopoeia from 1963 to 2015 editions. In the 18th century (1785), British mycologist Dickson introduced *O. sinensis* to western countries , and the species became known to the world, from which the door of modern international research was opened (Arber 1938, Cunningham, Manson et al. 1950). *O. sinensis* caught the attention of western herbalists in 1993, when Chinese track coach Ma Junren claimed that *O. sinensis*–based concoctions boosted the stamina of his record-setting runners(Stone 2008). The natural distribution of *O. sinensis* and its host is limited to alpine meadows in the Himalayas and on the Tibetan Plateau, between 3000 and 5000 m elevation, including parts of China, Bhutan and Nepal (Zang and Kinjo 1998). The current price of *O. sinensis* has reached US $45 000–90 000 KG^{-1} given its famous curative effect and reduced supply with its volume of trade ranges from 100 to 200 tonnes per year {Shrestha, 2012;Cannon, 2009;Winkler, 2009;Yen, 2015}. *O. sinensis* has been listed as an endangered species of the national key preserved wild plants in China (http://www.forestry.gov.cn/portal/main/s/3094/minglu1.htm). The high price has led to the emergence of many counterfeited products in the market, the morphological characteristics of which were almost the same, thereby causing confusion and threatening the safe use(Hsiaoche Kuo, Yonglin Su et al. 2005, Li, Yang et al. 2006, Choi, Shin et al. 2010). This high price also resulted in illegal harvest. *O. sinensis* grows poorly in laboratories because of technical limits; and thus, the majority of trades are satisfied through the wild harvest of insects (Stone 2008, Shrestha 2012, Zhang, Liang et al. 2016). Chinese entomologists estimate that more than 1 million individuals forage for *O. sinensis* on the Tibetan Plateau alone (Stone 2008). Unplanned harvest of the wild *O. sinensis* rapidly reduced the range of this species (Stone 2008, Yan, Li et al. 2017).

Several studies have been conducted on *O. sinensis* but none has explored the systematic and long time-span research on *O. sinensis*-related publications. Therefore, a quantitative evaluation of the increasing number of literature using bibliometric techniques is necessary. The present study aims to discover the global literature from 1970 to 2016. The global trends in *O. sinensis* research over the past 46 years are examined by analysing the general patterns in publications, languages, journals, subject category, country, institution, highly cited articles and hot topics. These findings provide useful information for future research and offer advice for policymakers.

2. Methodology and data

1. Data sources

The widely-accepted Science Citation Index (SCI) database is the most reliable bibliographic resource with its broad application in revealing patterns in various scientific fields (Liu, Liang et al. 2011, Zhuang, Liu et al. 2013, Fu and Ho 2016, Leydesdorff, Bornmann et al. 2016). For the data source, we accessed the online version of the Web of Science SCI Expanded database given that this database covers most of the important journals in the fields of natural and medical sciences (Braun, Schubert et al. 1997, Yu, Wei et al. 2016). We used the subject of "*Cordyceps sinensis*" and "*Ophiocordyceps sinensis*" as the research term to collect 811 publications, all of which were published from 1970-2016(Sung, Hywel-Jones et al. 2007).

2. Methods

Bibliometrics is a widely recognised, well-established research method in information science particularly for the evaluation of research performance of academics and universities. This method adopts quantitative analysis and statistical methods to analyse the quantitative relation and content information in a given field. Furthermore, this method examines the detailed characteristics and feature patterns of a research field. Bibliometric analysis has been used in various scientific fields, such as global groundwater, sustainable development, climate change and solar energy (Li, Wang et al. 2011, Dong, Xu et al. 2012, Hassan, Haddawy et al. 2014, Niu, Loáiciga et al. 2014). Most historians have generally recognised that bibliometrics owes its systematic development largely to Price and Garfield, the founders of the method (Godin 2006, Nicolaisen 2010). Traditional bibliometric method analysed the research trends of certain fields mainly from their publication output, subject category and journal, author, country and research institute, keyword frequencies and other factors (Almeidafilho, Kawachi et al. 2003). However, bibliometric network analysis has recently been increasingly applied to analyse the relationships between keywords, countries and research institutes and authors. Common network analysis includes co-word, co-citation, co-authorship and co-publication analyses, among others (Glänzel 2000, Seglen and Aksnes 2000, Ding, Chowdhury et al. 2001, He and Hui 2002, Lai and Wu 2005, Schmoch and Schubert 2008). Burst detection method indicates that the study subject changed sharply over a short period (Chen, Hu et al. 2012). We use CiteSpace software to conduct collaboration network analysis and burst detection (Synnestvedt, Chen et al. 2005, Chen 2009).

3. Results

1. General statistics

Among the 811 publications retrieved from Web of Science, 710 are articles (82.8%), followed by meeting abstracts (7.5%) and reviews (5.1%). Proceeding papers, letters, editorial materials, book chapters and corrections accounted for as low as 4.6% of the total

O. sinensis-related publications. Therefore, only articles were further analysed in this research. Articles related to *O. sinensis* used four languages. The vast majority of these articles were written in English with 797 records, accounting for 98.3%, followed by Chinese (1.0%) and Japanese (0.6%), as well as one Hungarian. Thus, English is the predominant language in *O. sinensis* research even in non-English speaking countries such as China and Japan.

1. Numbers of publications by countries

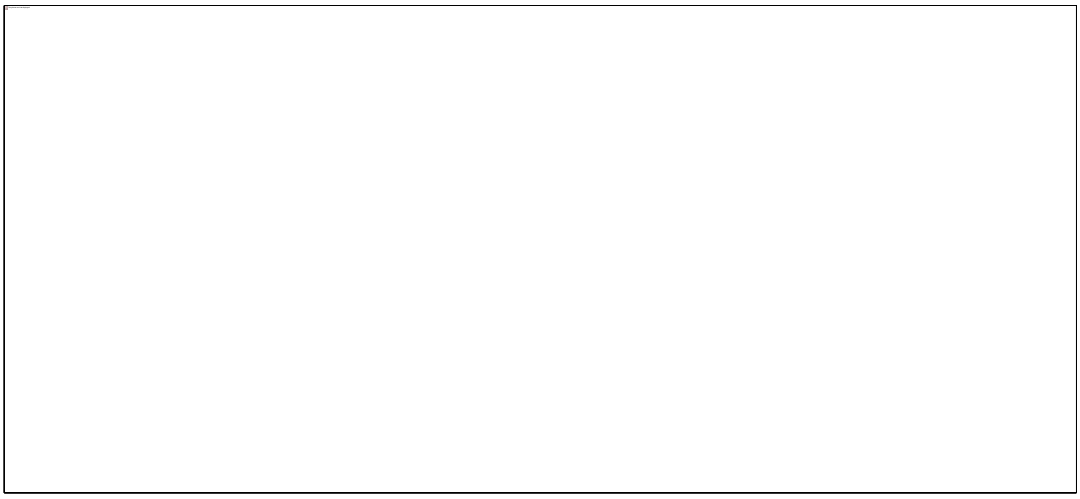

Fig. 1 Numbers of TP, TC and ACPP during the period of 1977-2016. TP: total publication; TC: total citation; ACPP: average citation per year per paper. Note: Countries in orange, green and yellow respectively correspond to the annual first, second and third largest published countries.

As shown in Fig. 1, the number of publications related to the *O. sinensis* grew unstable during the past 40 years. The figure indicates that total publication (TP) increased slowly in the first 24 years and then rapidly in 2000. The articles published in the last 16 years accounted for 96.3% of the total publications. Total citation (TC) peaked in 2006 with 1084, but the average citation per year per paper (ACPP) was constant, indicating that few papers were cited frequently. Other evident peaks included that in 1996 with 200 and in 1998 with 525. The peak in the 1988 ACPP was the highest in the period 1977-2016. The year 2001 recorded 688 publications, 567 in 2003 and 982 in 2009. In 2009, China, Bhutan, India and Nepal held a meeting supported by the World Wide Fund for Nature or World Wildlife Fund to discuss the resource management and trade area of *O. sinensis*. The event encouraged source countries of *O. sinensis* to strengthen the protection and rational and scientific use of *O. sinensis* and to ensure the sustainable development of these resources in the local, social, economic and ecological environments. By the end of 2012, the TC dropped gradually arguably due to the time required for the accumulated effects of new publications. In addition, the annual top countries in terms of publication include China (CN), USA (US),

Japan (JP), South Korea (KR), India (IN), Canada (CA), United Kingdom (UK) and Australia (AUS). Fig. 3 illustrates the geographical distribution of the total publications of 45 countries. China has been the topmost productive country from 1992 to 2016, reflecting its constant concern for *O. sinensis*. Japan was the first country to start the research, and three of the four earliest papers were from Japan, thereby establishing its position in this field.

Fig. 2a presents the collaborative relationship among countries. China and USA enjoy the widest cooperation among all the countries, and they equally cooperate with nine countries, in which France, Canada, India, South Korea and Ukraine are common collaborators. China, Australia, Israel and Taiwan (China) and five common countries cooperate with USA. Among these nine countries, Canada and USA cooperate more closely. USA, Thailand, Japan and UK and five common countries cooperate with China. Among these nine countries, Japan and China cooperate more closely. Fig. 2b shows the top 10 productive countries that published 890 records, accounting for 110% of the total searched publications, including China (69.5%), USA (10.6%), Japan (7.3%), South Korea (5.7%), India (5.4%), Canada (2.5%), UK (1.6%), Australia (1.5%), Thailand (1.5%) and France (1.4%). A total of 45 countries/regions were involved in *O. sinensis* research, and the full proportion was 119.5%, indicating that the cooperation among these countries was not high (The proportion was beyond 100% because of multi-national cooperation). Among these productive countries, China is the most productive, reflecting its leadership in the field of *O. sinensis*.

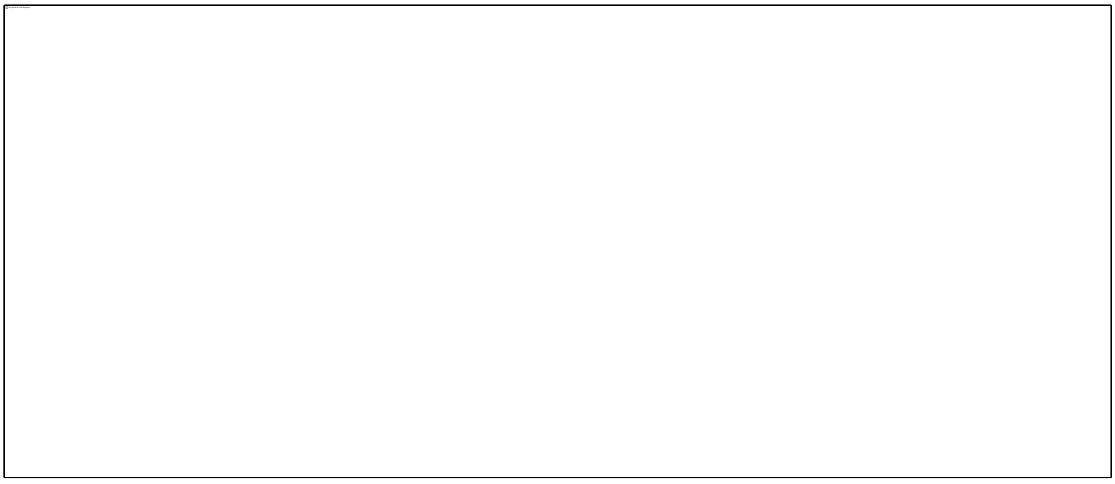

Fig. 2 a Cooperation relationship between countries; b The top 10 productive countries.

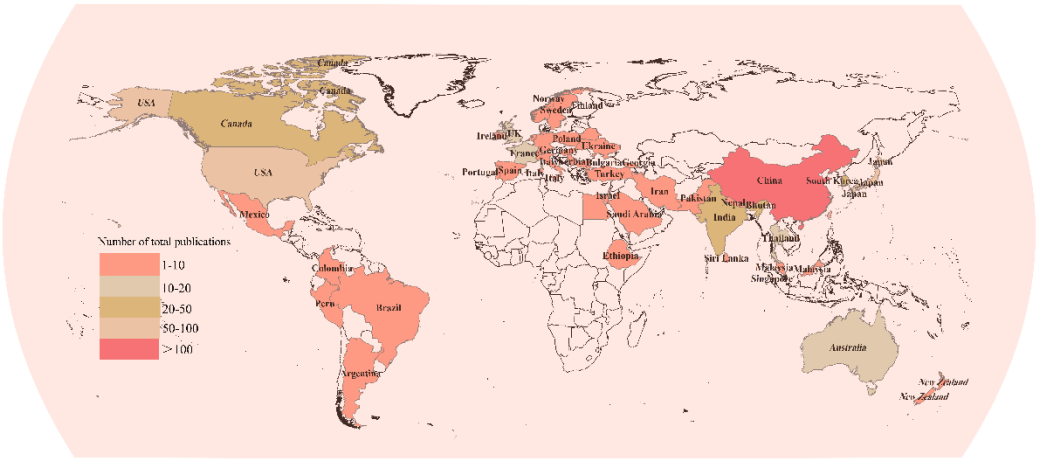

Fig. 3 Geographical distribution of publications, 1977-2016.

2. Institution statistics

Table 1 lists the performances of the top 10 productive institutions. Nine institutions are located in China, suggesting that Chinese research institutions (including universities and research institutes) are more active in such a field than other countries. The Chinese Academy of Sciences (Chinese Acad Sci) ranked first given that China is the No. 1 country in *O. sinensis* research. The Mukogawa Women's University is the only institution from Japan, and it ranked as the sixth productive institution globally. Within the top 10 productive institutions, none is from the USA although it is the second productive country, indicating that the study of *O. sinensis* in USA is scattered and discontinuous. Fig. 4 shows the collaborations between the institutes. Chinese Academy of Sciences plays an important role in domestic cooperation, but with insufficient in international collaboration. The Mukogawa Women's University conducts research independently.

Table 2 and Fig. 5 present the time evolution of the 10 most productive institutions from 1995 to 2016. An irregular tendency was generally observed in the number of publications from each institution. No production was performed in some years, whereas production increased considerably on other years. For example, the Chinese Acad Sci contributed no publications during 1995–1998 and in 2006; however, its production increased sharply in 2008, replacing National Cheng Kung University (Natl Cheng Kung Univ) in the lead on *O. sinensis* research. The Hong Kong Polytechnic University (Hong Kong Polytech Univ) started this research in 1999, and maintained the outputs until 2014 when the annual production reached 10 articles. Chinese Acad Sci, Hong Kong Polytech Univ, Sun Yat Sen University (Sun Yat Sen Univ) and University of Macau (Univ Macau) increased their outputs in the recent five years, indicating a power quality research boom in these institutions.

Table 1 Ranking of the top 10 most productive international institutions.

Institution	Country	TP	TP R (%)	TC
Chinese Acad Sci	China	75	9.2	1098
Hong Kong Polytech Univ	China	49	6.0	721
Natl Cheng Kung Univ	Taiwan(China)	34	4.2	504
Sun Yat Sen Univ	China	28	3.5	152
Univ Macau	China	24	3.0	730
Mukogawa Womens Univ	Japan	21	2.6	330
Zhejiang Univ	China	19	2.3	330
Nanjing Univ	China	16	2.0	323
China Med Univ	China	15	1.8	171
Natl Taiwan Univ	Taiwan(China)	15	1.8	162

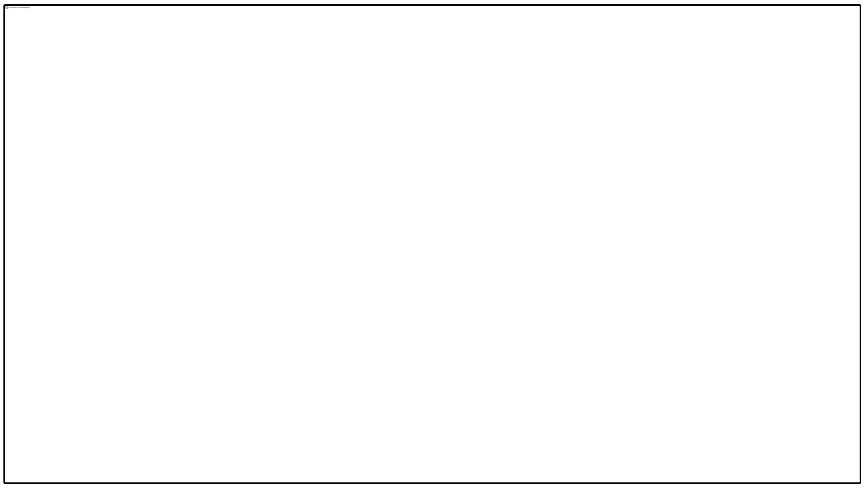

Fig. 4 Cooperation relationships between institutions.

Table 2 Publications from the 10 most productive institutions during the period 1995-2016.

stitution	Year																						Total
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	
Chinese Acad Sci	0	0	0	0	1	0	0	2	0	0	2	0	2	4	6	8	10	13	9	4	6	8	75
Hong Kong Polytech Univ	0	0	0	0	1	2	1	1	1	2	1	2	4	2	4	2	3	4	5	10	1	3	49
Natl Cheng Kung Univ	0	0	0	0	0	2	3	2	4	4	7	2	3	0	0	1	4	1	1	0	0	0	34
Sun Yat Sen Univ	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1	4	3	2	2	1	7	5	28
Univ Macau	0	0	0	0	0	0	0	0	1	0	0	2	2	0	3	3	0	1	1	0	5	4	24
Mukogawa Womens Univ	0	0	0	0	2	3	0	0	2	0	0	1	3	2	3	1	1	1	1	0	1	0	21
Zhejiang Univ	0	0	0	0	0	0	0	0	1	1	2	3	1	0	0	0	3	0	3	2	2	1	19
Nanjing Univ	1	0	0	0	0	0	0	0	0	0	2	2	0	1	0	1	5	1	1	1	1	0	16
China Med Univ	1	0	0	0	0	0	0	0	0	0	1	0	1	0	1	2	2	0	1	3	2	1	15
Natl Taiwan Univ	0	0	0	1	0	0	0	0	0	1	1	2	0	0	2	2	0	1	1	2	1	1	15

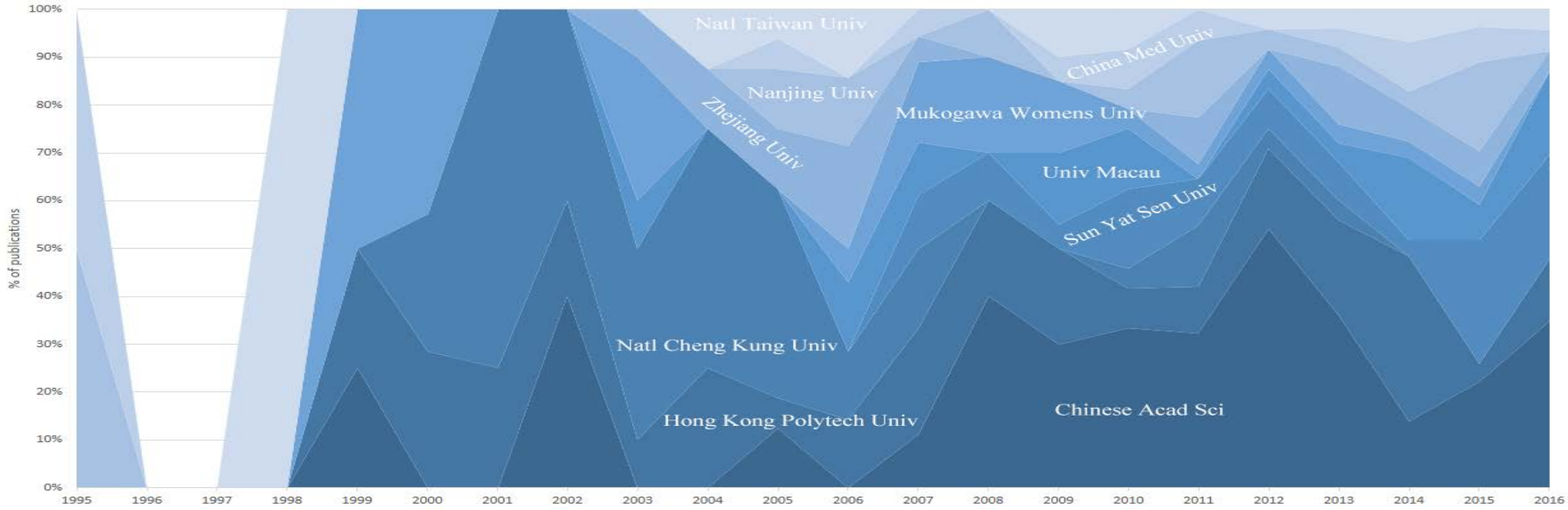

Fig. 5 Time evolution of the 10 most productive institutions during the period 1995-2016

3. Journal statistics

The collected 811 articles were published in 353 different journals indexed in the Web of Science, indicating the diversified nature of publication distributions and the broad interest on *O. sinensis*-related research. The top 10 productive journals that account for 20.6% of the total publications are further analysed in Table 3. Among all the journals, the International Journal of Medicinal Mushrooms is the most influential with 38 (4.7%) articles, followed by Carbohydrate Polymers with 25 (3.1%) articles and FASEB Journal with 20 (2.2%). Life Sciences ranked 6th by the number of publications (1.5%), but showed the highest TC of 332 and average citation per paper (ACP) of 27.67. Thus, Life Sciences is one of the key journals that significantly influence *O. sinensis* research.

Table 4 lists the top 10 journals with the highest impact factor (IF) in *O. sinensis* research, ranging from 40.1 to 7.4 with 16 articles published in these vital journals. These articles were related to cosmetic source, allergy, chemistry and pharmacology. Two of these articles belong to chemistry, one is about Cordycepin and the other one is on N-Containing compounds. Three of these articles belong to ecology and conservation, suggesting the limited resources of *O. sinensis* and the damage caused by over excavation. Eight of the sixteen articles discussed kidney disease, diabetes and renal-transplantation, suggesting the important applications of *O. sinensis* in human kidney diseases. The 16 listed articles show the application of *O. sinensis*, and reveal the problems that restrain its use.

Table 3 The top 10 productive journals.

Journal	TP	TP R(%)	TC	ACP	IF
INTERNATIONAL JOURNAL OF MEDICINAL MUSHROOMS	38	4.7	69	1.82	1.272
CARBOHYDRATE POLYMERS	25	3.1	124	4.96	4.811
FASEB JOURNAL	20	2.2	3	0.15	5.498
JOURNAL OF ETHNOPHARMACOLOGY	15	1.8	151	10.07	2.981
EVIDENCE-BASED COMPLEMENTARY AND ALTERNATIVE MEDICINE	13	1.6	19	1.46	1.740
LIFE SCIENCES	12	1.5	332	27.67	2.936
AMERICAN JOURNAL OF CHINESE MEDICINE	12	1.5	126	10.50	3.222
BIOLOGICAL & PHARMACEUTICAL BULLETIN	11	1.4	227	20.64	1.683
PHYTOTHERAPY RESEARCH	11	1.4	181	16.45	3.092
JOURNAL OF PHARMACEUTICAL AND BIOMEDICAL ANALYSIS	11	1.4	166	15.09	3.255

Table 4 The top 10 highest IF journals.

Journal	IF	TP	Title
Nature (1950)	40.1	1	Cordycepin, a metabolic product isolated from cultures of Cordyceps militaris (Linn.) Link.
Science (2008, 2010)	36.0	2	Mycology. Last stand for the body snatcher of the Himalayas?
			Bhutan. Improbable partners aim to bring biotechnology to a Himalayan kingdom.
Journal of the American college of cardiology (2014)	19.9	1	Preventive effects of cordyceps sinensis against contrast induced nephropathy in type 2 diabetics with renal insufficiency undergoing coronary angiography
Fungal diversity (2010, 2012, 2012)	13.5	3	Fungi-an unusual source for cosmetics
			Medicinal mushrooms in supportive cancer therapies: an approach to anti-cancer effects and putative mechanisms of action
			Prized edible Asian mushrooms: ecology, conservation and sustainability
Natural product reports (2005)	11.0	1	N-Containing compounds of macromycetes
Journal of the American society of nephrology (1994, 1995)	9.0	2	The application of cultivated Cordyceps-sinensis in renal-transplantation
			Effects of Cordyceps-sinensis(CS) in renal damage of hemorrhagic-fever with renal syndrome (HFRS)
Diabetes (2010)	8.7	1	Cordyceps sinensis Derivative Cultures Induces a Reduction in Transforming Growth Factor-beta(1), Dyslipidemia, Proteinuria in Diabetic Rats
Kidney International (1992, 1995, 2013)	8.4	3	Mechanism of Cordyceps-sinensis(CS) in the treatment of aminoglycoside induced acute-renal-failure(ARF)
			Effects of interference by Cordyceps sinensis(BERK) since on passive heymann nephritis
			Therapeutic use of traditional Chinese herbal medications for chronic kidney diseases
American journal of kidney disease (2015)	7.6	1	Recent Advances in Traditional Chinese Medicine for Kidney Disease
Allergy (2010)	7.4	1	Five cases of food allergy to vegetable worm (Cordyceps sinensis) showing cross-reactivity with silkworm pupae

4. Author statistics

Results show that 811 publications were produced by 2589 authors. Among them, 119 authors reported five or more publications in this field. Table 6 lists the top 15 productive authors, from which 11 were from China, and those that ranked the first and four are from Japan. The top 15 productive authors are completely from Asia. The most productive author is Wu, JY from China, with 35 records. Zhu, JS from China received the highest average citations per publications, with 17.95, followed by Li, SP, with 17.20. Li, SP ranked second in TP and total publication restricted in first author, first in TC, TC restricted in first author and average citations per publication restricted in first author. Therefore, Li, SP is the leading researcher in this field, followed by Zhu, JS.

Fig. 6 Represent the cooperation relationship between authors who published at least five articles. The top seven productive authors have no direct cooperation relationship, the Japanese researcher, as well as Huang, BM and Li, SP's research team lack of cooperation with other teams.

Table 6 The top 15 productive authors.

Authors	TP	TC	ACP	TPF	TCF	ACPF
Wu, JY	35	261	7.46	4	2	0.50
Li, SP	25	430	17.20	6	316	52.67
Huang, BM	25	182	7.28	5	75	15.00
Liu, X	23	54	2.35	1	0	0.00

Zhu, JS	22	395	17.95	10	335	33.50
Nakamura, K	22	202	9.18	5	64	12.80
Yao, YJ	21	197	9.38	0	0	0.00
Shinozuka, K	20	200	10.00	0	0	0.00
Zhang, Y	20	37	1.85	1	2	2.00
Kagota, S	19	198	10.42	0	0	0.00
Kunitomo, M	18	194	10.78	0	0	0.00
Li, Y	18	78	4.33	6	31	5.17
Zhang, GR	18	40	2.22	0	0	0.00
Zhao, J	16	101	6.31	1	9	9.00
Liu, XZ	14	92	6.57	0	0	0.00

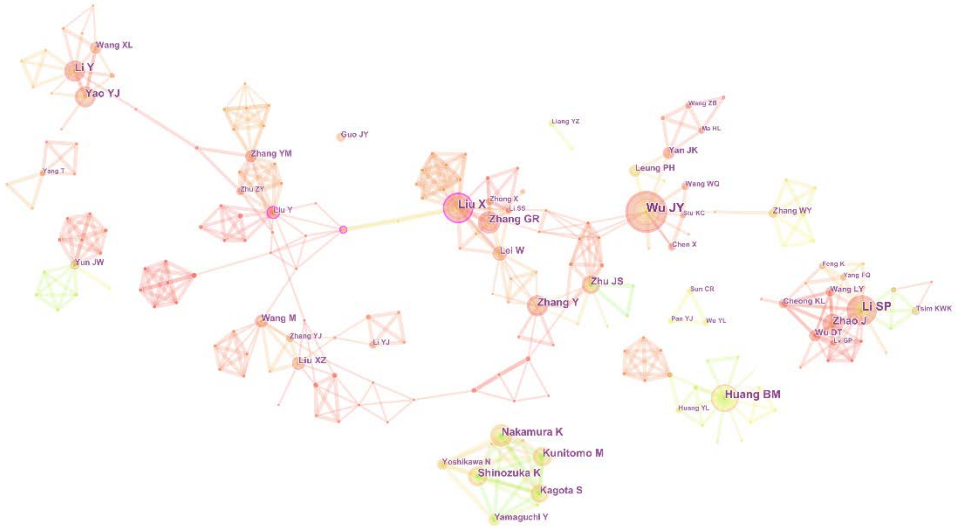

Fig. 6 Cooperation relationships between authors.

5. Article citation

The citation frequency of an article reflects its academic influence. Table 7 lists the top 15 frequently cited articles. The most cited article was cited 292 times and published in 1998 in the Journal of Alternative and Complementary Medicine, written by Zhu, JS from China. The number of author (NA) of this article is 3, and the cited reference (CR) is 40. Two of the top 15 articles were written by Zhu, JS, whereas 4 were written by Li, SP. According to CR, whether this publication is a review or not can be primarily judged because generally, when the CR is high, it is more likely a review. Among the top 15 frequently cited articles, 11 are from China. Thus, China has the greatest influence.

Table 7 The top 15 frequently cited articles.

Title	Year	Country	TC	Journal	NA	CR
The scientific rediscovery of an ancient Chinese herbal medicine: Cordyceps sinensis Part I	**1998**	**China**	**292**	**JOURNAL OF ALTERNATIVE AND COMPLEMENTARY MEDICINE**	**3**	**40**

Antitumor sterols from the mycelia of Cordyceps sinensis	1999	USA	196	PHYTOCHEMISTRY	5	35
A systematic survey of antioxidant activity of 30 Chinese medicinal plants using the ferric reducing antioxidant power assay	2006	China	196	FOOD CHEMISTRY	4	16
Cordyceps - A traditional Chinese medicine and another fungal therapeutic biofactory?	2008	Portugal	183	PHYTOCHEMISTRY	1	239
The Role of Culinary-Medicinal Mushrooms on Human Welfare with a Pyramid Model for Human Health	2012	China	182	INTERNATIONAL JOURNAL OF MEDICINAL MUSHROOMS.	2	97
The scientific rediscovery of a precious ancient Chinese herbal regimen: Cordyceps sinensis - Part II	1998	China	178	JOURNAL OF ALTERNATIVE AND COMPLEMENTARY MEDICINE	3	76
Cordyceps fungi: natural products, pharmacological functions and developmental products	2009	China	163	JOURNAL OF PHARMACY AND PHARMACOLOGY	5	127
A polysaccharide isolated from Cordyceps sinensis, a traditional Chinese medicine, protects PC12 cells against hydrogen peroxide-induced injury	2003	China	162	LIFE SCIENCES	9	26
Effect of Cordyceps sinensis on the proliferation and differentiation of human leukemic U937 cells	1997	China (Taiwan)	135	LIFE SCIENCES	4	25
Quality control of Cordyceps sinensis, a valued traditional Chinese medicine	2006	China	128	JOURNAL OF PHARMACEUTICAL AND BIOMEDICAL ANALYSIS	3	130
Optimization of submerged culture conditions for exo-biopolymer production by Paecilomyces japonica	2000	Korea	110	JOURNAL OF MICROBIOLOGY AND BIOTECHNOLOGY	5	33
Chemical properties and antioxidant activity of exopolysaccharides from mycelial culture of Cordyceps sinensis fungus Cs-HK1	2009	China	105	FOOD CHEMISTRY	4	29
Anti-oxidation activity of different types of natural Cordyceps sinensis and cultured Cordyceps mycelia	2001	China	103	PHYTOMEDICINE	4	20
Hypoglycemic activity of polysaccharide, with antioxidation, isolated from cultured Cordyceps mycelia	2006	China	97	PHYTOMEDICINE	7	30
Polysaccharides in fungi .36. Hypoglycemic activity of a polysaccharide (CS-F30) from the cultural mycelium of Cordyceps sinensis and its effect on glucose metabolism in mouse liver	1996	Japan	95	BIOLOGICAL & PHARMACEUTICAL BULLETIN	5	11

6. Research hot points

1. Subject category and Keyword's performances

All the 811 articles related to the O. sinensis area were divided into 61 subject categories in SCI and SCIE databases. Fig. 7a shows the categories with more than 10 frequencies indexed by the Web of Science. A bigger circle indicates more records. Pharmacology and Pharmacy is the first category, with a frequency of 197, followed by Chemistry with 148 and Biochemistry and Molecular Biology with 140. Oncology, Nutrition and Diabetes, Immunology, Toxicology, Agriculture and Ecology ranged from 10 to 20. Sport Science, Biodiversity and Conservation, Legal Medicine, Respiratory System, Cardiovascular System and Cardiology, Transplantation and Evolutionary Biology are the categories under 10. Fig. 7b shows the top 10 highest frequency subject categories. From the analysis of category, which indicate that O. sinensis was used to cure tumour, Respiratory System is greatly significant, followed by Cardiovascular System, Renal Transplantation and Diabetes. In its cardiovascular system function, O. sinensis was used in sport science to strengthen the performance of athletes. In TCM, O. sinensis was recorded as a tonic that benefits the lungs and kidneys. The study of the effects of O. sinensis on the respiratory system and renal disease or transplantation continued. However, the limited resources cannot satisfy the growing demand. Over harvesting caused biodiversity and conservation and ecology

problems. O. sinensis is a rare, prized tonic, but due to its limited resource and potent toxicity, the legitimacy of O. sinensis being a dietary supplement is questioned.

All 811 publications provided a total of 2396 keywords. On average, five keywords are available, for each article. To identify the research focus on O. sinensis, keyword analysis is conducted. Fig. 8 shows the keywords with more than 10 frequencies. In chemistry, extract, polysaccharide, exopolysaccharide, cordycepin, structural characterization, nucleoside and cytokine were the words with high frequencies. In pharmacology, tumour-bearing mice, mouse, mice, rat and cell were the most frequent words. In terms of function, antioxidant activity, anti-tumour and inflammation are the words with high frequency. Identification, anamorph, evolution, Ganoderma lucidum, Cordyceps military and Beauveria bassiana appeared more than 10 times. Cultured Cordyceps, mycelia, optimisation and submerged culture are the keywords for the artificial cultivation of O. sinensis, indicating that the artificial cultivation of O. sinensis attracted the attention of researchers. Fig. 8 shows that the extract, polysaccharides, cell and antioxidant activity are major keywords.

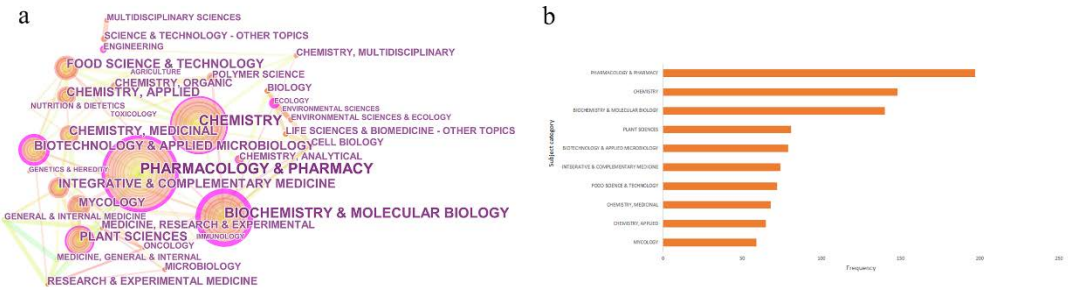

Fig. 7 a Category analysis; b The top 10 highest frequency subject categories.

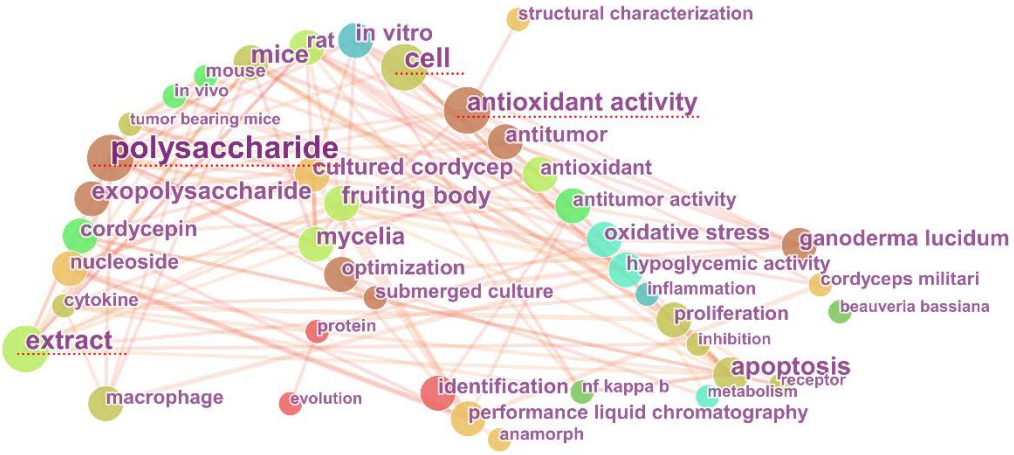

Fig. 8 Networks of Keywords that the frequency of occurrence exceeds 10.

2. burst detection

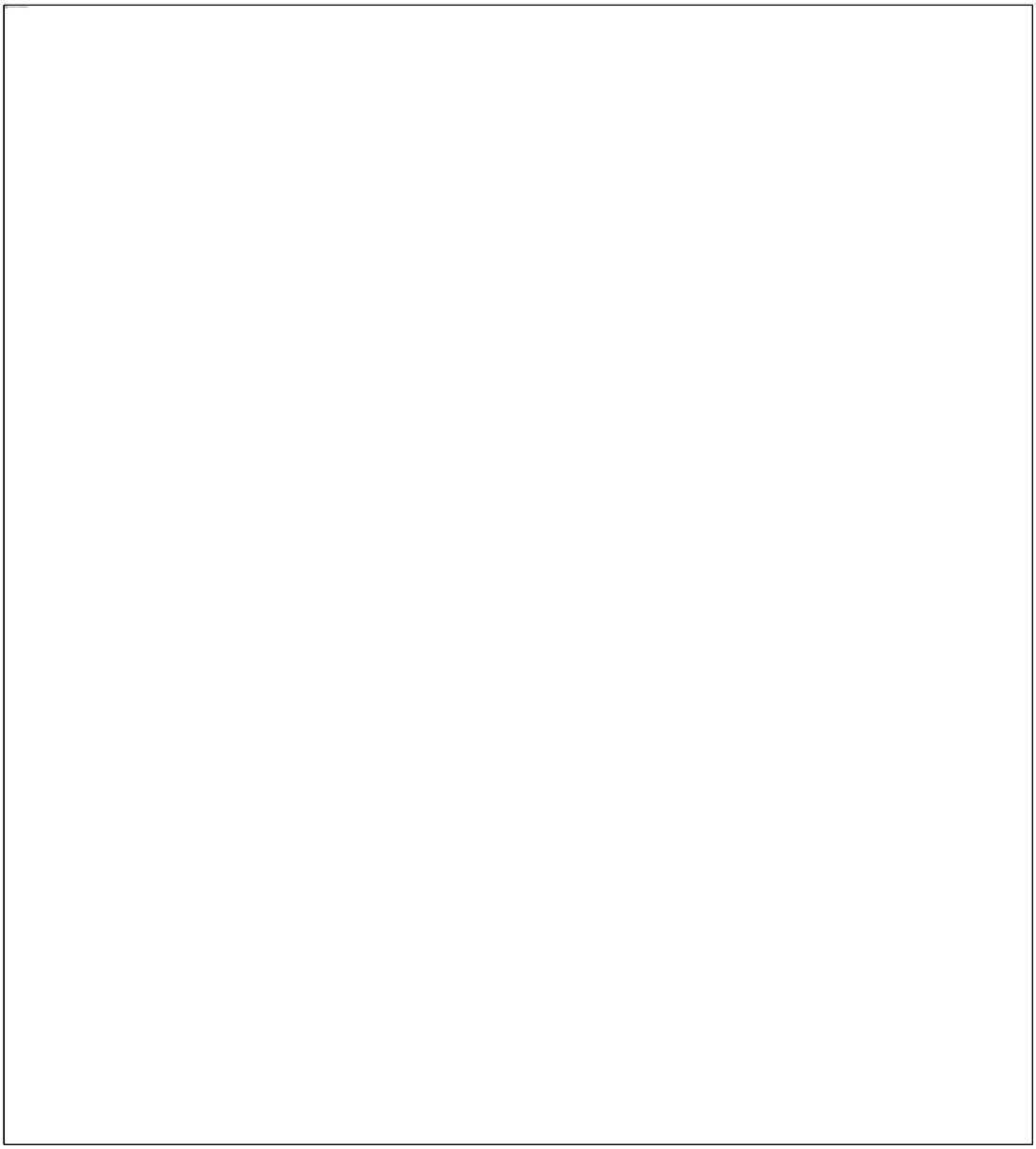

Fig. 9 a Category bursts. 2000-2016; b Keyword bursts. 2000-2016

Burst detection is a measure that shows the sudden change in the existing data of the analysis objects. We performed the burst detection of categories and keywords separately to identify future research areas. Fig. 9 a shows that medicine, research and experiment, pharmacology and pharmacy and research and experimental medicine are the first subjects that burst, from 2000 to 2004. Agriculture burst from 2005 to 2010, immunology from 2008 to 2011 and nutrition and diabetes from 2008 to 2011. The subjects that burst in 2016 included environmental sciences and ecology and polymer science and multidisciplinary sciences. Thus, these subjects are potential hot issues in future research.

Fig. 9 b shows the keyword burst analysis results. Polysaccharide burst in 2000–2001, metabolism in 2000–2005, cytokine in 2006–2011 and anti-tumour in 2009–2012. Structural

characterisation and conservation burst in 2014–2016, indicating their focus on *O. sinensis* research.

7. Conclusion

A total of 811 publications related to *O. sinensis* were retrieved SCI and SCIE databases (1970–2016) using the bibliometric methods, and 82.8% of these publications were journal articles. Analysis reveals that the articles on *O. sinensis* gained a rapid growth over the past 46 years. A total of 353 journals published *O. sinensis*-related articles classified into 61 subject categories. Ten most influential journals were identified, including the International Journal of Medicinal Mushrooms, Carbohydrate Polymers, FASEB Journal, Journal of Ethnopharmacology, Evidence-based Complementary and Alternative Medicine. These journals contribute to more than 10% of the total publications on *O. sinensis*. Pharmacology and Pharmacy is the most popular subject with a record of 197. The high frequency of Pharmacology and Pharmacy indicates the current emphasis on the exploration and verification of *O. sinensis* research. Nutrition and Diabetes, Biodiversity and Conservation, Legal Medicine, Transplantation and Evolutionary Biology are the categories under 20. High IF journals explored these subjects, indicating that *O. sinensis* used in renal transplantation and diabetes is a new prospect. However, the damage caused by over harvesting *O. sinensis* increased, raising researcher concerns. Researchers also considered the artificial cultivation of *O. sinensis*. Extract, polysaccharides and antioxidant activity are the major keywords, indicating that the extraction of polysaccharides from *O. sinensis* and its antioxidant activity were extensively studied. The burst detection of subject categories and keywords shows that environmental sciences and ecology, polymer science, multidisciplinary sciences, structural characterisation and conservation are potential focused areas in future research.

China is the most productive country with the highest frequencies across all indicators, indicating its leadership in *O. sinensis* research. Among the top 10 productive countries, China is also the first in international collaboration. Among the top 10 productive institutions, nine institutions are located in China. The Chinese Academy of Sciences is the most productive institution, followed by the Hong Kong Polytechnic University. All the top 10 institutions indicated feeble cooperative relationships with other institutions if at all.

Bibliometric technique evaluates and quantifies the patterns of publications that address a particular subject and examines publication characteristic such as authorships, citations and IF. This technique offers a quantitative perspective to better understand the characteristics associated with international *O. sinensis* research. Hot topics and popular research directions were identified. Moreover, the present study revealed the most productive institutions in *O. sinensis* research. This study could encourage international collaboration with these institutions in future endeavours.

References

Almeidafilho, N., I. Kawachi, A. P. Filho and J. N. Dachs (2003). "Research on health inequalities in Latin America and the Caribbean: bibliometric analysis (1971-2000) and descriptive content analysis (1971-1995)." American Journal of Public Health **93**(12): 2037.

Arber, A. (1938). Herbals: Their Origin and Evolution(edn 2). Cambridge University U.K., Cambridge, U.K.

Braun, T., A. Schubert and S. Zsindely (1997). "Nanoscience and nanotecnology on the balance." Scientometrics **38**(2): 321-325.

Bucci, L. R. (2000). "Selected herbals and human exercise performance." American Journal of Clinical Nutrition **72**(2 Suppl): 624S.

Cannon, P. F., N. L. Hywel-Jones, N. Maczey, L. Norbu, Tshitila, T. Samdup and P. Lhendup (2009). "Steps towards sustainable harvest of Ophiocordyceps sinensis in Bhutan." Biodiversity & Conservation **18**(9): 2263-2281.

Chen, C. (2009). "CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature." Journal of the China Society for Scientific & Technical Information **57**(3): 359-377.

Chen, C., Z. Hu, S. Liu and H. Tseng (2012). "Emerging trends in regenerative medicine: a scientometric analysis in CiteSpace." Expert Opinion on Biological Therapy **12**(5): 593.

Chen, H. and S. Li (2015). Polysaccharides from Medicinal Mushrooms and Their Antitumor Activities, Springer International Publishing.

Choi, G. S., Y. S. Shin, J. E. Kim, Y. M. Ye and H. S. Park (2010). "Five cases of food allergy to vegetable worm (Cordyceps sinensis) showing cross-reactivity with silkworm pupae." Allergy **65**(9): 1196-1197.

Cunningham, K. G., W. Manson, F. S. Spring and S. A. Hutchinson (1950). "Cordycepin, a Metabolic Product isolated from Cultures of Cordyceps militaris (Linn.) Link." Nature **166**(4231): 949-949.

Ding, Y., G. G. Chowdhury and S. Foo (2001). "Bibliometric Cartography of Information Retrieval Research by Using Co-Word Analysis." Information Processing & Management **37**(6): 817-842.

Dong, B., G. Xu, X. Luo, Y. Cai and W. Gao (2012). "A bibliometric analysis of solar power research from 1991 to 2010." Scientometrics **93**(3): 1101-1117.

Fu, H. Z. and Y. S. Ho (2016). Highly cited Antarctic articles using Science Citation Index Expanded: a bibliometric analysis, Springer-Verlag New York, Inc.

Glänzel, W. (2000). "Science in Scandinavia: A Bibliometric Approach." Scientometrics **49**(2): 357-357.

Godin, B. (2006). "On the origins of bibliometrics." Scientometrics **68**(1): 109-133.

Hassan, S. U., P. Haddawy and J. Zhu (2014). "A bibliometric study of the world's research activity in sustainable development and its sub-areas using scientific literature." Scientometrics **99**(2): 549-579.

He, Y. and S. C. Hui (2002). "Mining a Web Citation Database for author co-citation analysis." Information Processing & Management **38**(4): 491-508.

Hiyoshi, T., M. Fujiwara, F. Akasu, T. Ishii and N. Taketomo (1996). "20.Cordyceps sinensis effects on cardiopulmonary function of long-distance runners." Japanese Journal of Physical Fitness & Sports Medicine **45**.

Hsiaoche Kuo, ‡, Yonglin Su, Hueylang Yang, ‡, § And and Tzongyueh Chen, ‡, § (2005). "Identification of Chinese Medicinal Fungus Cordyceps sinensis by PCR-Single-Stranded Conformation Polymorphism and Phylogenetic Relationship." J Agric Food Chem **53**(10): 3963-3968.

Hyde, K. D., A. H. Bahkali and M. A. Moslem (2010). "Fungi—an unusual source for cosmetics." Fungal Diversity **43**(1): 1-9.

Lai, K. K. and S. J. Wu (2005). "Using the patent co-citation approach to establish a new patent classification system." Information Processing & Management **41**(2): 313-330.

Leydesdorff, L., L. Bornmann and P. Zhou (2016). "A Reproducible Journal Classification and Global Map of Science Based on Aggregated Journal-Journal Citation Relations."

Li, J., M. H. Wang and Y. S. Ho (2011). "Trends in research on global climate change: A Science Citation Index Expanded-based analysis." Global & Planetary Change **77**(1–2): 13-20.

Li, S. P., F. Q. Yang and K. W. K. Tsim (2006). "Quality control of Cordyceps sinensis , a valued traditional Chinese medicine." Journal of Pharmaceutical & Biomedical Analysis **41**(5): 1571.

Liu, X., Z. Liang and H. Song (2011). "Global biodiversity research during 1900-2009: a bibliometric analysis." Biodiversity & Conservation **20**(4): 807-826.

Nicolaisen, J. (2010). "Bibliometrics and Citation Analysis: From the Science Citation Index to Cybermetrics." Journal of the American Society for Information Science & Technology **61**(1): 205–207.

Niu, B., H. A. Loáiciga, Z. Wang, F. B. Zhan and S. Hong (2014). "Twenty years of global groundwater research: A Science Citation Index Expanded-based bibliometric survey (1993–2012)." Journal of Hydrology **519**(10): 966-975.

Schmoch, U. and T. Schubert (2008). "Are international co-publications an indicator for quality of scientific research?" Scientometrics **74**(3): 361-377.

Seglen, P. O. and D. W. Aksnes (2000). "Scientific Productivity and Group Size: A Bibliometric Analysis of Norwegian Microbiological Research." Scientometrics **49**(1): 125-143.

Shao, P. L., K. J. Zhao, N. J. Zhao, H. S. Zong, T. T. X. Dong, C. K. Lo, J. K. H. Cheung, Q. Z. Shang and K. W. K. Tsim (2003). "A polysaccharide isolated from Cordyceps sinensis , a traditional Chinese medicine, protects PC12 cells against hydrogen peroxide-induced injury." Life Sciences **73**(19): 2503.

Shrestha, U. B. (2012). "Asian medicine: A fungus in decline." Nature **482**(7383): 35.

Silva, D. D. D., S. Rapior, F. Fons, A. H. Bahkali and K. D. Hyde (2012). "Medicinal mushrooms in supportive cancer therapies: an approach to anti-cancer effects and putative mechanisms of action." Fungal Diversity **55**(1): 1-35.

Stone, R. (2008). "Mycology. Last stand for the body snatcher of the Himalayas?" Science **322**(5905): 1182.

Sung, G. H., N. L. Hywel-Jones, J. M. Sung, J. J. Luangsa-Ard, B. Shrestha and J. W. Spatafora (2007). "Phylogenetic classification of Cordyceps and the clavicipitaceous fungi." Studies in Mycology **57**(57): 5.

Synnestvedt, M. B., C. Chen and J. H. Holmes (2005). "CiteSpace II: visualization and knowledge discovery in bibliographic databases." AMIA ... Annual Symposium proceedings / AMIA Symposium. AMIA Symposium **2005**: 724.

Winkler, D. (2009). "Caterpillar Fungus (Ophiocordyceps sinensis) Production and Sustainability on the Tibetan Plateau and in the Himalayas." Asian Medicine **5**(2): 291-316.

Yan, Y., Y. Li, W. J. Wang, J. S. He, R. H. Yang, H. J. Wu, X. L. Wang, L. Jiao, Z. Tang and Y. J. Yao (2017). "Range shifts in response to climate change of Ophiocordyceps sinensis, a fungus endemic to the Tibetan Plateau." Biological Conservation **206**: 143-150.

Yu, H., Y. M. Wei, B. J. Tang, Z. Mi and S. Y. Pan (2016). "Assessment on the research trend of low-carbon energy technology investment: A bibliometric analysis." Applied Energy **184**: 960-970.

Zang, M. and N. Kinjo (1998). "Notes on the alpine Cordyceps of China and nearby nations." Mycotaxon **66**: 215-229.

Zhang, H. W., Z. X. Lin, Y. S. Tung, T. H. Kwan, C. K. Mok, C. Leung and L. S. Chan (2014). "Cordyceps sinensis (a traditional Chinese medicine) for treating chronic kidney disease." Cochrane Database of Systematic Reviews **12**(12): CD008353.

Zhang, Z. Y., G. H. Liang, L. Liang, L. Yan-Hua, L. I. Wen-Jia and J. J. Xie (2016). "Effects of medium and environmental conditions on the sporulation of Ophiocordyceps sinensis in solid fermentation." Mycosystema.

Zhuang, Y., X. Liu, T. Nguyen, Q. He and S. Hong (2013). "Global remote sensing research trends during 1991–2010: a bibliometric analysis." Scientometrics **96**(1): 203-219.