Pak. J. Bot., 51(5): 1907-1916, 2019. DOI: http://dx.doi.org/10.30848/PJB2019-5(26)

GLOBAL HIMALAYA PLANT RESEARCH TREND AND PERFORMANCE IN SCIENCE CITATION INDEX FROM 1998 TO 2017

DA-CHENG HAO[1ϴ*], XUE YUAN[2ϴ], YAN-HONG DI[2] AND PEI-GEN XIAO[3]

[1]*Biotechnology Institute, School of Environment and Chemical Engineering, Dalian Jiaotong University, Dalian 116028, China*
[2]*Agricultural Information Institute, Chinese Academy of Agricultural Sciences, Beijing 100081, China*
[3]*Institute of Medicinal Plant Development, Chinese Academy of Medical Sciences, Beijing 100193, China*
[*]*Corresponding author's email: hao@djtu.edu.cn; diyanhong@caas.cn*
[ϴ]*Contributed equally to this work*

Abstract

Himalaya plants have essential ecological implications and are frequently used by local tribes for various purposes, many of which are traditionally used to cure various ailments in humans and livestock. In this study, we aimed to evaluate the global scientific production of Himalaya plant research, study the characteristics of Himalaya plant research activities, and identify patterns, tendencies, and regularities of related articles. Data were based on the online version of Science Citation Index Expanded (SCI-Expanded), from the Web of Science database. Articles referring to Himalaya plant were assessed by the trend of publication output during 1998 to 2017. Globally, 2,471 papers were published during the 20-year study period. The most productive countries, institutions, Web of Science subject categories, and journals, as well as the most cited articles, were identified. The mainstream research on Himalaya plant was in the plant sciences, ecology, environmental sciences, pharmacology and pharmacy. India, China, USA, and Pakistan held the majority of total world production. Research on the species diversity and conservation, medicinal plants, and ethnobotany remained the hotspot during the 20-year study period, whereas that on the related topic "climate change" increased dramatically since 2009. CONCLUSION: With synthetic analysis of word in article title, author keyword, abstract, and Key Words Plus Key Words Plus, it can be concluded that application of compounds derived from Himalaya plants in clinical medicine, pharmacology and oncology, and research related to chemistry, genetics, and microbiology is the ongoing Himalaya plant research in the 21st century. Gaps are present in knowledge about the genomics, epigenomics, transcriptomics, proteomics, metabolomics and bioinformatics of Himalaya plants and their associated microbes.

Key words: Science citation index (SCI), Bibliometric, Research trend, Himalaya plant.

Introduction

Himalaya forms a mountain range in Asia separating the plains of the Indian subcontinent from the Qinghai Tibetan Plateau (QTP). The flora and microflora of the Himalayas vary with climate, precipitation, elevation, and soils (Wang *et al*., 2018). The climate ranges from tropical at the base of the mountains to permanent ice and snow at the highest elevations. The amount of yearly rainfall increases from west to east. This diversity of altitude, rainfall and soil conditions combined with the very high snow line supports a variety of distinct plant (Fig. 1) and microbial communities. The extremes of high altitude combined with extreme cold favor extremophile organisms, which are the gold mine of novel medicinal compounds (Iyer *et al*., 2017; Singh *et al*., 2017). The Himalayas are home to a diversity of medicinal resources. Plants from the forests and grasslands have been used for millennia to treat conditions ranging from simple coughs to snake bites (Hao *et al*., 2015a, 2016). Different parts of the plants, i.e., root, flower, stem, leaves, and bark, are used as remedies for different ailments (Vieira *et al*., 2016; Singh *et al*., 2017). For example, six species of Leguminosae and five species of Lamiaceae are used to treat coughs and bronchitis (Amber *et al*., 2017). Twenty five species of 17 families are used for wound healing, toothache and gum infections in Manoor Valley (Northern Himalaya), Pakistan (Rahman *et al*., 2016). *Moringa oleifera* oil is used in cosmetics, folk medicines and skin care formulations (Nadeem & Imran, 2016). At least half of the gymnosperms, angiosperms and pteridophytes in the Himalayas are found to have medicinal properties, and more are likely to be discovered. However, the unique floral wealth of the Himalayas is undergoing structural and compositional changes due to climate change (Bajpai *et al*., 2016), which may pose threats to the sustainable conservation and utilization of phytomedicinal resources.

The first Himalaya plant papers were published in 1960s (Scott & Smillie, 1966). Since then, the Himalaya plant studies stride into a new era. Some research hotspots, such as western Himalaya (Kashyap *et al*., 2018), conservation (Aryal *et al*., 2018), eastern Himalaya (Liu *et al*., 2018), medicinal plants (Pyakurel *et al*., 2018), genetic diversity (Mangla *et al*., 2018), Nepal Himalaya (Kunwar *et al*., 2018), and chemical composition (Mahajan *et al*., 2018), have been noticed in recent years. However, there is no quantitative study addressing the global trend of Himalaya plant research. In this study, we briefly review the history of Himalaya plant studies and elucidate the current trend of related fields with bibliometric methods.

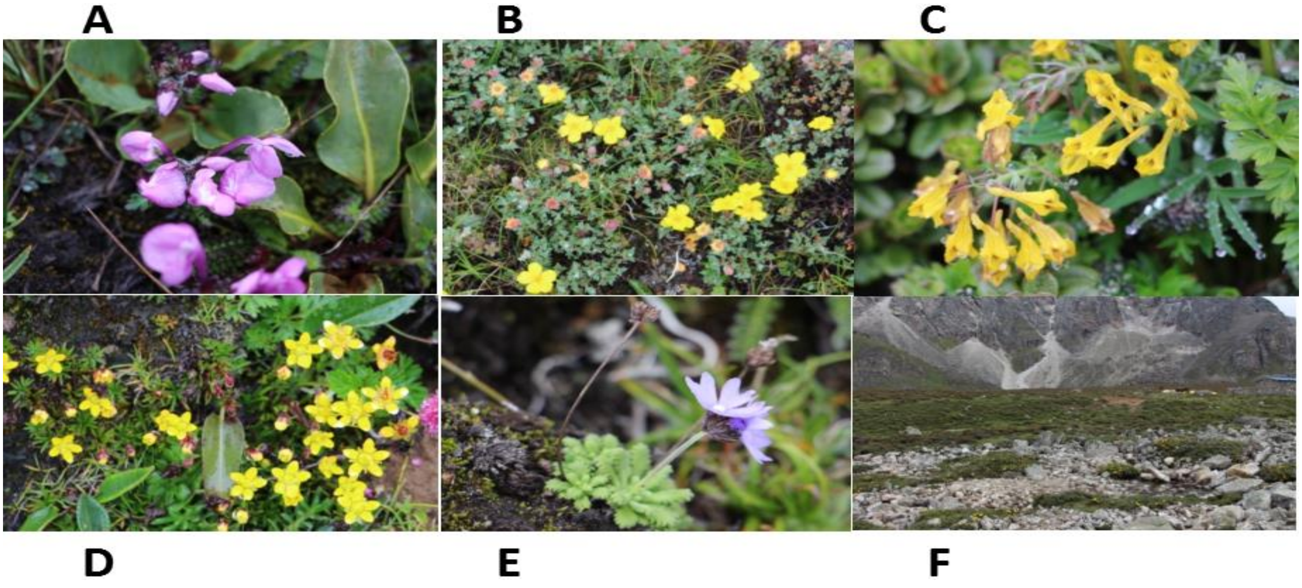

Fig. 1. Representative Himalaya medicinal plants and their habitats. A, *Pedicularis confertiflora*; B, *Potentilla fruticosa*; C, *Corydalis dasyptera*; D, *Saxifraga montana*; E, *Primula bella*; F, a typical habitat at the elevation of around 4,800 m. Photos were taken in Gama valley, Tingri County, Tibet, China.

Materials and Methods

Documents used in this study were derived from the SCI-Expanded Web of Science database of the Thomson Reuters/Clarivate Analytics. According to Journal Citation Reports (JCR), it indexes approximately 12,000 scholarly and technical journals with citation references across 252 scientific disciplines in 2017. Documents with "Himalaya" and "plant" (or "plants" or "flora" or "floras" or "florae" or "botany") in titles, abstracts, authors' key words and KeyWords Plus were downloaded from 1998 to 2017. Document information included names of authors, contact address, title, year of publication, author key words, abstract, KeyWords Plus, Web of Science subject categories, names of journals publishing the articles, and citations in each year for each article. The records were downloaded into Microsoft Excel 2013, and additional coding was manually performed for all data analyses. Bibexcel software (http://homepage.univie.ac.at/ juan.gorraiz/ bibexcel) was used to extract institutes with more than one publication. InCites (https://clarivate.com/ products/incites), Derwent Data Analyzer (https:// clarivate.com/ products/derwent-data-analyzer) and VOS viewer (http://www.vosviewer.com) were used in the bibliometric analysis and visualization.

Articles originating from England, Scotland, Northern Ireland, and Wales were reclassified as being from the United Kingdom (UK). Collaboration type was determined by the addresses of the authors, where the term "country/institute independent article" was assigned if the researchers' addresses were from the same country/institute. The term "internationally collaborative article" was designated to those articles that were coauthored by researchers from multiple countries. The term "inter-institutionally collaborative article" was assigned if authors were from different institutes. The impact factor of a journal was determined for each document as reported in the JCR (2016).

Results and Discussion

Document type and language of publication: The distribution of document types identified by Web of Science was analyzed. From this study, 10 document types were found in the total of 2,471 publications during the 20-year study period. Research article (2,273) is the most frequently used document type accounting for 92% of all publications, which was followed by conference papers (115; 4.7%) and reviews (91; 3.7%) and the remainder having less significance. 99.6% of all these articles were published in English. Four other languages were also used, including four Chinese publications. A significant correlation was found between the yearly cumulative number of articles (y) and the year from 1998 to 2017 (x), i.e., $y = 18.244x-37.058$ ($r^2 = 0.9264$; Figure available upon request).

Distribution of output in subject categories and journals: Based on the classification of subject categories in Web of Science, the publication output data of Himalaya plant research was distributed in 83 subject categories in JCR science edition during the last 20 years. The top 10 productive subject categories are shown in Fig. 2. The annual publications of the top four productive subject categories are analyzed. The number of scientific articles per category exhibited remarkable fluctuation during the time period covered. Plant science has been the leading category since 1999, which showed a sharp upward trend, and the other subjects increased slightly. Ecology followed plant sciences until 1999 and was not caught up by environmental sciences, and the latter was followed by pharmacology and pharmacy. Publications of genetics and heredity, and biodiversity conservation also reached the considerable quantity in recent two decades. Plant science and biochemistry and molecular biology represent the basic aspects of Himalaya plant research, while pharmacology and pharmacy, and biodiversity conservation represent its applied fields. It is expected that the total number of articles in the former would be overtaken by that of the latter in the next 20 years.

A total of 2,471 articles were published in 717 journals. The top 10 productive journals through the recent 20 years are available upon request. As the leading journal of this particular research field, Current Science published 108 articles comprising 4.4% of all the articles, followed by Pakistan Journal of Botany and Indian Journal of Traditional Knowledge, contributing 2.3 and 2.1% of all publications, respectively. Journal of Ethnopharmacology ranked the fifth, followed by PLoS One and Biodiversity and Conservation, etc.

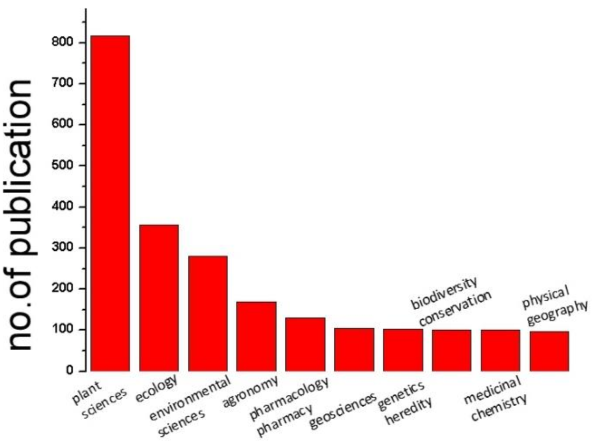

Fig. 2. Top ten Web of Science categories.

Distribution of institutions and countries: During the study period, the Council of Scientific & Industrial Research (CSIR) of India had the best outputs, publishing 255 articles (Table 1), which is followed by Chinese Academy of Sciences (CAS) and Indian Council of Agricultural Research (ICAR). On the other hand, the total citation of CAS was the most (3,251), followed by CSIR and University of CAS. University of CAS (14.32), CAS (14.07), and University of Delhi (12.31) are the top three institutions in citation impact.

The contribution of different countries/territories was estimated by the location of the affiliation of at least one author of the published papers. Sample data involved 83 countries or regions. Publications of the top 10 and 30 countries accounted for 80% and 95% of the total, respectively. The top 18 countries/territories ranked by number of publications are listed in Table 2. India (1,505), China (320) and USA (262) are the top three countries. Among top ten, Australia (3.92%), Germany (3.77%) and UK (2.77%) are top three in the percentage of highly cited paper. It is not surprising that Pakistan and Nepal are on the list, as the significant part of their territories is within the extensive range of Himalaya (Devkota *et al*., 2017; Amber *et al*., 2017). The number of research papers reflects the increasing activity and academic level of these developing countries. With the increasing research funds, both basic and translational aspects of the Himalaya plant research are emphasized and strengthened in China.

In the cooperation between countries, India had close collaboration with the United States, Germany and China. In addition to India, China worked closely with the United States, UK and Switzerland, and the cooperative publications of China and India are in the forefront of other countries.

Table 1. Top 17 most productive institutions based on the number of publications.

	Rank	No. of SCI publications	No. of citations	Percentage of high citation articles[a] / %	Average citation per article	Country
Council of Scientific & Industrial Research (CSIR) - India	1	255	1937	0	7.6	India
Chinese Academy of Sciences	2	231	3251	1.3	14.07	China Mainland
Indian Council of Agricultural Research (ICAR)	3	161	987	0	6.13	India
Institute of Himalayan Bioresource Technology	4	93	840	0	9.03	India
Kumaun University	5	83	600	1.2	7.23	India
University of Chinese Academy of Sciences	6	77	1103	0	14.32	China Mainland
Quaid I Azam University	7	64	708	0	11.06	Pakistan
Punjabi University	8	60	256	0	4.27	India
University of Kashmir	9	59	352	0	5.97	India
Department of Science & Technology (India)	10	49	551	2.04	11.24	India
Indian Institute of Technology (IIT)	11	48	434	0	9.04	India
Defence Research & Development Organisation (DRDO)	12	44	356	0	8.09	India
University of Delhi	12	42	517	0	12.31	India
Govind Ballabh Pant University of Agriculture Technology	13	38	228	0	6	India
ICAR - Indian Agricultural Research Institute	14	37	193	0	5.22	India
Czech Academy of Sciences	15	35	430	0	12.29	Czech Republic
ICAR - National Bureau of Plant Genetics Resources	16	35	146	0	4.17	India
Indian Institute of Integrative Medicine (IIIM), Jammu	17	33	259	0	7.85	India

[a]Top 1% cited papers (including research papers and reviews)

Table 2. Top 18 most productive countries based on the number of publications.

	Rank	No.of SCI publications	No. of citations	Percentage of high citation articles[a]/%	Average citation per article
India	1	1505	11750	0.27	7.81
China Mainland	2	320	4264	0.94	13.32
Usa	3	262	8054	1.53	30.74
Uk	4	215	4368	2.77	20.32
Pakistan	5	172	1662	0.58	9.66
Nepal	6	120	1369	0	11.41
Germany (Fed Rep Ger)	7	106	1736	3.77	16.38
Japan	8	63	1122	0	17.81
Switzerland	9	52	779	0	14.98
Australia	10	51	1337	3.92	26.22
Czech Republic	11	46	546	0	11.87
Canada	12	43	472	0	10.98
Norway	13	37	1118	0	30.22
France	14	36	787	2.78	21.86
Austria	15	34	760	0	22.35
Italy	16	30	335	0	11.17
Poland	17	23	189	4.35	8.22
Denmark	18	22	344	4.55	15.64

[a]Top 1% cited papers (including research papers and reviews)

Research trend and hotspots

Distribution of words in article title: Word statistical analysis was used to reveal the research tendency of this field. The statistical analysis of word in title, author key words, and the KeyWords Plus might facilitate discovering main directions of explorations. The title of an article always includes the core information that authors prefer to express to the readers, which would be browsed by all the readers at first. It is useful in inferring the scientific literature and identifying the subject focus and emphasis specified by authors. In this study, we statistically analyzed all the single words in the title of Himalaya plant related articles. All empty words including "of", "in", "and", "the", "a", "for", "with", "by" and "to" are discarded in such an analysis. The 25 most frequently used single words in title are listed in Table 3. They can be divided into three groups according to their apparent features. The first group consists of geographic locations such as "India" (304), "western Himalaya" (133), "Nepal" (76) and "northwest Himalaya" (76) (Singh *et al*., 2017), suggesting more active investigations in these regions than in "eastern Himalaya" (66), "central Himalaya" (54), and "Sikkim" (33) (Gurung *et al*., 2018). In recent two decades, especially in recent decade, China has more efforts in the Himalaya plant related studies, resulting in more publications of eastern Himalaya and Hengduan mountains; however, only a minor part of them were published in SCI journals and in English (Table 3). It is essential and urgent to translate some outstanding results from Chinese into English, to propagate them around the world, and to promote the interaction between research peers of pan-Himalaya regions.

The second group is made up of medicinal plant related words such as "medicinal plants" (49), "essential oil" (32), "antioxidant" (28) and "endangered medicinal plant" (26), suggesting the increasing importance of Himalaya flora in bioprospecting and mining chemodiversity. A major part of Himalaya plants has medicinal/food uses. The high frequencies of "conservation", "diversity" and "growth" reflect the highlighted studies of Himalaya botanical resources. The third group includes "effect (influence, impact)" (150), "case study" (48), "characterization" (31), and "implications" (30), etc., representing the general contents of Himalaya plant studies. The case study is especially useful in the investigations of environmental changes and ethnobotanical uses in a specified Himalaya region (Sharma *et al*., 2016).

Distribution of author's key words: The author key words analysis further offer the clues of research trend on which researchers have paid more attention. Some title keywords are reinstated in the articles' "Key words" part, and some other key words, not appearing in the article titles, are emphasized in the "Key words" part by authors, which contribute more details of the research trend. The 22 most frequently used keywords are listed in Table 3. They can be divided into three groups according to their apparent features. The first group is closely related with medicinal research, e.g., "medicinal (& aromatic)" plant (124), "(biodiversity) conservation" (119), "essential oil" (59) and "phylogeny (& phylogeography)" (56) (Liu *et al*., 2018), suggesting more research activities in these aspects of Himalaya medicinal plants than in "yield" (29), "HPLC (& GC-MS)" (32), and "taxonomy" (34) (Mehraj *et al*., 2017). Studies of "species richness (diversity)" (54), "biodiversity" (50), "diversity" (49), and "genetic diversity" (44) (Mahajan *et al*., 2018) are fundamental to the sustainable conservation and utilization of Himalaya pharmaceutical resources. "antioxidant (activity)" (49) is the most frequently investigated bioactivity of Himalaya plants, and such studies are very often inspired by the "ethnobotany" (46) and "traditional (indigenous) knowledge" (46) (Benedetto *et al*., 2018). Genetic diversity and chemodiversity of medicinal plants are intimately influenced by "biogeography" (43) factors (Xiang *et al*., 2017), while the latter can be an integral part of ethnobotanical data (Popović *et al*., 2016).

Table 3. The most frequently used title keywords, author keywords, and Key Words Plus.

Rank	Top 25 title keywords	No. of publication	Top 22 author keywords	No. of publication	Top 23 Key words plus	No. of publication
1.	India	304	Himalaya, Himalayas, Himalayan region	225	Plants, plant, vegetation	418
2.	Effect, influence, impact, effects	150	medicinal plants, Medicinal plant, medicinal and aromatic plants	124	Diversity, plant diversity, biodiversity, species richness, species-diversity, plant-species richness, biodiversity hotspots, plant biodiversity, species-richness	373
3.	western Himalaya, western Himalayas, West Himalaya, western Himalayan region, Western Himalayas (India)	133	Conservation, Biodiversity conservation	119	Conservation, biodiversity conservation	170
4.	Himalaya, Himalayas, Himalayan region	103	climate change, climate, palaeoclimate, Global Warming, paleoclimate	80	India, northeast India	163
5.	Nepal	76	India, Indian Himalayan region	73	Himalaya, Himalayas, Himalayan region, Himalayan	162
6.	North-Western Himalayas, North Western Himalaya north western Himalayas, north-western Himalaya, North-West Himalaya, North Western Himalaya, northwest Himalayas (India), north western Indian Himalayas, Northwest Himalayas	76	Altitude, altitudinal gradient, Elevation gradient, elevation, High altitude, Elevational gradient	67	Growth, plant-growth	132
7.	Pakistan	67	Nepal	60	Populations, population-structure, natural-populations, population, population-growth, plant-populations, population-size	126
8.	eastern Himalaya, Eastern Himalayas, Eastern Himalayan region	66	essential oil, essential oil composition, Essential oils	59	Evolution, evolutionary history, evolutionary, molecular evolution	119
9.	Kashmir Himalaya, Kashmir	63	Phylogeny, phylogeography, molecular phylogeny	56	Climate-change, climate	117
10.	central Himalayan region, Central Himalayas, Central Himalaya, Indian Central Himalaya	54	species richness, Species diversity	54	Medicinal-plants, medicinal herb	113
11.	Conservation	51	Biodiversity, Plant diversity	50	Communities, community structure, community, plant-communities, microbial communities	103
12.	medicinal plants, Himalayan medicinal plants	49	western Himalaya, Western Himalayas, West Himalaya	50	Patterns, pattern, global patterns	100
13.	case study	48	Diversity	49	Phylogeny, molecular phylogenetic-relationships, phylogeny, phylogeography, phylogenetic analysis, phylogenies	88
14.	Diversity	47	Antioxidant, Antioxidant activity, Antioxidants	49	Tibetan plateau, qinghai-tibetan plateau	84
15.	China	45	Ethnobotany	46	Forest, forests	81
16.	Uttarakhand, Uttarakhand Himalaya	45	traditional knowledge, indigenous knowledge	46	China, Southwest China, South China	78
17.	genetic diversity	37	genetic diversity	44	Management	75
18.	Sikkim Himalaya, Sikkim	33	Biogeography, Phytogeography	43	Bacteria, rhizobacteria, antibacterial activity, antibacterial, growth-promoting rhizobacteria, phosphate-solubilizing bacteria	75
19.	growth	32	Taxonomy	34	Nepal, western Nepal, Central Nepal	72
20.	essential oils, essential oil composition, essential oil	32	HPLC,GC-MS	32	Soil, soils	66
21.	Characterization	31	Yield	29	Leaves, leaf	62
22.	Implications	30	Biomass	25	l.	59
23.	Assessment	29			Western Himalayas, Western Himalaya, West Himalaya	55
24.	Antioxidant Properties, antioxidant, antioxidant activity	28				
25.	endangered medicinal herb, endangered medicinal plant	26				

The second group is made up of geographic locations; the frequency of "Himalaya" (225) is higher than "India" (73), followed by "Nepal" (60) and "western Himalaya" (50). These are also high frequency title keywords. The third group is more related with environment, including "climate change (global warming)" (80), "altitude (elevation) gradient" (67), and "biomass" (25). Despite merely a brief summary of the versatile aspects of Himalaya plant studies, the present analysis displays the mosaics of this upsurging field.

Distribution of keywords plus: The KeyWords Plus in the SCI database supplied additional and complementary search terms extracted from the titles of articles cited by authors in the references and footnotes. The KeyWords Plus analysis, as an independent supplement, reveals the research contents and links between studies with more details. As a whole, the research tread revealed by KeyWords Plus largely agrees with author/title keywords. "Plant (vegetation)" (418), "plant diversity (species richness and synonymous words)" (373), "conservation" (170), and "India" (163) were also highlighted in KeyWords Plus in the study period (Table 3). "Himalaya" (162), "growth" (132), "climate change" (117), and "medicinal plants" (113) were also frequently used. However, KeyWords Plus gave special prominence to "population" (126), "evolution" (119), "community" (103), and "Qinghai-Tibetan Plateau" (84). Meanwhile, it weakened the leading status of "Nepal" (19th) and "western Himalaya" (23rd), while "pattern" (12th), "forest" (15th), "management" (17th), and "bacteria (& antibacterial)" (18th) moved steadily up the rankings, which were distinct from author/title keywords. KeyWords Plus are usually more concerned about the novel research direction rather than the mature direction in the field (Garfield, 1990a, b). For example, "soil" (66) and organisms therein is a rapidly developing direction to decipher the crosstalk between soil environment and plant (Tomer *et al*., 2017; Manish *et al*., 2017). "Leaves" (62) are very common medicinal/edible part of Himalaya plants (Shiva Kumar *et al*., 2017). Leaves of many species are often used in ethnomedicines against bronchitis (Amber *et al*., 2017). The frequently used "L." (59; plant species named after Carl Linnaeus) suggests that studies have been extended to more single species (Yu *et al*., 2015; Rajashekhara *et al*., 2014).

Principal component analysis (PCA): PCA was performed with SAS software, version 9.2, using the PROC PRINCOMP procedure. Only those components with accumulative contribution rates greater than 85 percent were selected as the principal components (PCs). Altogether, 400 PCs were selected and ranked based on title keywords. Cluster analysis was performed according to the PC scores. Sea buckthorn (*Hippophae rhamnoides*; Mangla *et al*., 2018) and *Swertia chirayita* (Cunningham *et al*., 2018) are two prominent medicinal plants in the cluster (Fig. 3A). For artificial cultivation and germplasm conservation, the germination of endangered medicinal herb (Rana and Sreenivasulu, 2013) is also a subject of concern. Among medicinal compounds, phenolic content (Belwal *et al*., 2016) is more often mentioned in the titles. Studies of west Himalaya plants were mainly conducted by India/China (Hu *et al*., 2015; Giri *et al*., 2017). There were more reports on plants of Jammu (Jan *et al*., 2016), Ladakh (Mangla *et al*., 2018), and Himachal (Bhardwaj *et al*., 2016) of west Himalaya.

Cluster analysis was performed according to the PC scores of 400 author keywords. *Picrorhiza kurroa* (Siddiqi *et al*., 2018), *Anthemis cotula* (Vucković *et al*., 2011), Apiaceae (Thakur *et al*., 2016a), liverwort, wild edible plants (Nadeem & Imran, 2016), and cushion plant (Yang *et al*., 2017) have various medicinal uses (Fig. 3B). The representative medicinal components, picrosides (Ganeshkumar *et al*., 2017), steviol glycosides (Modi *et al*., 2014), podophyllotoxin (Nadeem *et al*., 2007), and essential oil (Benedetto *et al*., 2018; Mahajan *et al*., 2018), are included in the cluster. Phytometabolites of these "hotspot" plants showed anticancer (Ganeshkumar *et al*., 2017), antimicrobial (Shameem *et al*., 2017) and antioxidant (Benedetto *et al*., 2018) activities. ISSR and RAPD markers are commonly used in the population studies of medicinal plants (Thakur *et al*., 2016a). Indegenous uses of native plants (Ahmad *et al*., 2017; Devkota *et al*., 2017) have double implications in both cultural heritage and drug development. Again, "arbuscular mycorrhiza" is closely related with plant wellness with regard to the soil type and plant species (Shah *et al*., 2009). *A. cotula*, despite its medicinal value, is an invasive plant in Himalaya region.

Hengduan Mountains (Guo *et al*., 2016), at the east margin of Qinghai-Tibetan Plateau and spanning east Tibet, northwest Yunnan and southwest Sichuan, is a world-renowned biodiversity hotspot and the glacial refugia during Quaternary period. The chloroplast DNA markers are used to elucidate the phylogenetic relationship of different populations with regard to their geographic locations (Liu *et al*., 2018). The nuclear markers and genomic data are also indispensable in the studies of molecular phylogeny and biogeography of Himalaya species (Yu *et al*., 2015; Zhang *et al*., 2017; Xiang *et al*., 2017; Deng *et al*., 2018). The inferred phylogenies are the basis of plant pharmacophylogeny (Hao and Xiao, 2015, 2017), a powerful tool of bioprospecting and sustainable exploitation of phytomedicinal resources.

Cluster analysis was also performed according to the PC scores of 700 KeyWords Plus to cross validate the "hot" terms and to obtain the complementary and enlightening information. Studies of the model plant *Arabidopsis thaliana* (Singh & Roy, 2017; Fig. 3C) are important references in the later explorations of gene expression and biosynthesis of Himalaya plants. Ranunculaceae plants (Thakur *et al*., 2016b; Xiang *et al*., 2017), thriving in alpine habitats, are rich in various bioactive compounds (Hao *et al*., 2015, 2018). Research experiences of Caryophyllaceae (Yang *et al*., 2017), *Podophyllum hexandrum* (Thakur *et al*., 2016b), *Pisum sativum* (Tomer *et al*., 2017), and food plants (Ma *et al*., 2017) contribute fundamental knowledge of growth and yield of Himalaya plants. Besides ISSR and RAPD markers, nuclear ribosomal DNA (e.g., ITS; Shah *et al*., 2017), AFLP (Ma *et al*., 2014) and SSR (Sharma *et al*., 2017) markers are also complementary and alternative in genetic diversity studies. Rhizobacteria (Chauhan *et al*., 2015), fluorescent pseudomonads (Thakur *et al*., 2018), and phosphate solubilizing bacteria (Tomer *et al*., 2017) of rhizosphere have intricate relationship with mycorrhiza fungi and have significant impact on plant health. Numerous ethnobotanical surveys have been performed to collate rapidly vanishing traditional knowledge from various districts of Himalaya region (Thakur *et al*., 2016b; Ahmad *et al*., 2017; Kunwar *et al*., 2018).

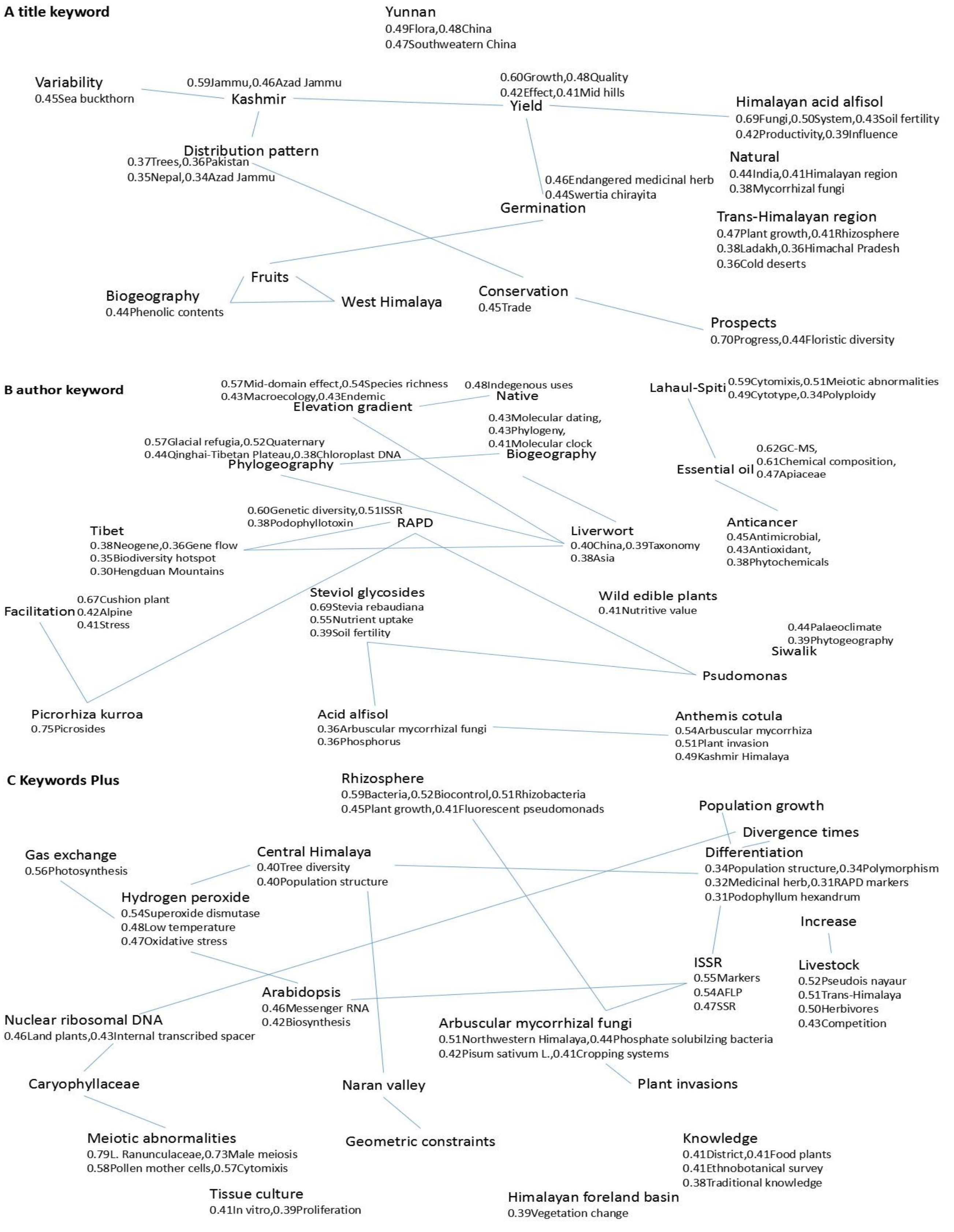

Fig. 3 Principal component analysis (PCA) of the high frequency words. Key words were extracted from 2471 sample publications via Natural Language Processing (NLP), including author keywords and title keywords, and totally 19,839 information key words. The high frequency (≥ 5) words with subject representation, including 277 title keywords (A), 324 author keywords (B), and 576 KeyWords Plus (C), were selected by professional judgments for the following PCA to explore the list items frequently appearing together in the data set, in which each node in the map represents a cluster of the subject word, the connection between nodes represents the similarity between two subject words, and the size of the connection indicates the degree of similarity. In order to avoid visual confusion, only the most similar parts are displayed.

Conclusion and Perspective

It is no doubt that the Himalaya plant research is an exciting and revolutionary multidisciplinary field at the center of many current key scientific issues. In this study, we obtained some significant points on the worldwide research trends throughout the period from 1998 through 2017. The effort provided a panorama, as well as clues to the impacts of the Himalaya plant related topic. English was by far the dominant language, while intriguing findings in other languages should be translated into English to be fully used. The Himalaya plant research and development became more globally connected. The CSIR of India and Chinese Academy of Sciences are the blazing twin star in this field. The pan-Himalaya countries, together with USA, UK, and Germany, are strong in this field. They not only have the absolute ascendancy of publication, but also are the most frequent research partners. The mainstream of Himalaya plant research was in plant sciences and ecology, and more reports of pharmacology and pharmacy, medicinal chemistry, and biodiversity conservation are emerging in recent decade. Systematically analyzing the distribution of paper title words, author keywords, and KeyWords PlusKeyWords Plus, we suggest that Himalaya plant research with respect to ethnopharmacology mainly focused on two branches. One was phytochemistry and biotechnology, especially on medicinal compound biosynthesis, chemodiversity, and cell culture production of phytometabolites; the other was medicinal biodiversity and conservation of traditional ethnobotanical knowledge. Although semi-synthesis and subsequent plant cell culture-based production efforts could decrease the need for harvesting the endangered species, production still depends on plant-based processes. Recent developments in metabolic engineering and synthetic biology offer new pathways for the large scale production of complex natural products by optimizing more technically amenable microbial hosts. Moreover, the ethnopharmacological study of Himalaya plants should go deeper into the molecular and cellular levels (Syed *et al*., 2016; Giorgi *et al*., 2017), which will accelerate the study of Himalaya pharmaceutical resources, and promote the research and development of novel therapeutics. The bibliometric method can help relevant researchers realize the scenario of global Himalaya plant research, and establish the further research direction. Based on the bibliometric results, we find that gaps are present in knowledge about the genomics, epigenomics, transcriptomics, proteomics, metabolomics and bioinformatics of Himalaya plants and their associated microbes. Systems biology, network pharmacology (Hao and Xiao, 2014) and various omics technologies will play an increasingly important role in the coming decades. This study provides a paradigm of assessing research performance and trend of any medicinal plants with bibliometric methods.

Acknowledgment

This work is supported by Natural Science Fund of Liaoning province (20180550190).

References

Ahmad, K.S., A. Hamid, F. Nawaz, M. Hameed, F. Ahmad, J. Deng, N. Akhtar, A. Wazarat and S. Mahroof. 2017. Ethnopharmacological studies of indigenous plants in Kel village, Neelum Valley, Azad Kashmir, Pakistan. *J. Ethnobiol. Ethnomed*., 13(1): 68.

Amber, R., M. Adnan, A. Tariq and S. Mussarat. 2017. A review on antiviral activity of the Himalayan medicinal plants traditionally used to treat bronchitis and related symptoms. *J. Pharm. Pharmacol*., 69(2): 109-122.

Aryal, K.P., S. Poudel, R.P. Chaudhary, N. Chettri, P. Chaudhary, W. Ning and R. Kotru. 2018. Diversity and use of wild and non-cultivated edible plants in the Western Himalaya. *J. Ethnobiol. Ethnomed*., 14(1): 10.

Bajpai, R., S. Mishra, S. Dwivedi and D.K. Upreti. 2016. Change in atmospheric deposition during last half century and its impact on lichen community structure in Eastern Himalaya. *Sci. Rep*., 6: 30838.

Belwal, T., P. Dhyani, I.D. Bhatt, R.S. Rawal and V. Pande. 2016. Optimization extraction conditions for improving phenolic content and antioxidant activity in *Berberis asiatica* fruits using response surface methodology (RSM). *Food Chem*., 207: 115-124.

Benedetto, C., M. D'Auria, M. Mecca, P. Prasad, P. Singh, S. Singh, C. Sinisgalli and L. Milella. 2018. Chemical and biological evaluation of essential oil from *Saussurea costus* (Falc.) Lipsch. from Garhwal Himalaya collected at different harvesting periods. *Nat. Prod. Res*., 2018: 1-4.

Bhardwaj, D.R., M. Banday, N.A. Pala and B.S. Rajput. 2016. Variation of biomass and carbon pool with NDVI and altitude in sub-tropical forests of northwestern Himalaya. *Environ. Monit. Assess*., 188(11): 635.

Chauhan, A., C.K. Shirkot, R. Kaushal and D.L.N. Rao. 2015. Plant growth-promoting rhizobacteria of medicinal plants in NW Himalayas: Current status and future prospects. In: (Eds.): Egamberdieva, D., S. Shrivastava, A. Varma. Plant-Growth-Promoting Rhizobacteria (PGPR) and Medicinal Plants 381-412. Berlin: Springer.

Cunningham, A.B., J.A. Brinckmann, U. Schippmann and D. Pyakurel. 2018. Production from both wild harvest and cultivation: The cross-border *Swertia chirayita* (Gentianaceae) trade. *J. Ethnopharmacol*., 225: 42-52.

Deng, M., X.L. Jiang, A.L. Hipp, P.S. Manos and M. Hahn. 2018. Phylogeny and biogeography of East Asian evergreen oaks (Quercus section Cyclobalanopsis; Fagaceae): Insights into the Cenozoic history of evergreen broad-leaved forests in subtropical Asia. *Mol. Phylogenet. Evol*., 119: 170-181.

Devkota, S., R.P. Chaudhary, S. Werth and C. Scheidegger. 2017. Indigenous knowledge and use of lichens by the lichenophilic communities of the Nepal Himalaya. *J. Ethnobiol. Ethnomed*., 13(1): 15.

Ganeshkumar, Y., A. Ramarao and C. Veeresham. 2017. Picroside I and picroside II from tissue cultures of *Picrorhiza kurroa*. *Pharmacog. Res*., 9: S53-56.

Garfield, E. 1990a. KeyWords Plus^{TM} - ISIS breakthrough retrieval method. 1. Expanding your searching power on current-contents on diskette. *Curr. Contents*, 32: 5-9.

Garfield, E. 1990b. KeyWords Plus^{TM} takes you beyond title words. Expanded journal coverage for Current Contents on Diskette. Includes social and behavioral sciences. *Curr. Contents*, 33: 5-9.

Giorgi, A., A. Bassoli, G. Borgonovo, S. Panseri, A. Manzo, D. Pentimalli, A. Schiano Moriello and L. De Petrocellis. 2017. Extracts and compounds active on TRP ion channels from *Waldheimia glabra*, a ritual medicinal plant from Himalaya. *Phytomedicine*, 32: 80-87.

Giri, L., A.K. Jugran, A. Bahukhandi, P. Dhyani, I.D. Bhatt, R.S. Rawal, S.K. Nandi and U. Dhar. 2017. Population genetic structure and marker trait associations using morphological, phytochemical and molecular parameters in Habenaria edgeworthii-a threatened medicinal orchid of west Himalaya, India. *Appl. Biochem. Biotechnol*., 181(1): 267-282.

Guo, W., J. Yang, X.D. Sun, G.J. Chen, Y.P. Yang and Y.W. Duan. 2016. Divergence in eco-physiological responses to drought mirrors the distinct distribution of *Chamerion angustifolium* cytotypes in the Himalaya-Hengduan Mountains region. *Front. Plant Sci*., 7: 1329.

Gurung, B., P.K. Bhardwaj, A.K. Rai and D. Sahoo. 2018. Major ginsenoside contents in rhizomes of *Panax sokpayensis* and *Panax bipinnatifidus*. *Nat. Prod. Res*., 32(2): 234-238.

Hao, D.C. 2018. Ranunculales medicinal plants: Biodiversity, chemodiversity and pharmacotherapy. London: Academic Press.

Hao, D.C. and L. Yang. 2016. Drug metabolism and disposition diversity of *Ranunculales phytometabolites*: a systems perspective. *Expert Opin. Drug Metab. Toxicol*., 12(9): 1047-1065.

Hao, D.C. and P.G. Xiao. 2014. Network pharmacology: a Rosetta Stone for traditional Chinese medicine. *Drug Dev. Res*., 75(5): 299-312.

Hao, D.C. and P.G. Xiao. 2015b. Genomics and evolution in traditional medicinal plants: Road to a healthier life. *Evol. Bioinform*., 11: 197-212.

Hao, D.C. and P.G. Xiao. 2017. An introduction of plant pharmacophylogeny. Beijing: Chemical Industry Press.

Hao, D.C., G.B. Ge, P.G. Xiao, P. Wang and L. Yang. 2015a. Drug metabolism and pharmacokinetic diversity of ranunculaceae medicinal compounds. *Curr. Drug Metab*., 16(4): 294-321.

Hu, Z.J., Y.L. Zhang and H.B. Yu. 2015. Simulation of Stipa purpurea distribution pattern on Tibetan Plateau based on MaxEnt model and GIS. *Ying Yong Sheng Tai Xue Bao*, 26(2): 505-511.

Iyer, M., A.K. Gujjari, V. Gowda and S. Angadi. 2017. Antifungal response of oral-associated candidal reference strains (American Type Culture Collection) by supercritical fluid extract of nutmeg seeds for geriatric denture wearers: An *In vitro* screening study. *J. Ind. Prosthodont. Soc*., 17(3): 267-272.

Jan, S., A.N. Kamili, J.A. Parray, Y.S. Bedi and P. Ahmad. 2016. Microclimatic variation in UV perception and related disparity in tropane and quinolizidine alkaloid composition of *Atropa acuminata*, *Lupinus polyphyllus* and *Hyoscyamus niger*. *J. Photochem. Photobiol. B*, 161: 230-235.

Kashyap, R., R. Sharma and S.K. Uniyal. 2018. Bioindicator responses and performance of plant species along a vehicular pollution gradient in western Himalaya. *Environ. Monit. Assess*., 190(5): 302.

Kunwar, R.M., M. Fadiman, M. Cameron, R.W. Bussmann, K.B. Thapa-Magar, B. Rimal and P. Sapkota, 2018. Cross-cultural comparison of plant use knowledge in Baitadi and Darchula districts, Nepal Himalaya. *J. Ethnobiol. Ethnomed*., 14(1): 40.

Liu, H.R., Q.B. Gao, F.Q. Zhang, G. Khan and S.L. Chen. 2018. Westwards and northwards dispersal of *Triosteum himalayanum* (Caprifoliaceae) from the Hengduan Mountains region based on chloroplast DNA phylogeography. *Peer J*., 6: e4748.

Ma, C., J. Liao and P. Fan. 2017. Food selection in relation to nutritional chemistry of Cao Vit gibbons in Jingxi, China. *Primates*, 58(1): 63-74.

Ma, Y., W. Xie, X. Tian, W. Sun, Z. Wu and R. Milne. 2014. Unidirectional hybridization and reproductive barriers between two heterostylous primrose species in north-west Yunnan, China. *Ann. Bot*., 113(5): 763-775.

Mahajan, V, R. Chouhan, S. Kitchlu, K. Bindu, S. Koul, B. Singh, Y.S. Bedi and S.G. Gandhi. 2018. Assessment of chemical and genetic variability in *Tanacetum gracile* accessions collected from cold desert of Western Himalaya. *3 Biotech*., 8(6): 284.

Mangla, Y., K. Das, S. Bali, H. Ambreen, S.N. Raina, R. Tandon and S. Goel. 2018. Occurrence of subdioecy and scarcity of gender-specific markers reveal an ongoing transition to dioecy in Himalayan seabuckthorn (*Hippophae rhamnoides* ssp. *turkestanica*). *Heredity* doi: 10.1038/s41437-018-0084-z.

Manish, K., M.K. Pandit, Y. Telwala, D.C. Nautiyal, L.P. Koh and S. Tiwari. 2017. Elevational plant species richness patterns and their drivers across non-endemics, endemics and growth forms in the Eastern Himalaya. *J. Plant Res*., 130(5): 829-844.

Mehraj, G., A. Anzar, A.A. Khuroo, I. Muzafar, I. Rashid and A.H. Malik. 2017. An updated taxonomic inventory of flora of Srinagar City (Kashmir Himalaya) India, using herbarium reconstruction approach. *Proc. Natl. Acad. Sci. India B: Biol. Sci*., doi 10.1007/s40011-017-0840-5.

Modi, A., N. Litoriya, V. Prajapati, R. Rafalia and S. Narayanan. 2014. Transcriptional profiling of genes involved in steviol glycoside biosynthesis in *Stevia rebaudiana* bertoni during plant hardening. *Dev. Dyn*., 243(9): 1067-1073.

Nadeem, M. and M. Imran. 2016. Promising features of Moringa oleifera oil: recent updates and perspectives. *Lipids Health Dis*., 15(1): 212.

Nadeem, M., L.M. Palni, A. Kumar and S.K. Nandi. 2007. Podophyllotoxin content, above- and belowground biomass in relation to altitude in *Podophyllum hexandrum* populations from Kumaun region of the Indian Central Himalaya. *Planta Med*., 73(4): 388-391.

Popović, Z., R. Matić, S. Bojović, M. Stefanović and V. Vidaković. 2016. Ethnobotany and herbal medicine in modern complementary and alternative medicine: An overview of publications in the field of I&C medicine 2001-2013. *J. Ethnopharmacol*., 181: 182-192.

Pyakurel, D., I. Bhattarai Sharma and C. Smith-Hall. 2018. Patterns of change: The dynamics of medicinal plant trade in far-western Nepal. *J. Ethnopharmacol*., 224: 323-334.

Rahman, I.U., F. Ijaz, Z. Iqbal, A. Afzal, N. Ali, M. Afzal, M.A. Khan, S. Muhammad, G. Qadir and M. Asif. 2016. A novel survey of the ethno medicinal knowledge of dental problems in Manoor Valley (Northern Himalaya), Pakistan. *J. Ethnopharmacol*., 194: 877-894.

Rajashekhara, N., B.K. Ashok, P.P. Sharma and B. Ravishankar. 2014. Evaluation of acute toxicity and anti-ulcerogenic study of rhizome starch of two source plants of Tugaksheeree (*Curcuma angustifolia* Roxb. and *Maranta arundinacea* Linn.). *Ayu*, 35(4): 433-437.

Rana, B. and Y. Sreenivasulu. 2013. Protein changes during ethanol induced seed germination in *Aconitum heterophyllum*. *Plant Sci*., 198: 27-38.

Scott, K.J. and R.M. Smillie. 1966. Metabolic regulation in diseased leaves. I. The respiratory rise in barley leaves infected with powdery mildew. *Plant Physiol*., 41(2): 289-297.

Shah, A., M.A. Rather, Q.P. Hassan, M.A. Aga, S. Mushtaq, A.M. Shah, A. Hussain, S.A. Baba and Z. Ahmad. 2017. Discovery of anti-microbial and anti-tubercular molecules from *Fusarium solani*: an endophyte of *Glycyrrhiza glabra*. *J. Appl. Microbiol*., 122(5): 1168-1176.

Shah, M.A., Z.A. Reshi and D. Khasa, 2009. Arbuscular mycorrhizal status of some Kashmir Himalayan alien invasive plants. *Mycorrhiza*, 20(1): 67-72.

Shameem, N., A.N. Kamili, M. Ahmad, F.A. Masoodi and J.A. Parray. 2017. Antimicrobial activity of crude fractions and morel compounds from wild edible mushrooms of north western Himalaya. *Microb. Pathog*., 105: 356-360.

Sharma, M., G. Areendran, K. Raj, A. Sharma and P.K. Joshi. 2016. Multitemporal analysis of forest fragmentation in Hindu Kush Himalaya-a case study from Khangchendzonga Biosphere Reserve, Sikkim, India. *Environ. Monit. Assess*., 188(10): 596.

Sharma, V., M.S. Wani, V. Singh, K. Kaur and R.C. Gupta. 2017. Development and characterization of novel microsatellite markers in *Trillium govanianum*: a threatened plant species from North-Western Himalaya. *3 Biotech*., 7(3): 190.

Shiva Kumar, A., K. Jeyaprakash, D.R. Chellappan and R. Murugan. 2017. Vasorelaxant and cardiovascular properties of the essential oil of *Pogostemon elsholtzioides*. *J. Ethnopharmacol*., 199: 86-90.

Siddiqi, A., Z. Nazneen, S.S. Haqnawaz, Alam and S. Tariq. 2018. Mechanism of nephroprotection by Picrorhiza Kurroa. *J. Ayub. Med. Coll. Abbottabad.*, 30(2): 184-186.

Singh, A. and S. Roy. 2017. High altitude population of Arabidopsis thaliana is more plastic and adaptive under common garden than controlled condition. *BMC Ecol*., 17(1): 39.

Singh, A., M.C. Nautiyal, R.M. Kunwar and R.W. Bussmann. 2017. Ethnomedicinal plants used by local inhabitants of Jakholi block, Rudraprayag district, western Himalaya, India. *J. Ethnobiol. Ethnomed*., 13(1): 49.

Syed, A.A., S. Lahiri, D. Mohan, G.R. Valicherla, A.P. Gupta, S. Kumar, R. Maurya, H.K. Bora, K. Hanif and J.R. Gayen. 2016. Cardioprotective effect of *Ulmus wallichiana* Planchon in β-adrenergic agonist induced cardiac hypertrophy. *Front. Pharmacol*., 7: 510.

Thakur, J., M.D. Dwivedi, P. Sourabh, P.L. Uniyal and A.K. Pandey. 2016a. Genetic homogeneity revealed using SCoT, ISSR and RAPD markers in micropropagated *Pittosporum eriocarpum* Royle- an endemic and endangered medicinal plant. *PLoS One*, 11(7): e0159050.

Thakur, M., R.K. Asrani, S. Thakur, P.K. Sharma, R.D. Patil, B. Lal and O. Parkash. 2016b. Observations on traditional usage of ethnomedicinal plants in humans and animals of Kangra and Chamba districts of Himachal Pradesh in North-Western Himalaya, India. *J. Ethnopharmacol*., 191: 280-300.

Thakur, V., V. Kumar, S. Kumar and D. Singh. 2018. Diverse culturable bacterial communities with cellulolytic potential revealed from pristine habitat in Indian trans-Himalaya. *Can. J. Microbiol*., doi: 10.1139/cjm-2017-0754.

Tomer, S., D.C. Suyal, A. Shukla, J. Rajwar, A. Yadav, Y. Shouche and R. Goel. 2017. Isolation and characterization of phosphate solubilizing bacteria from Western Indian Himalayan soils. *3 Biotech*., 7(2): 95.

Vieira, M.N., P. Winterhalter and G. Jerz. 2016. Flavonoids from the flowers of Impatiens glandulifera Royle isolated by high performance countercurrent chromatography. *Phytochem. Anal*., 27(2): 116-125.

Vucković, I., L. Vujisić, C.A. Klaas, I. Merfort and S. Milosavljević. 2011. NF-κB DNA binding activity of sesquiterpene lactones from *Anthemis arvensis* and *Anthemis cotula*. *Nat. Prod. Res*., 25(8): 800-805.

Wang, X., T. Wang, H. Guo, D. Liu, Y. Zhao, T. Zhang, Q. Liu and S. Piao. 2018. Disentangling the mechanisms behind winter snow impact on vegetation activity in northern ecosystems. *Glob. Chang. Biol*., 24(4): 1651-1662.

Xiang, K.L., L. Zhao, A.S. Erst, S.X. Yu, F. Jabbour and W. Wang. 2017. A molecular phylogeny of Dichocarpum (Ranunculaceae): Implications for eastern Asian biogeography. *Mol. Phylogenet. Evol*., 107: 594-604.

Yang, Y., J.G. Chen, C. Schöb and H. Sun. 2017. Size-mediated interaction between a cushion species and other non-cushion species at high elevations of the Hengduan Mountains, SW China. *Front. Plant Sci*., 8: 465.

Yu, W.B., M.L. Liu, H. Wang, R.R. Mill, R.H. Ree, J.B. Yang and D.Z. Li. 2015. Towards a comprehensive phylogeny of the large temperate genus Pedicularis (Orobanchaceae), with an emphasis on species from the Himalaya-Hengduan Mountains. *BMC Plant Biol*., 15: 176.

Zhang, M.Y., P.W. Fritsch, P.F. Ma, H. Wang, L. Lu and D.Z. Li. 2017. Plastid phylogenomics and adaptive evolution of Gaultheria series Trichophyllae (Ericaceae), a clade from sky islands of the Himalaya-Hengduan Mountains. *Mol. Phylogenet. Evol*., 110: 7-18.

(Received for publication 10 February 2018)