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The ethnopharmacological literature: An analysis of the scientific landscape

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Abstract

Ethnopharmacological relevance: The research into bioactive natural products originating from medicinal plants, fungi and other organisms has a long history, accumulating abundant and diverse publications. However no quantitative literature analysis has been conducted.

Aim of the study: Here we analyze the bibliometric data of ethnopharmacology literature and relate the semantic content to the publication and citation data so that the major research themes, contributors, and journals of different time periods could be identified and evaluated.

Materials and Methods: Web of Science (WoS) was searched to identify relevant publications. The Analyze function of WoS and bibliometric software (VOSviewer) were utilized to perform the analyses.

Results: Until the end of November 2018, 59,576 publications -linked to ‘ethnopharmacology’ indexed by WoS, published since 1958 in more than 5,600 journals, and contributed by over 20,600 institutions located in more than 200 countries/regions, were identified. The papers were published under four dominating WoS categories, namely pharmacology/pharmacy (34.4%), plant sciences (28.6%), medicinal chemistry (25.3%), and integrative complementary medicine (20.6%). India (14.6%) and China (13.2%) were dominating the publication space. The United States and Brazil also had more than 8.0% contribution each. The rest of the top ten countries/regions were mainly from Asia. There were around ten-fold more original articles (84.6%) than reviews (8.4%).

Conclusions: Ethnopharmacological research has a consistent focus on food and plant sciences, (bio)chemistry, complementary medicine and pharmacology, with a more limited scientific acceptance in the socio-cultural sciences. Dynamic global contributions have been shifting from developed countries to economically and scientifically emerging countries in Asia, South

America and the Middle East. Research on recording medicinal plant species used by traditional medicine continues, but the evaluation of specific properties or treatment effects of extracts and compounds has increased enormously. Moreover increasing attention is paid to some widely distributed metabolites, such as curcumin, quercetin, and rutin.

Keywords (6): ethnopharmacology; medicinal plants; traditional medicine; bibliometric analysis; citation analysis; Web of Science.

1. Introduction

There has been a long history of abundant and diverse ethnopharmacological studies focusing on the biological, pharmacological and socio-cultural aspects of medicinal plants and fungi as well as other natural sources with a local or traditional usage (Heinrich and Jäger, 2015). Ethnopharmacology (sometimes also called ethnopharmacy) is an interdisciplinary exploration of bioactive agents with traditionally uses, and thus incorporates concepts and methods from botany, pharmacology, toxicology, chemistry, and anthropology (Holmstedt, 1991), among others. In 2015, experts in the field provided their own definitions of the term "ethnopharmacology", with a wide spectrum of views expressed. A very traditional definition is "the examination of non-Western medicinal plant use in terms of Western plant use" (Heinrich and Jäger, 2015, p. xxiii – xv). For instance, the evaluation of antimicrobial activity of essential oils from the South African *Lippia javanica* (Burm.f.) Spreng. leaf (Viljoen et al., 2005) and the anticancer activity of artesunate, a semi-synthetic derivative of artemisinin, a constituent of Chinese *Artemisia annua* L. (Efferth et al., 2001), are only two examples of successfully investigated non-Western medicinal plants which result in novel active preparations for a widespread use. Many approved drugs in the modern days are derived from medicinal plants, to name a few: aspirin, morphine, and pilocarpine (Gilani, 2005). Plants continue to be important sources of drug discovery today, especially with the rising popularity of the genomics approach (Atanasov et al., 2015; Harvey et al., 2015; Singh et al., 2018).

Currently, not only the local and traditional knowledge in remote regions, but also that among urban immigrant communities is being studied (Heinrich and Casselman, 2018). Besides, studies also consider the sustainable use of natural resources, the effects of phytochemical mixtures on specific diseases, their safety, and the link between food and medicinal uses of plants and fungi (Heinrich and Casselman, 2018; Yeung et al., 2018a).

With such a vibrant and dynamic research community, there are certainly some challenges to be addressed, including the detailed authentication of botanical species investigated, a sound understanding of the local/traditional uses of plants (and other bioactive agents) and their importance for the community, the detailed information reporting of an extract and its composition as well as the chemical analysis conducted, and finally, the adherence to the state-of-the-art standards set by modern pharmacological researches using *in vivo* models or clinical trials (Heinrich, 2014). The safety of the herbal medicines is particularly an important issue that needs to conform to the required international standards under the drug regulatory frameworks (Ekor, 2014). Besides, more collaborative approaches are advocated to reduce overlapping and redundancy of resources and efforts, especially in the case of developing medicinal plant databases for knowledge and data sharing (Ningthoujam et al., 2012). In response to these challenges, a number of guidelines were published, such as to define a best practice in developing, conducting and reporting ethnopharmacological field studies (Heinrich et al., 2018), and for randomized controlled trials evaluating Chinese herbal medicine (Cos et al., 2006; Flower et al., 2012). While such guidelines and initiatives are relevant, the 40th anniversary of the *Journal of Ethnopharmacology* offers an opportunity to take stock and to assess what is actually the current scope and focus of ‘ethnopharmacology’.

These examples above lack a systematic analysis of how the field is developing. Therefore, this work aims to quantitatively evaluate the ethnopharmacology literature over time. With such a rich and diverse literature, we particularly want to identify major research themes in different decades, and to investigate the trends and changes in the popularity of themes of research as well as the contributions from different countries/regions. What do the terms from the titles, abstracts, and keywords of the publications tell us about the evolution of the field of research ‘ethnopharmacology’? This work analyzes the quantitative data of this field from a bibliometric perspective complementing the various reviews of specific natural products, therapeutic areas, medical traditions or historical developments.

2. Materials and Methods

2.1 Data Sources

The web-based, multidisciplinary Web of Science (WoS) Core Collection database, hosted by Clarivate Analytics, was the data source for the current work (www.webofknowledge.com). It covers peer-reviewed articles published in scientific journals of various aspects, such as health, life, physical, and social sciences. In November 2018, we searched WoS to identify publications with the following string: TOPIC= (ethnopharmacolog* OR ethnobotan* OR ethnomedic* OR "medicinal plant*" OR "folk medicine*" OR "traditional medicine*"). This search string identified publications with any of these terms, phrases and/or their derivatives in the articles’ title, abstract or keywords. No additional restrictions were placed on the search, such as the publication year, publication language or type (e.g., research article, review, editorial, letter, etc.).

2.2 Data Extraction

The full bibliometric records for the identified publications were firstly analyzed by "Analyze Results" function of WoS, which provided frequency counts of the publications in terms of numerous parameters, such as WoS category, publication year, publication type, institution, authorship, journal, country/region, and language. Then, the full bibliometric records were downloaded and imported into VOSviewer for more detailed analyses, separated into four time periods: year 1990 and before, 1991–2000, 2001–2010, and 2011–2018.

We identified the key journals that published articles on ethnopharmacology in each of the four time periods by considering the Bradford's law of scattering, which states that a few core journals should have been accounted for publishing one-third of total articles within a specified period of time (Vickery, 1948; Yeung et al., 2017). This analysis should enable us to identify journals that were perennial heavyweights, rising stars, and on the decline.

2.3 Term map

Words in the titles and abstracts of the identified ethnopharmacology publications were analyzed by VOSviewer (van Eck and Waltman, 2009), a bibliometric software that relates the terms with the citation data, resulting in a term map that shows their frequency of occurrence by bubble size, as well as co-occurrence among the publications by the distance between bubbles and the averaged citation counts of publications indicated with the color of a dot. We produced four such term maps, one each for the four time periods analyzed (year 1990 and before, 1991–2000, 2001–2010, and 2011–2018). Each term map only visualized terms that appeared in at least 1.0% of the papers published in that particular time period. An exception was the term map for "year 1990 and before", in which we used a lower threshold of 0.5% of total publications due to far fewer publications identified. Citations per publication (CPP) for each term was calculated as the total citation count received by all publications containing that term divided by the number of publications containing that term, i.e. total citation count divided by publication count.

We also produced similar maps for the keywords (author's keywords and KeyWords Plus tagged by WoS) listed with the publications. The threshold was also 1.0% of the publications in each particular time period. Irrelevant terms were removed manually.

Each term map was shown twice, with the second one having a different color coding to show clusters of terms. The clustering was done by the default normalization method used by VOSviewer, which was based on association strength. Default values were used. In addition, we set the minimum cluster size, so that each cluster should contain at least 10% of the terms displayed in the map.

2.4 Publication trends concerning common medical conditions

We examined the trends of common medical conditions and effects that are often investigated in ethnopharmacological research, namely AIDS/HIV, cancer, cardioprotection, diabetes, diarrhea, hepatoprotection, hypertension, infection, inflammation, neuroprotection, pain, parasites, tuberculosis, hallucinogenic and psychoactive effects (Heinrich, 2010; Tewari et al., 2017; Tewari et al., 2018; Waltenberger et al., 2016). Toxicity, drug interactions and related concepts are also important aspects (Ezuruike and Prieto, 2014). Therefore, we searched the ethnopharmacological publications using the "Refine Results > Search within results" function of WoS to search these terms within each time period, using search (meta-)words of "AIDS" or

"HIV", "cancer*, "diabet*", "diarrh*", "inflammat*", "tubercul*", "hallucin*", "psychoactiv*", psychoactive substances "ayahuasca OR *Banisteriopsis caapi*" and "cannabi*", "toxic*", "drug interact*", "adultera*", "pain*", "parasit*", "infecti*", "hypertens*", "neuroprotect*", "cardioprotect*", and "hepatoprotect*". This function searches through the full record of each indexed publication and identified the words regardless of where they were listed. In addition, we used the same search (meta-)words to identify the first appearance of these medical terms in the titles of the respective ethnopharmacology papers, and the most cited ones among them.

Finally, we examine the publication trend of ethnopharmacological articles with clinical relevance. Clinical research search filter is unfortunately not available in WoS. Therefore, as an exploratory analysis, we searched in PubMed by (ethnopharmacolog* OR ethnobotan* OR ethnomedic* OR "medicinal plant*" OR "folk medicine*" OR "traditional medicine*") in "All Fields". Then we limited the "Article type" to "Clinical Study".

3. Results and Discussion

3.1 Overall literature overview

Between 1958 and the end of November 2018, 59,576 publications on ethnopharmacology indexed by WoS were published in more than 5,600 journals belonging to 232 WoS categories, and contributed by over 200 countries/territories, involved over 20,600 institutions, and over 100,000 authors. Four WoS categories dominate, namely pharmacology/pharmacy (n = 20,513; 34.4%), plant sciences (n = 17,017; 28.6%), medicinal chemistry (n = 15,053, 25.3%), and integrative and complementary medicine (n = 12,262; 20.6%).

Each of these four categories had >10% contributions during each of the four time periods surveyed (Table 1). The next tier of WoS categories, each accounted for around 5.0% of total publications, which included biochemistry/molecular biology (n = 3,833; 6.4%), food science technology (n = 3,368; 5.7%), and multidisciplinary chemistry (n = 3,112; 5.2%). However, research focusing on the socio-cultural aspects of ethnopharmacology were less common. There were only 621 papers classified as anthropology, 260 as biomedical social sciences, 121 as folklore, and 116 as sociology. It should be noted that the WoS categories were not mutually exclusive, with some publications being assigned to multiple WoS categories. For instance, publications appeared in *Journal of Ethnopharmacology* would be assigned to 4 categories: medicinal chemistry, integrative and complementary medicine, pharmacology/pharmacy, and plant sciences. Readers may notice that in the first two periods the summed percentages were around 130%, whereas in the last two periods they were 114% and 104% respectively. The decline in the overlap over time was due to a broader distribution of publications in more journals, as demonstrated by the increased number of core journals according to Bradford's law (discussed in the next paragraph).

[Insert Table 1]

Analyzing the distribution according to the Bradford's law, there were 23 all-time core journals that altogether have accounted for one-third of the total publications. The most dominating journal was the *Journal of Ethnopharmacology* (n = 7,163; 12.0%), followed by *Planta Medica* (n = 1,240; 2.1%). Other journals with >1.0% contributions included *Pharmaceutical Biology*, *Phytotherapy Research*, *Evidence-Based Complementary and Alternative Medicine*, *BMC*

Complementary and Alternative Medicine, *Molecules*, *International Journal of Pharmaceutical Sciences and Research*, and the *Journal of Medicinal Plants Research*. The edge of *Journal of Ethnopharmacology*'s share was similarly reflected by its share of the 100 most cited ethnopharmacology articles (Yeung et al., 2018b). There was a steady temporal increase in journal number publishing ethnopharmacological research (Table 2).

[Insert Table 2]

With respect to publication year, we observed a steady growth of literature in the recent two decades (Figure 1). The earliest publication identified with the search string "ethnopharmacolog*" within this collection of literature was published in 1969 (Cohen, 1969), which was a book review on a book titled "Ethnopharmacologic search for psychoactive drugs" (Efron et al., 1967), which contained the proceedings of a symposium held in 1967. Interestingly, this book was not tagged under "ethnopharmacolog*".

[Insert Figure 1]

The ethnopharmacology publications were mainly original articles (n = 50,385; 84.6%) and a much smaller number of reviews (n = 5,011; 8.4%), while the remaining of about 7.0% (n = 4,180) belong to a wide range of document types such as editorial materials, notes, and letters.

With regards to country/territory, India (n = 8,674; 14.6%) and China (n = 7,856; 13.2%) dominate the list. The United States (n = 5,134) and Brazil (n = 5,103) also had more than 8.0% contribution each. The rest of the top ten countries/regions were mainly from Asia, i.e. South Korea, Pakistan, and Japan, as well as South Africa and Turkey (ranging from 5.1% to 2.8%). These proportions of contributions were different from what we reported on the 100 most cited ethnopharmacology papers – European countries and The United States had more contributions (41% and 29%, respectively) within that highly cited group of publications (Yeung et al., 2018b). In other words, there was a larger share of papers contributed by Asian but also South- Central American and African countries/territories outside the collection of the 100 most cited papers. This could be partly explained by the fact that papers written in the United States are traditionally and consistently more cited than those published by other countries across various science fields (Bornmann and Leydesdorff, 2013). However, China, India, and South Korea have been growing as emerging powers in terms of publication and citation shares (Adams, 2013; Smith et al., 2014). We will elucidate these trends in the following sections for each time period (for the top 5 most productive countries/territories see Table 3). In terms of language, the vast majority of the publications were written in English (n = 57,128; 95.9%), certainly also an outcome of WoS's focus on the scientific literature coverage, published in non-English papers were usually written in Portuguese, Spanish, German, French, Chinese and Japanese, with prevalence range from 1.0% to 0.2%.

[Insert Table 3]

In terms of institution, the Council of Scientific and Industrial Research of India (n = 1,133; 1.9%), the Chinese Academy of Sciences (n = 1,121; 1.9%), and the University of KwaZulu-Natal (South Africa, n = 641; 1.1%) were the top contributors. They were the only institutions with more than 1.0% (n = 596) contribution each. In addition, top 5 most productive institutions in each of the four publication periods (Table 4) show a number of other institutions active in this field of research in North America, Africa and the UK.

[Insert Table 4]

Initially, we aimed to identify the top five most prolific authors. The top one author was Johannes van Staden (n = 330; 0.6%). However, the rest of the top authorships could not be assigned to a specific person. No individual identifier was used at the time and the list exclusively has Chinese names like "Wang Y". Clearly, this will refer to a large number of researchers who have worked in the field. Therefore, we did not attempt to further analyze the data regarding authorship, but limit the outcome of our analysis to the number one top author, who is Johannes van Staden.

3.2 Publications up to 1990

Over 60% of the 1,552 publications of this period are original articles (n = 936; 60.3%), followed by notes (n = 210; 13.5%) and book reviews (n = 165; 10.6%). Reviews were a tiny minority (n = 43; 2.8%). During this period, Satyesh Chandra Pakrashi was the most prolific author (n = 51; 3.3%), with a series of studies on Indian medicinal plants that identified many chemicals/chemical classes, such as alkaloids from *Glycosmis arborea* (Roxb.) DC. (Pakrashi et al., 1963). On the other hand, the most cited publication was a very broad and strategically placed article presenting plant-derived drugs (Bull. World Health Organ), with their actions or uses in therapy as well as the identity of the plant sources (Farnsworth et al., 1985) (with 564 citations).

Considering the terms in the titles and abstracts (Figure 2A), the research directions in this time period focused most prominently on:

- (1) The “activity” (n = 62; CPP = 30.1) of medicinal plants from specific geographic origins, such as antimalarial activity of Tanzanian medicinal plants (Weenen et al., 1990), and oral hypoglycemic activity of Sri Lanka plants (Karunanayake et al., 1984);
- (2) Surveys on the “traditional use” (n = 41; CPP = 13.1) / “practice” (n = 29; CPP = 3.4) of medicinal plants or local medicines that produced an extensive list of plant species with their medicinal use, such as among the Fuji Indians living in South Pacific country of Fiji (Singh, 1986), and among the Zulu people living in Southern Africa (Hutchings, 1989);
- (3) Phytochemical “screening” (n = 27; CPP = 25.5) and “isolation” (n = 35; CPP = 17.7) of natural products in plant species, such as from Nigerian (Odebiyi and Sofowora, 1978) and Tanzanian (Chhabra et al., 1984) medicinal plants.

The clustering of terms by VOSviewer resulted in 5 clusters, which were related to the traditional practice and use of medicinal plants (red, 25 terms), the determination of active principle or constituent (green, 16 terms), the isolation of and treatment using flavonoid (blue, 13 terms), the alkaloid content in tropical and Indian medicinal plants (yellow, 12 terms), and the cytological effect of phytochemicals from medicinal plants (purple, 9 terms) (Figure 2B).

[Insert Figure 2]

This research certainly followed the traditions started in the 19th century searching for the active principles in medicinal plants and studied the species' pharmacology (Heinrich and Jäger, 2015). Often the concepts "medicinal plant" were combined with a geographic or country name, such as "Indian medicinal plant" (n = 72; CPP = 13.7), "African medicinal plant" (n = 36; CPP = 14.4), "Mexican medicinal plant" (n = 17; CPP = 7.9), "Indonesian medicinal plant" (n = 12; CPP = 15.2), "Nigerian medicinal plant" (n = 12; CPP = 17.6), "tropical medicinal plant" (n = 11; CPP = 24.0), "Argentine medicinal plant" (n = 9; CPP = 17.3), or were referring to regional traditional medical systems such as "Chinese traditional medicine" (n = 31; CPP = 20.0) and "Formosan (Taiwan) folk medicine" (n = 8; CPP = 16.5). The wide spectrum of geographic origins of the medicinal plants studied was certainly accompanied by diverse cultural and traditional meanings of the use of such plants (Bernardi, 1980; Moerman, 2007). It implied that medical anthropology and social sciences were also an interesting and important part of ethnopharmacology. There were indeed considerable shares of publications belonging to the WoS categories of anthropology (n = 85; 5.5%) and biomedical social sciences (n = 42; 2.7%). For instance, a paper reported the observations from a fieldwork that focused on the ethnomedicinal practice among the Garifuna ethnic group in Honduras with regard to the ethnic group's concepts towards illness and subsequent management including herbal treatment (Cohen, 1984).

Therefore, during the time period of 1990 and before, there was a considerable share of surveys/field studies in non-Western regions and phytochemical screening in laboratories that focused on plant sciences, pharmacology and chemistry. At the same time, the socio-cultural values of such *materia medica* were also investigated.

Many of these earlier publications either had no abstract or had an abstract not indexed in the WoS database. This situation also applied to keywords. There were only four keywords that occurred in multiple publications, namely medicinal plants (n = 3; CPP = 25.3), ^{13}C NMR spectroscopy (Carbon-13 nuclear magnetic resonance spectroscopy, n = 2; CPP = 3.5), constituents (n = 2; CPP = 4.5), and natural products (n = 2; CPP = 38.5). This issue of missing information did limit the comprehensiveness of literature analysis during this period, and therefore, we did not produce a keyword map for this period.

3.3 Publications 1991–2000

Over 80% of the 3,545 publications were original articles (n = 2,959; 83.5%). The share of reviews remained low but nearly doubled compared to the previous period (n = 194; 5.5%). During this period, Michael Heinrich was the most prolific author (n = 36; 1.0%), with one of his research foci being the use of medicinal plants (such as the selection criteria by indigenous people, the identity of the plants, and the phytochemical composition of the plants) for curing gastrointestinal illness in Mexico (Heinrich et al., 1998a; Heinrich et al., 1992; Heinrich et al., 1998b). The most cited publication during this period was a review paper that summarized the results from botanical screening and *in vivo* studies of the effects and toxicity of plant products as antimicrobial agents (Cowan, 1999) (with 3,052 citations).

Considering the terms in the titles and abstracts (Figure 3A), some of the research directions in the last period still continued. In general, the research efforts in this period of time can be divided into four main directions. (1) Studies on "activity" (n = 1,058; CPP = 45.9) of medicinal plants focusing both on the specific properties of medicinal plants found in specific geographic origins and specific (classes of) natural products. The effects include:

(a) "anti-inflammatory activity" (n = 47; CPP = 58.6), with notable examples of curcumin, flavonoids, and pentacyclic triterpenes (Ammon and Wahl, 1991; Ferrandiz and Alcaraz, 1991; Safayhi and Sailer, 1997);

(b) "antibacterial activity" (n = 83; CPP = 62.7), such as from Palestinian, South African and Turkish medicinal plants (Essawi and Srour, 2000; Rabe and Van Staden, 1997; Sokmen et al., 1999), and the inhibitory effect of propolis extracts against oral bacteria including *Streptococcus mutans* and *Actinomyces naeslundii* (Koo et al., 2000);

(c) "antifungal activity" (n = 45; CPP = 41.5), such as from medicinal plants used by the British Columbian native people and the Palestinians (Ali-Shtayeh and Abu Ghdeib, 1999; McCutcheon et al., 1994);

(d) "antiviral activity" (n = 49; CPP = 36.9), potentially useful against respiratory syncytial virus, rhinovirus and human immunodeficiency virus (HIV) (Lee-Huang et al., 1995; McCutcheon et al., 1995; Vlietinck and Berghe, 1991), while many of the investigated natural products/medicinal plants were identified as "antimicrobial" (n = 85; CPP = 68.8) – effective against multiple groups of pathogens, including bacteria, fungi, and viruses with variable potency;

(e) “analgesic” effect (n = 43; CPP = 37.1) (Elisabetsky et al., 1995; Lorenzetti et al., 1991).

(2) Surveys on the traditional “use” (n = 638; CPP = 44.8) / “practice” (n = 167; CPP = 22.9) of medicinal plants or local medicine became an important theme. Particular common were studies in China, India, Mexico, South Africa, Turkey and Italy, as well as the use of foreign medicinal plants, introduced from developed nations, in northern South America (Bennett and Prance, 2000; Bhandary et al., 1995; Heinrich et al., 1998a; Liu and Xiao, 1992; Pieroni, 2000; Williams et al., 2000; Yeşilada et al., 1995).

(3) Phytochemical “screening” (n = 153; CPP = 51.4) and “isolation” (n = 170; CPP = 36.1) of natural products from plant species, such as from Congolese (Tona et al., 1998) and Brazilian (Alves et al., 2000) medicinal plants, as well as investigations into the differences in various extraction methods for the screening and isolation of natural products (Eloff, 1998).

(4) One new research focus during this period was the potential relevance of “treatment” (n = 647; CPP = 40.7) by natural products/medicinal plants for various “diseases” (n = 354; CPP = 45.3), mainly in association with “cancer” (n = 53; CPP = 69.3) (Graham et al., 2000; Pettit et al., 1995; Surh, 1999) and malaria (n = 54; CPP = 41.4) (Agyepong, 1992; Carvalho et al., 1991), and some other examples including Alzheimer’s disease (Perry et al., 1999) and atopic eczema (Sheehan and Atherton, 1992).

When the clustering by VOSviewer was considered, there were 4 clusters, which were related to the use of plant species for traditional medicine (red, 104 terms), the chemical assay and evaluation of activities of plant extracts against bacteria, fungi, microbiota, etc (green, 75 terms), the treatment efficacy and toxicity evaluation using animal and cell models (blue, 60 terms), and the various parts of plants used, such as seed, leaf, and shoot (grey, 24 terms) (Figure 3B).

Meanwhile, the shares of WoS categories of anthropology (n = 107; 3.0%) and biomedical and social sciences (n = 89; 2.5%) were smaller compared to the last period.

[Insert Figure 3]

The keyword map reaffirms that publications concerning antibacterial/antimicrobial activity and flavonoids had many citations (Figure 4A). As reported above, during this period, Cowan has published a very comprehensive and highly cited review on plant products as antimicrobial agents, ranging from phenolics, terpenoids, essential oils, alkaloids, lectins to polypeptides, and polyacetylenes (Cowan, 1999). Meanwhile, VOSviewer classified the keywords into 4 clusters, which were related to the potential use of alkaloids and flavonoids to treat malaria (red, 12 terms), the glycosides derived from plants of the Asteraceae family (green, 7 terms), the conservation of ethnobotany especially in Mexico (blue, 6 terms), and the antibacterial and antimicrobial activities of traditionally used medicinal plants (yellow, 6 terms) (Figure 4B).

[Insert Figure 4]

3.4 Publications 2001–2010

Over 85% of the 15,875 publications were original articles (n = 13,685; 86.2%). The share of reviews increased slightly compared to the previous period (n = 1,065; 6.7%). Johannes van

Staden was the most prolific author (n = 125; 0.8%), with one of his research foci being antibacterial, antifungal, anti-inflammatory and antimutagenic properties of traditional medicinal plants in South Africa (Buwa and Van Staden, 2006; Eldeen et al., 2005; Motsei et al., 2003; Verschaeve and Van Staden, 2008). The most cited publication during this period was a review of the biological effects of essential oils, which could be partially linked to the pro-oxidant effects on the cellular level (Bakkali et al., 2008) (with 2,660 citations).

Based on the terms in the titles and abstracts (Figure 5A), there were some changes in the research directions as well. (1) Studies of the “activity” (n = 3,632; CPP = 25.2) of medicinal plants was still the mainstream. In this period, “antioxidant activity” (n = 619; CPP = 31.2) was popular than “anti-inflammatory activity” (n = 292; CPP = 29.9), “antibacterial activity” (n = 409; CPP = 19.9), “antifungal activity” (n = 197; CPP = 22.6), and “antimicrobial activity” (n = 520; CPP = 22.2). Some of the most highly cited publications of this period were studies involving *in vitro* tests of antioxidant activity and phenolic content of traditional Algerian, Chinese and Polish medicinal plants (Cai et al., 2004; Djeridane et al., 2006; Wojdyło et al., 2007). Also highly cited were papers that described the enzyme inhibition by natural products such as down-regulation of COX-2, iNOS and ACE by phenolics (Ranilla et al., 2010; Surh et al., 2001). (2) “Surveys” (n = 429; CPP = 23.8) on identifying or listing the traditional use or practice of medicinal plants or local medicines in specific populations or geographic locations were published less frequently, with an increased attention to specific “disease” (n = 1,534; CPP = 28.1) treatments, such as cancer (n = 379; CPP = 38.5) (Ashidi et al., 2010; Ceylan et al., 2002), diabetes (n = 283; CPP = 27.9) (Eddouks et al., 2002; Tahraoui et al., 2007), and malaria (n = 191; CPP = 26.4) (Kvist et al., 2006; Titanji et al., 2008). (3) Phytochemical screening of medicinal plants was on the decline with only 168 publications identified listing “phytochemical screening” or “screening of phytochemicals”; a development certainly driven by the changes in the technologies available globally and the changes in journal policies.

VOSviewer classified the terms into 3 clusters, which were related to the use and applications of medicinal plant for traditional medicine (red, 89 terms), the chemical assay and evaluation of activities of plant extracts (green, 77 terms), and the testing of treatment dose, mechanism, and toxicity evaluation using animal and cell models (blue, 54 terms) (Figure 5B).

The shares of WoS categories of anthropology (n = 172; 1.1%) and biomedical and social sciences (n = 65; 0.4%) continued to shrink. In a study among the rural populations of the Atlantic Forest of Brazil, elderly people were reported to be more knowledgeable and willing to use traditional medicinal plants than the younger generation, as there were more and more introduced species to treat pains, fever, respiratory and gastrointestinal illnesses (Begossi et al., 2002). It needs to be highlighted that this decline is very concerning in the context of the current fast sociocultural changes related to ‘traditional medicine’ and more specifically medicinal plants. Conservation, sustainable use and benefits have been highlighted as politically important areas (Chen et al., 2016), but research is not yet addressing these challenges sufficiently.

[Insert Figure 5]

Moreover, the keyword map reaffirmed the findings that publications on antioxidant activity and associated concepts (e.g., lipid peroxidation and oxidative stress), cancer (and cytotoxicity), and inflammation had many citations (Figure 6A). However, as discussed above and shown at the center of the keyword map, many of these studies were conducted *in vitro*. Consequently, the therapeutic relevance of their findings is highly uncertain. Meanwhile, the 4 clusters identified by VOSviewer were related to oxidative stress and cytotoxicity (red, 18 terms), identification of alkaloids in plants (green, 9 terms), various activities of essential oils (blue, 6 terms), and antioxidant activity of flavonoids (yellow, 4 terms) (Figure 6B).

[Insert Figure 6]

3.5 Publications 2011–2018

85% of the 38,604 publications were original articles (n = 32,805; 85.0%). The share of reviews further increased compared to the previous time period (n = 3,709; 9.6%). During this time period, “Wang Y” was the most prolific author (n = 193; 0.5%). However, as discussed in section *3.1*, “Wang Y” actually represented multiple authors. Following “Wang Y”, Johannes van Staden was the second-most prolific author (n = 185; 0.5%), with many of his most cited publications during this period evaluating the antimicrobial properties of medicinal plants in South Africa, for example against *Staphylococcus aureus*, *Escherichia coli*, and *Candida albicans* (Mulaudzi et al., 2011; Ncube et al., 2012; Ncube et al., 2011). During this period, the most cited publication was a review paper that discussed the basic mechanisms of different extraction techniques for bioactive compounds from plant materials (Azmir et al., 2013) (with 373 citations).

Considering the terms in the titles and abstracts (Figure 7A), the following four research directions could be identified: (1) Studies on the "activity" (n = 14,450; CPP = 7.6) of medicinal plants was still an intensive area of research while "antioxidant activity" (n = 3,349; CPP = 7.0) was far more commonly evaluated compared to "anti-inflammatory activity" (n = 1,305; CPP = 8.7), "antibacterial activity" (n = 1,624; CPP = 5.9), "antifungal activity" (n = 677; CPP = 6.3), and "antimicrobial activity" (n = 1,851; CPP = 6.2). (2) "Surveys" (n = 1,584; CPP = 8.0) on identifying or listing the traditional use or practice of medicinal plants or local medicines in specific geographic locations were focused on the Middle East and South Asia regions, such as Iran, Turkey, India, and Pakistan (Ayyanar and Ignacimuthu, 2011; Cakilcioglu et al., 2011; Haq et al., 2011; Mosaddegh et al., 2012). (3) Phytochemical screening of medicinal plants focused more on antioxidant and antimicrobial activities (da Silva Trentin et al., 2011; Khaled-Khodja et al., 2014; Pochapski et al., 2011). (4) The disease groups studied and their symptoms were more diverse during this period, such as cancer (n = 2,444; CPP = 10.0), diabetes (n = 838; CPP = 8.6), fever (n = 769, CPP = 7.3), malaria (n = 683; CPP = 8.5), asthma (n = 604; CPP = 7.8), hypertension (n = 574; CPP = 8.4), diarrhea (n = 566; CPP = 8.4), and cough (n = 500; CPP = 8.0).

Terms scattered in the lower left corner of Figure 7 are mainly related to cancer (red bubbles). On the one hand, publications focusing on antioxidant capacities of medicinal plants or fruits continued to receive much attention and were linked to potential therapeutic benefits of antioxidants in cancer, which, however, would be limited to preventive effects (Fu et al., 2011; Krishnaiah et al., 2011) and is no of therapeutic relevance. The relevance most important of chemical assays has recently been debated and more *in vivo* models and clinical trials are advocated to test for actual antioxidant capacity and therapeutic benefits of traditionally used plant preparations and their constituents when consumed by human (Granato et al., 2018). Results obtained through *in vitro* and *in vivo* models is often not replicated in clinical trials, for example, the case of curcumin (Nelson et al., 2017). We further examined the original articles concerning antioxidant effects published in this period, to see how cell-based antioxidant assays and simple chemical screening tests were cited. We searched TOPIC=(antioxida*) AND TOPIC=(cell*) for the former, and TOPIC=(antioxida*) NOT TOPIC=(cell*) for the latter. For the former, we found 2,865 articles with CPP = 7.7. The most cited paper was investigating 14 Chinese medicinal plants (Zhang et al., 2011). For the latter, we found 5,716 articles with CPP = 6.9. The most cited paper was investigating 62 fruits (Fu et al., 2011). The number of studies using cell-based assays was only half of that using chemical screening tests, but with comparable CPP.

The 3 clusters classified by VOSviewer were quite similar to those from the preceding time period, related to the use and applications of medicinal plant for traditional medicine (red, 193 terms), the chemical assay and evaluation of activities of plant extracts (green, 151 terms), and the testing of treatment dose, mechanism, and toxicity evaluation using animal and cell models (blue, 137 terms) (Figure 7B).

In addition, the shares of WoS categories of anthropology (n = 257; 0.7%) and biomedical and social sciences (n = 64; 0.2%) became trivial.

[Insert Figure 7]

A closer examination at the keyword map gives additional insights into the publications of this period. For example, publications concerning biosynthesis (n = 430; CPP = 9.2) and drug discovery (n = 465; CPP = 10.6) were relatively more frequently cited (Figure 8A). Furthermore, databases and analysis platforms were set up for systems pharmacology targeting traditional Chinese medicine and African medicinal plants, indicating that researchers select relevant natural products for further evaluation in a more systematic way (Ntie-Kang et al., 2013; Ru et al., 2014). The concept of systems pharmacology was successfully utilized to identify bioactive components and their potential targets from licorice, the root of *Glycyrrhiza glabra* L. (Liu et al., 2013). One of the latest examples of potential drug discovery are the synthetic C_{14}-urea-tetrandrine derivatives with potent anticancer activity, which were structurally modified from derivatives of tetrandrine, a dibenzyltetrahydroisoquinoline alkaloid found in *Stephania tetrandra* S. Moore (Lan et al., 2018). Another example is the discovery the anti-*Mycobacterium tuberculosis* fusarubin, from *Fusarium solani*, an endophytic fungus of *G. glabra* (Shah et al., 2017).

VOSviewer identified 4 clusters of keywords, which were related to oxidative stress and inflammation (red, 30 terms), antioxidant activity of phytochemicals (green, 20 terms), ethnobotany and conservation (blue, 17 terms), and various activities of plants, their extracts, and essential oils (yellow, 14 terms) (Figure 8B).

[Insert Figure 8]

3.6 Trends over the last fifty years

The above sections described the cross-sectional research landscape in four-time periods. This section aims to provide additional insights into the temporal changes of contributions.

Next, we examined the trends of common medical conditions and effects that are often investigated in ethnopharmacological research. Across the four time periods surveyed, the publication numbers covering inflammation, infection, pain, toxicity, cancer and diabetes increased exponentially, whereas those of diarrhea, AIDS/HIV, tuberculosis, drug interaction, adulteration, hallucinogenic and psychoactive effects/substances maintained a more linear growth (Table 5). As one would expect, the most cited papers on inflammation, infection, diabetes, toxicity, and cancer had much more citations than the other medical terms (Table 6).

[Insert Tables 5 and 6]

By an exploratory PubMed search, we found 40,777 ethnopharmacological articles, 520 (1.3%) of which were "Clinical Studies". There were 16 clinical studies published in 1990 and before, 41 during 1991–2000, 140 during 2001–2010, and 323 during 2011–2018. The oldest clinical study was published in 1965 in German on the use of medicinal plant extracts in inflammation of joints (Franke, 1965). It is not indexed in WoS, and according to Google Scholar it received no citations. The majority of the clinical studies (450; 86.5%) are indexed in WoS. These 450 studies had an average citation count of 16. According to WoS, the most cited one among these 450 clinical studies was a randomized controlled trial on the use of *Salvia officinalis* extract in the treatment of Alzheimer's disease patients, which produced a better outcome in terms of cognitive functions relative to placebo (Akhondzadeh et al., 2003). The 10 most cited clinical studies tagged as being ethnopharmacological (Table 7) covers a wide range of medical conditions.

[Insert Table 7]

The chemicals/chemical classes frequently mentioned by publications during each time period (Table 8) also changed. Phytochemical classes such as flavonoids, alkaloids, tannins, saponins, phenols, and terpenoids were always prominent themes. Some common natural products, such as quercetin, and rutin have in recent years been associated with a very broad range of reported activities (Amin et al., 2015; Habtemariam and Belai, 2018; Martin-Aragon et al., 2016). They were frequently mentioned by papers published in 2011–2018, with their averaged citation count (quercetin, 7.6; rutin, 7.5) higher than that of tannins during this period, and similar to those of flavonoids and alkaloids. The chemical structures of quercetin, rutin, and selected prominent representatives of the other discussed chemical classes are presented in Figure 9.

[Insert Table 8 and Figure 9]

Table 9 shows the trends of WoS journal categories that were at least once among the top 10 of a time period for ethnopharmacological articles. In particular, there is a rise of research in food science technology, biotechnology/applied microbiology, agronomy, and applied chemistry. At the same time, anthropology and organic chemistry were on the decline. The trends of countries/regions that were at least once among the top 10 contributors of each time period are presented in Figure 10. The presented trends graph show that China and Brazil have become prominent since the 1991–2000 period, whereas Iran, South Korea, and Pakistan had respectable publication share since the 2001–2010 period. Meanwhile, the shares of The United States and Japan have been shrinking gradually, as well as that of Ghana. Naturally, this shift in the country/region contributions cannot be interpreted as a reduction of ethnopharmacology research in Japan and the United States in total numbers. Instead, it implies that ethnopharmacology research is having more involvement and thus authorship of local experts, particularly with a new attention in the Middle East and Asia.

[Insert Table 9 and Figure 10]

In fact, simply counting numbers of publications by country cannot account for the fact that co-authored publications (international collaborations) increased over the years. To illustrate the collaborative strengths, we visualized collaborative networks for each time period (Figure 11). It could be observed that the network has become more and more intertwined.

[Insert Figure 11]

3.7 Beyond ethnopharmacology: What is needed to understand the field of medicinal plant research?

The foremost limitation of the current analysis is the search strategy. A publication would not be identified if its title, abstract and keywords did not contain the predefined search terms. For instance, we searched “ayahuasca” OR “*Banisteriopsis caapi*” in title, abstract and keywords fields, and returned with 460 publications, 426 of which were not tagged as ethnopharmacology and, therefore, are not included in the current analysis. One notable example was an *in vitro* study that quantified the amount of monoamine oxidase inhibitors in ayahuasca (McKenna et al., 1984) (163 citations). There were other similar examples, such as artemisinin (8,064 out of 8,331 publications identified by searching "artemisinin" were not indexed under ethnopharmacology), artesunate (3,949 out of 3,999 were not indexed under ethnopharmacology), herbal medicine ("herbal medic*" - 15,573 out of 18,941 were not indexed under ethnopharmacology), and phytotherapy ("phytotherap*" - 2,120 out of 2,995 publications identified by searching were not indexed under ethnopharmacology). The problem was twofold. Firstly, WoS only indexed the title of some publications but not their abstracts and keywords. Secondly, some papers did not have keywords, and did not contain the predefined search (meta-)words in its title and abstract. More generally, this highlights ambiguities and inconsistencies in the way authors and databases index publications.

Importantly, this work is based on a retrospective analysis that cannot identify the latest research themes that are still gaining momentum, or predict future trends. Similarly, with such an approach the quality of the research cannot be assessed. Another limitation is that WoS frequently does not index earlier works so that some seminal works may be missed, such as the works from Richard E. Schultes (1915–2001), Gordon Wasson (1898–1986) and Albert Hofmann (1906–2008) that recorded the narcotic mushrooms and isolated the hallucinogenic compounds psilocybin and psilocin (Hofmann et al., 1959; Schultes, 1940; Wasson and Wasson, 1957). We notice that in general current publication and citation analyses do not seem to reflect the emphasis on psychoactive research in ethnopharmacology (McKenna, 2018). This example implies that scientific impact and attention may not necessarily be represented by citations.

4. Conclusions

We have analyzed the ethnopharmacology literature with regard to publication and citation data. Consistent to our previous analysis on the most cited ethnopharmacology articles (Yeung et al., 2018b), there is a strong link between food and plant sciences, (bio)chemistry, complementary medicine and pharmacology, with a lack of scientific interaction with socio-cultural aspects (cf., *3.1 Overall literature overview*). The analysis demonstrates that ethnopharmacology is indeed a diversified and multidisciplinary research field with dynamic global contributions. In recent decades a strong shift from the developed countries to emergent countries in Asia, South America and the Middle East can be demonstrated quantitatively.

The overall trend of the field of research seems to be shifting away from identifying and recording the medicinal plant species used in traditional medicine or unknown to modern medicine. Currently the evaluation of specific properties or treatment effects of particular natural products, even to the synthesis of new drugs inspired or derived from natural products receives more attention. Meanwhile, the phytochemical classes such as flavonoids, alkaloids, tannins, saponins, phenols, and terpenoids have always been prominent theme, with emerging attention to some often widespread natural products, such as quercetin, and rutin which have a very broad range of reported activities (Figure 9).

A bibliometric analysis has some intrinsic limitations; most basically it requires an article to be tagged as "ethnopharmacological research". Thus, from our analysis this seems to be more likely in case of phytotherapeutic practices and local / traditional medicines outside of Europe. Similarly, we highlight that research on hallucinogenic substances, the initial starting point of ethnopharmacology, is now no longer tagged accordingly. More broadly, it is likely that as soon as research reaches a translational stage, the ethnopharmacological foundation is no longer seen as relevant. Consequently, what such a bibliometric analysis cannot answer is how such research has helped in creating better healthcare or new products. The current study highlights that such field specific analyses are a relevant exercise, though researchers and readers should note there exist limitations of capturing information quantitatively. Moreover, the current analysis could not evaluate the efficacy of treatment or quality of research; we could only demonstrate the lack of clinical studies in the field. To make ethnopharmacology be taken more seriously by pharmacologists in general, the beneficial properties of phytochemicals should be more critically assessed, published, and substantiated.

At the 40th anniversary of the *Journal of Ethnopharmacology*, our data highlight the fast development of the field and that it will continue to evolve dynamically supporting further development of more evidence-based traditional medicines.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

AWKY and AGA conceived the work. AWKY acquired data and drafted the work. AWKY, MH and AGA analysed data. MH provided detailed input on the development of the field. NTT sketched all representative structures. All authors critically revised the work. All authors have approved the final content of the manuscript.

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Table 1. Web of Science journal categories that had >10% contributions in each publication period.

Category	1990 and before	1991–2000	2001–2010	2011–2018
	Number of publications (% of total in each period)			
Pharmacology/pharmacy	550 (35.4%)	1,518 (42.8%)	5,851 (36.9%)	12,594 (32.6%)
Plant sciences	568 (36.6%)	1,361 (38.4%)	4,869 (30.7%)	10,219 (26.5%)
Medicinal chemistry	412 (26.5%)	1,180 (33.3%)	4,444 (28.0%)	9,017 (23.4%)
Integrative and complementary medicine	271 (17.5%)	738 (20.8%)	2,975 (18.7%)	8,278 (21.4%)
Multidisciplinary chemistry	186 (12.0%)			

Table 2. Core journals that published one-third of publications in each period.

Core journal	1990 and b4	1991-2000	2001-2010	2011-2018
Journal of Ethnopharmacology	*	*	*	*
Planta Medica	*	*	*	*
Economic Botany	*	*	*	
Chemical and Pharmaceutical Bulletin	*	*		
Phytochemistry	*	*		
Phytotherapy Research		*	*	*
Journal of Natural Products		*	*	
Indian Journal of Traditional Knowledge			*	*
Journal of Ethnobiology and Ethnomedicine			*	*
Journal of Medicinal Plants Research			*	*
Pharmaceutical Biology			*	*
Brazilian Journal of Pharmacognosy			*	*
South African Journal of Botany			*	*
African Journal of Biotechnology			*	
Biological and Pharmaceutical Bulletin			*	
Fitoterapia			*	
Food Chemistry			*	
Journal of Agricultural and Food Chemistry			*	
Phytomedicine			*	
Acta Horticulturae				*
African Journal of Traditional Complementary and Alternative Medicines				*
BMC Complementary and Alternative Medicine				*
Evidence Based Complementary and Alternative Medicine				*
Industrial Crops and Products				*
International Journal of Pharmaceutical Sciences and Research				*
Molecules				*
Natural Product Communications				*
Natural Product Research				*
Pakistan Journal of Botany				*
Pakistan Journal of Pharmaceutical Sciences				*
PLOS One				*

Table 3. Top 5 most productive countries/regions in each publication period.

1990 and before	1991–2000	2001–2010	2011–2018
United States (n = 353; 22.7%)	United States (n = 607; 17.1%)	India (n = 2,347; 14.8%)	China (n = 6,051; 15.7%)
India (n = 160; 10.3%)	Japan (n = 421; 11.9%)	China (n = 1,621; 10.2%)	India (n = 5,873; 15.2%)
Japan (n = 131; 8.4%)	India (n = 294; 8.3%)	United States (n = 1,614; 10.2%)	Brazil (n = 3,404; 8.8%)
Germany (n = 53; 3.4%)	Germany (n = 206; 5.8%)	Brazil (n = 1,504; 9.5%)	United States (n = 2,560; 6.6%)
England (n = 49; 3.2%)	Brazil (n = 183; 5.2%)	South Korea (n = 775; 4.9%)	Iran (n = 2,439; 6.3%)

Table 4. Top 5 most productive institutions in each publication period.

1990 and before	1991–2000	2001–2010	2011–2018
Council of Scientific and Industrial Research of India (n = 66; 4.3%)	University of California (n = 64; 1.8%)	Chinese Academy of Sciences (n = 329; 2.1%)	Chinese Academy of Sciences (n = 729; 1.9%)
University of Pittsburgh (n = 41; 2.6%)	Council of Scientific and Industrial Research of India (n = 58; 1.6%)	Council of Scientific and Industrial Research of India (n = 291; 1.8%)	Council of Scientific and Industrial Research of India (n = 718; 1.9%)
University of California (n = 38; 2.4%)	University of London (n = 58; 1.6%)	University of KwaZulu-Natal (n = 229; 1.4%)	Islamic Azad University of Iran (n = 476; 1.2%)
Kwame Nkrumah University of Science and Technology, Ghana (n = 32; 2.1%)	National Autonomous University of Mexico (n = 54; 1.5%)	University of São Paulo (n = 197; 1.2%)	King Saud University of Saudi Arabia (n = 434; 1.1%)
University of Illinois (n = 26; 1.7%)	University of Illinois (n = 51; 1.4%)	University of London (n = 177; 1.1%)	Tehran University of Medical Sciences (n = 409; 1.1%)

Table 5. Temporal changes in the publication number of terms related to common medical conditions and effects investigated by ethnopharmacology.

Search term	1990 and before	1991-2000	2001-2010	2011-2018
inflammat*	5	207	1768	6599
cancer*	7	129	1323	4953
toxic*	12	297	1494	4675
infecti*	10	179	1083	3481
diabet*	2	85	829	3233
pain*	1	81	527	1744
parasit*	1	77	405	994
diarrh*	5	45	326	932
hepatoprotect*	2	38	247	852
hypertens*	5	41	235	819
AIDS OR HIV	5	84	384	773
neuroprotect*	0	5	102	637
tubercul*	0	15	166	454
drug interact*	0	3	66	267
adultera*	0	3	64	235
cardioprotect*	0	3	31	201
cannabi*	1	6	41	138
psychoactiv*	8	10	34	71
hallucin*	5	10	25	36
ayahuasca OR Banisteriopsis caapi	1	5	11	17

Table 6. Medical terms with their first appearance in the titles of ethnopharmacology papers, and their most cited papers.

	First appearance in paper title	Most cited paper
AIDS/HIV	World Health Organization. (1989). In vitro screening of traditional medicines for anti-HIV activity: Memorandum from a WHO meeting. *Bulletin of the World Health Organization*, *87*, 613-618. (4 citations)	Gustafson, K. R., Cardellina, J. H., McMahon, J. B., Gulakowski, R. J., Ishitoya, J., Szallasi, Z., ... & Weislow, O. S. (1992). A nonpromoting phorbol from the samoan medicinal plant Homalanthus nutans inhibits cell killing by HIV-1. *Journal of Medicinal Chemistry*, *35*(11), 1978-1986. (150 citations)
Cancer	Durodola, J. I. (1979). Contribution of traditional medicine to the chemotherapy of cancer. *Nigerian Medical Journal*, *9*(5-6), 613-618. (0 citation)	Lansky, E. P., & Newman, R. A. (2007). Punica granatum (pomegranate) and its potential for prevention and treatment of inflammation and cancer. *Journal of Ethnopharmacology*, *109*(2), 177-206. (554 citations)
Diabetes	Kimura, M., & Suzuki, J. (1981). The pattern of action of blended Chinese traditional medicines to glucose tolerance curves in genetically diabetic KK-CAy mice. *Journal of Pharmacobio-dynamics*, *4*(12), 907-915. (25 citations)	Grover, J. K., Yadav, S., & Vats, V. (2002). Medicinal plants of India with anti-diabetic potential. *Journal of Ethnopharmacology*, *81*(1), 81-100. (747 citations)
Diarrhea	Johnson, C. A. (1979). Infant diarrhea and folk medicine in South Texas. *Texas Medicine*, *75*(1), 69-73. (3 citations)	Shoba, F. G., & Thomas, M. (2001). Study of antidiarrhoeal activity of four medicinal plants in castor-oil induced diarrhoea. *Journal of Ethnopharmacology*, *76*(1), 73-76. (144 citations)
Inflammation	Shimizu, K., Amagaya, S., & Ogihara, Y. (1984). Combination effects of shosaikoto (Chinese traditional medicine) and prednisolone on the anti-inflammatory action. *Journal of Pharmacobio-dynamics*, *7*(12), 891-899. (25 citations)	Surh, Y. J., Chun, K. S., Cha, H. H., Han, S. S., Keum, Y. S., Park, K. K., & Lee, S. S. (2001). Molecular mechanisms underlying chemopreventive activities of anti-inflammatory phytochemicals: down-regulation of COX-2 and iNOS through suppression of NF-κB activation. *Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis*, *480*, 243-268. (1,050 citations)
Tuberculosis	Vecchiato, N. L. (1997). Sociocultural aspects of tuberculosis control in Ethiopia. *Medical Anthropology Quarterly*, *11*(2), 183-201. (25 citations)	Lall, N., & Meyer, J. J. M. (1999). In vitro inhibition of drug-resistant and drug-sensitive strains of Mycobacterium tuberculosis by ethnobotanically selected South African plants. *Journal of Ethnopharmacology*, *66*(3), 347-354. (114 citations)
Hallucinogenic	Guerra, F. (1967). Mexican phantastica—a study of the early ethnobotanical sources on hallucinogenic drugs. *British Journal of Addiction to Alcohol & Other Drugs*, *62*(1-2), 171-187. (8 citations)	Rivier, L., & Lindgren, J. E. (1972). "Ayahuasca," the South American hallucinogenic drink: An ethnobotanical and chemical investigation. *Economic Botany*, *26*(2), 101-129. (83 citations)
Psychoactive	Cohen, S. (1969). Ethnopharmacologic Search For Psychoactive Drugs-Efron, DH, Holmstedt, B And Kline, NS. *International Journal of the Addictions*, *4*(1), 137-138. (0 citation)	Díaz, J. L. (1977). Ethnopharmacology of sacred psychoactive plants used by the Indians of Mexico. *Annual Review of Pharmacology and Toxicology*, *17*(1), 647-675. (29 citations)
Cannabis	Sharma, G. K. (1977). Ethnobotany and its significance for Cannabis studies in the	Martín-Sánchez, E., Furukawa, T. A., Taylor, J., & Martin, J. L. R. (2009). Systematic review and meta-analysis of

	Himalayas. *Journal of Psychedelic Drugs*, *9*(4), 337-339. (4 citations)	cannabis treatment for chronic pain. *Pain medicine*, *10*(8), 1353-1368. (108 citations)
Ayahuasca or *Banisteriopsis caapi*	Rivier, L., & Lindgren, J. E. (1972). "Ayahuasca," the South American hallucinogenic drink: An ethnobotanical and chemical investigation. *Economic Botany*, *26*(2), 101-129. (83 citations)	McKenna, D. J. (2004). Clinical investigations of the therapeutic potential of ayahuasca: rationale and regulatory challenges. *Pharmacology & therapeutics*, *102*(2), 111-129. (115 citations)
Toxicity	Wat, C. K., Johns, T., & Towers, G. N. (1980). Phototoxic and antibiotic activities of plants of the Asteraceae used in folk medicine. *Journal of Ethnopharmacology*, *2*(3), 279-290. (46 citations)	Ali, B. H., Blunden, G., Tanira, M. O., & Nemmar, A. (2008). Some phytochemical, pharmacological and toxicological properties of ginger (Zingiber officinale Roscoe): a review of recent research. *Food and Chemical Toxicology*, *46*(2), 409-420. (455 citations)
Drug interaction	Chan, T. Y. (1998). Drug interactions as a cause of overanticoagulation and bleedings in Chinese patients receiving warfarin. *International Journal of Clinical Pharmacology and Therapeutics*, *36*(7), 403-405. (26 citations)	Wang, X., Zhang, H., Chen, L., Shan, L., Fan, G., & Gao, X. (2013). Liquorice, a unique "guide drug" of traditional Chinese medicine: a review of its role in drug interactions. *Journal of Ethnopharmacology*, *150*(3), 781-790. (92 citations)
Adulteration	Pires, V. S., Guillaume, D., Gosmann, G., & Schenkel, E. P. (1997). Saponins from Ilex dumosa, an erva-maté (Ilex paraguariensis) adulterating plant. *Journal of Agricultural and Food Chemistry*, *45*(4), 1027-1031. (22 citations)	Wang, C. Z., Ni, M., Sun, S. H. I., Li, X. L., He, H. U. I., Mehendale, S. R., & Yuan, C. S. (2009). Detection of adulteration of notoginseng root extract with other panax species by quantitative HPLC coupled with PCA. *Journal of Agricultural and Food Chemistry*, *57*(6), 2363-2367. (47 citations)
Pain	Wehling, P., & Reinecke, J. (1997). Acupuncture together with cytokine depressing herbs in comparison to injection therapy with steroids in sciatic pain. *Schmerz*, *11*(3), 180-184. (3 citations)	Son, D. J., Lee, J. W., Lee, Y. H., Song, H. S., Lee, C. K., & Hong, J. T. (2007). Therapeutic application of anti-arthritis, pain-releasing, and anti-cancer effects of bee venom and its constituent compounds. *Pharmacology & Therapeutics*, *115*(2), 246-270. (228 citations)
Parasites	Gupta, P. C. (1974). Parasitic fungi on medicinal plants from India II. Some pycnidial and perithecial forms. *Mycopathologia*, *54*(1), 127-130. (1 citation)	Marimuthu, S., Rahuman, A. A., Rajakumar, G., Santhoshkumar, T., Kirthi, A. V., Jayaseelan, C., ... & Kamaraj, C. (2011). Evaluation of green synthesized silver nanoparticles against parasites. *Parasitology Research*, *108*(6), 1541-1549. (106 citations)
Infection	Verma, V. S., Raychaudhuri, S. P., & Khan, A. M. (1970). Effect of medicinal plant extracts on the infectivity of potato virus X. *Planta Medica*, *18*(02), 177-184. (4 citations)	Cos, P., Vlietinck, A. J., Berghe, D. V., & Maes, L. (2006). Anti-infective potential of natural products: how to develop a stronger in vitro 'proof-of-concept'. *Journal of Ethnopharmacology*, *106*(3), 290-302. (575 citations)
Neuroprotection	Kim, Y., Park, E. J., Kim, J., Kim, Y. B., Kim, S. R., & Kim, Y. C. (2001). Neuroprotective constituents from *Hedyotis diffusa*. *Journal of Natural Products*, *64*(1), 75-78. (58 citations)	Dajas, F. (2012). Life or death: neuroprotective and anticancer effects of quercetin. *Journal of Ethnopharmacology*, *143*(2), 383-396. (130 citations)
Hypertension	Payne, Z. A., & Hall, W. D. (1978, January). Folk medicine practices in control of hypertension. In *Preventive Medicine*, *7*(1), 121. (0 citation)	Ziyyat, A., Legssyer, A., Mekhfi, H., Dassouli, A., Serhrouchni, M., & Benjelloun, W. (1997). Phytotherapy of hypertension and diabetes in oriental Morocco. *Journal of ethnopharmacology*, *58*(1), 45-54. (234 citations)
Cardioprotection	Rachkov, A. K., Spiridonov, N. A., & Kondrashova, M. N. (1994). Adaptogenic and	Wattanapitayakul, S. K., Chularojmontri, L., Herunsalee, A., Charuchongkolwongse, S., Niumsakul, S., & Bauer, J.

	cardioprotective action of *Galleria mellonella* extract in rats and frogs. *Journal of Pharmacy and Pharmacology*, *46*(3), 221-225. (0 citation)	A. (2005). Screening of antioxidants from medicinal plants for cardioprotective effect against doxorubicin toxicity. *Basic & Clinical Pharmacology & Toxicology*, *96*(1), 80-87. (59 citations)
Hepatoprotection	Fleurentin, J., Hoefler, C., Lexa, A., Mortier, F., & Pelt, J. M. (1986). Hepatoprotective properties of *Crepis rueppellii* and *Anisotes trisulcus*: two traditional medicinal plants of Yemen. *Journal of Ethnopharmacology*, *16*(1), 105-111. (7 citations)	Banskota, A. H., Tezuka, Y., Adnyana, I. K., Ishii, E., Midorikawa, K., Matsushige, K., & Kadota, S. (2001). Hepatoprotective and anti-*Helicobacter pylori* activities of constituents from Brazilian propolis. *Phytomedicine*, *8*(1), 16-23. (127 citations)

Table 7. The 10 most cited clinical studies of ethnopharmacology.

Article	Citation count
Akhondzadeh, S., Noroozian, M., Mohammadi, M., Ohadinia, S., Jamshidi, A. H., & Khani, M. (2003). *Salvia officinalis* extract in the treatment of patients with mild to moderate Alzheimer's disease: a double blind, randomized and placebo-controlled trial. *Journal of Clinical Pharmacy and Therapeutics*, *28*(1), 53-59.	142
Goldbach-Mansky, R., Wilson, M., Fleischmann, R., Olsen, N., Silverfield, J., Kempf, P., ... & Costello, R. (2009). Comparison of *Tripterygium wilfordii* Hook F versus sulfasalazine in the treatment of rheumatoid arthritis: a randomized trial. *Annals of Internal Medicine*, *151*(4), 229-240.	136
Zhang, G., Qin, L., & Shi, Y. (2007). *Epimedium*-derived phytoestrogen flavonoids exert beneficial effect on preventing bone loss in late postmenopausal women: a 24-month randomized, double-blind and placebo-controlled trial. *Journal of Bone and Mineral Research*, *22*(7), 1072-1079.	134
Christybapita, D., Divyagnaneswari, M., & Michael, R. D. (2007). Oral administration of *Eclipta alba* leaf aqueous extract enhances the non-specific immune responses and disease resistance of *Oreochromis mossambicus*. *Fish & Shellfish Immunology*, *23*(4), 840-852.	125
Akhondzadeh, S., Tahmacebi-Pour, N., Noorbala, A. A., Amini, H., Fallah-Pour, H., Jamshidi, A. H., & Khani, M. (2005). *Crocus sativus* L. in the treatment of mild to moderate depression: a double-blind, randomized and placebo-controlled trial. *Phytotherapy Research*, *19*(2), 148-151.	123
Noorbala, A. A., Akhondzadeh, S. H., Tahmacebi-Pour, N., & Jamshidi, A. H. (2005). Hydro-alcoholic extract of *Crocus sativus* L. versus fluoxetine in the treatment of mild to moderate depression: a double-blind, randomized pilot trial. *Journal of Ethnopharmacology*, *97*(2), 281-284.	119
Naef, M., Curatolo, M., Petersen-Felix, S., Arendt-Nielsen, L., Zbinden, A., & Brenneisen, R. (2003). The analgesic effect of oral delta-9-tetrahydrocannabinol (THC), morphine, and a THC-morphine combination in healthy subjects under experimental pain conditions. *Pain*, *105*(1-2), 79-88.	112
Wang, L. S., Zhou, G., Zhu, B., Wu, J., Wang, J. G., El-Aty, A. A., ... & Zhong, X. Y. (2004). St John's wort induces both cytochrome P450 3A4–catalyzed sulfoxidation and 2C19–dependent hydroxylation of omeprazole. *Clinical Pharmacology & Therapeutics*, *75*(3), 191-197.	97
Dehkordi, F. R., & Kamkhah, A. F. (2008). Antihypertensive effect of *Nigella sativa* seed extract in patients with mild hypertension. *Fundamental & Clinical Pharmacology*, *22*(4), 447-452.	82
Zakay-Rones, Z., Thom, E., Wollan, T., & Wadstein, J. (2004). Randomized study of the efficacy and safety of oral elderberry extract in the treatment of influenza A and B virus infections. *Journal of International Medical Research*, *32*(2), 132-140.	79

Table 8. The chemicals/chemical classes frequently mentioned by publications in each publication period.

1990 and before	1991–2000	2001–2010	2011–2018
Alkaloids (84; 14.0)	Alkaloids (176; 65.8)	Flavonoids (608; 30.7)	Flavonoids (3,643; 7.4)
Tannins (17; 53.9)	Flavonoids (114; 85.4)	Alkaloids (384; 25.2)	Alkaloids (1,898; 7.0)
Flavonoids (16; 29.6)	Saponins (68; 32.8)	Tannins (272; 18.0)	Tannins (1,282; 5.3)
	Tannins (67; 99.3)	Saponins (238; 20.5)	Glycosides (1,242; 7.1)
		Phenolic compounds (228; 35.1)	Saponins (1,210; 6.2)
			Quercetin (918; 7.6)
			Polyphenols (835; 8.5)
			Phenols (833; 5.8)
			Terpenoids (636; 6.8)
			Rutin (489; 7.5)
			Chlorogenic acid (407; 7.5)

The numbers in parenthesis indicate the number of publications and citations per publication (CPP) respectively.

Table 9. Temporal changes in publication shares of selected journal categories. It should be noted that the categories are not mutually exclusive.

WoS category	1990 and before	1991-2000	2001-2010	2011-2018
PHARMACOLOGY PHARMACY	35%	43%	37%	33%
PLANT SCIENCES	37%	38%	31%	26%
CHEMISTRY MEDICINAL	27%	33%	28%	23%
INTEGRATIVE COMPLEMENTARY MEDICINE	17%	21%	19%	21%
BIOCHEMISTRY MOLECULAR BIOLOGY	9%	7%	6%	6%
FOOD SCIENCE TECHNOLOGY	1%	2%	6%	6%
CHEMISTRY MULTIDISCIPLINARY	12%	7%	5%	5%
BIOTECHNOLOGY APPLIED MICROBIOLOGY	0%	2%	5%	4%
MULTIDISCIPLINARY SCIENCES	2%	2%	1%	4%
AGRONOMY	1%	1%	2%	3%
MEDICINE GENERAL INTERNAL	7%	3%	2%	2%
ANTHROPOLOGY	5%	3%	1%	1%
CHEMISTRY ORGANIC	4%	2%	1%	1%
PUBLIC ENVIRONMENTAL OCCUPATIONAL HEALTH	4%	4%	2%	1%
CHEMISTRY ANALYTICAL	2%	2%	4%	2%
CHEMISTRY APPLIED	0%	2%	3%	3%
MEDICAL LABORATORY TECHNOLOGY	0%	3%	2%	1%

Figure Captions

Figure 1. Cumulative number of ethnopharmacology articles published over the years. The growth has been steady particularly in the 2010s.

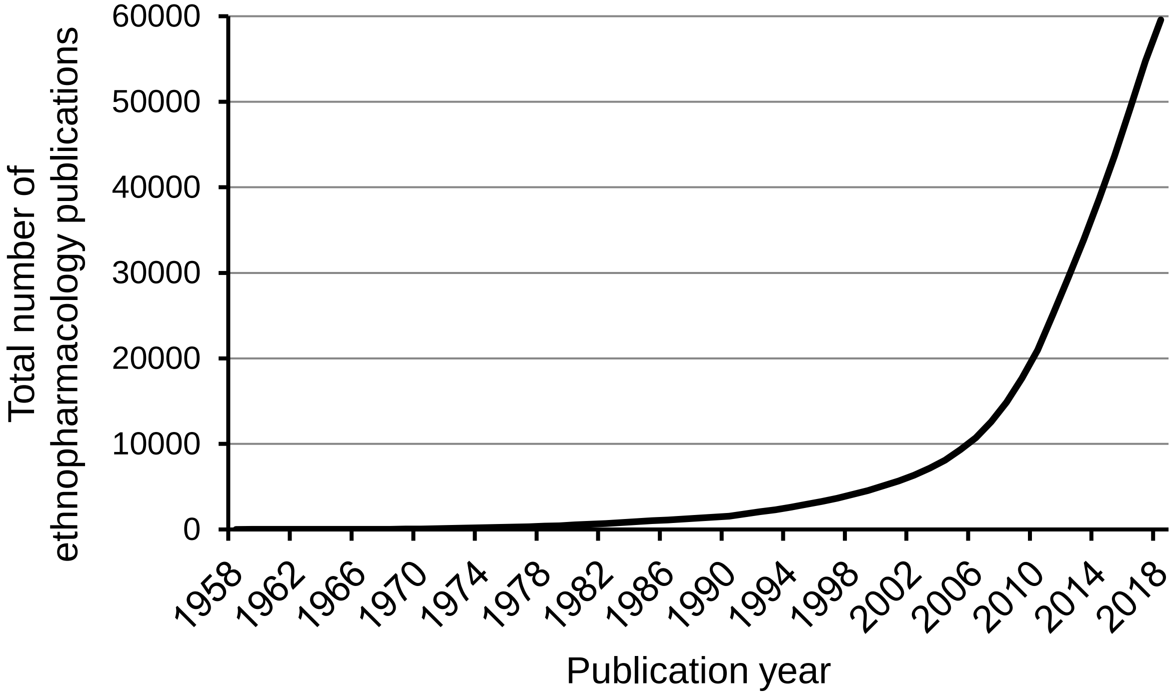
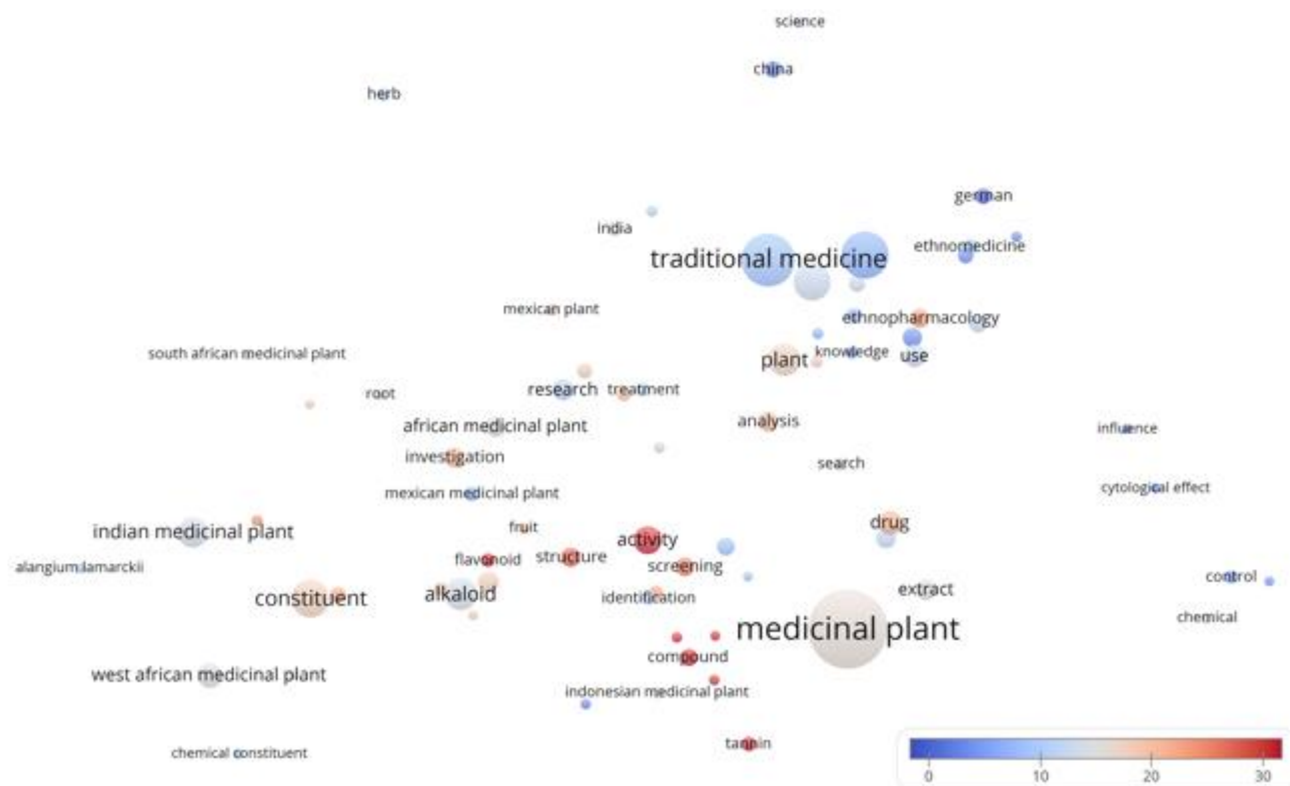


Figure 2. Term map using words from titles and abstracts of ethnopharmacology publications of 1990 and before. (A) Words from titles and abstracts were analyzed and visualized by VOSviewer, a bibliometric software that relates the terms with the citation data, resulting in a term map that shows their frequency of occurrence by bubble size, their frequency of co-occurrence among the publications by the distance between bubbles, and the averaged citation counts of publications containing them by bubble color. There were 75 terms that appeared in at least 0.5% (n = 8) of the 1,552 publications and are hence visualized. The studies on medicinal plants had worldwide foci, ranging from Asian to African regions. (B) The same term map with a different color coding to show 5 clusters of terms. The clustering was done with the default method by VOSviewer, and each cluster was set to have at least 10% (n = 8) of the 75 terms. The 5 clusters were related to the traditional practice and use of medicinal plants (red, 25 terms), the determination of active principle or constituent (green, 16 terms), the isolation of and treatment using flavonoid (blue, 13 terms), the alkaloid content in tropical and Indian medicinal plants (yellow, 12 terms), and the cytological effect of phytochemicals from medicinal plants (purple, 9 terms).

(A)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treatment
african medicinal plant
analysis
influence
investigation
search
mexican medicinal plant
cytological effect
indian medicinal plant
fruit
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drug
alangium lamarckii
flavonoid
structure
screening
constituent
alkaloid
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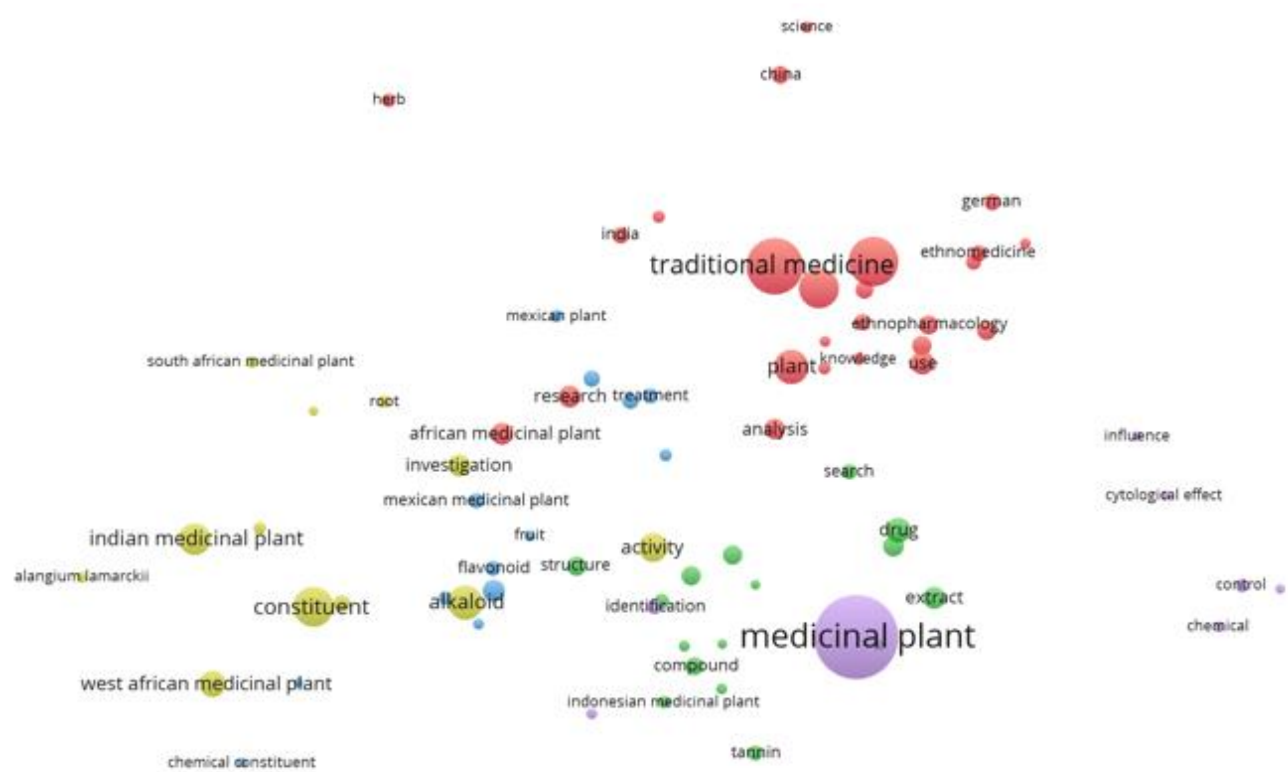
(B)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treatment
african medicinal plant
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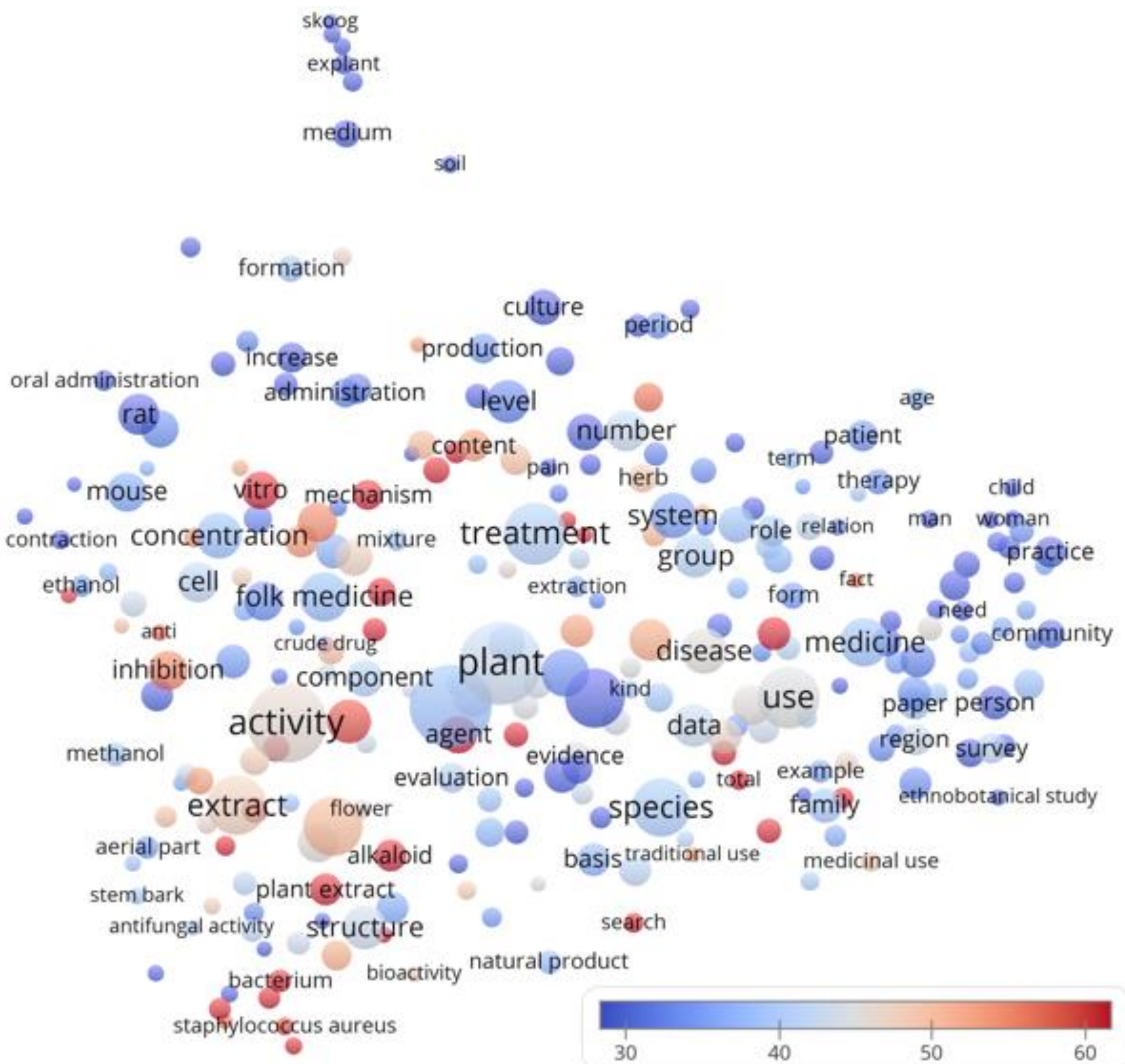
influence
investigation
search
mexican medicinal plant
cytological effect
indian medicinal plant
fruit
activity
drug
alangium lamarckii
flavonoid
structure
constituent
alkaloid
extract
control
identification
medicinal plant
chemical
compound
west african medicinal plant
indonesian medicinal plant
chemical constituent
tannin

Figure 3. Term map using words from titles and abstracts of ethnopharmacology publications of 1991–2000. (A) Words from titles and abstracts were analyzed and visualized by VOSviewer, a bibliometric software that relates the terms with the citation data, resulting in a term map that shows their frequency of occurrence by bubble size, their frequency of co-occurrence among the publications by the distance between bubbles, and the averaged citation counts of publications containing them by bubble color. There were 263 terms that appeared in at least 1.0% (n = 36) of the 3,545 publications and are hence visualized. A large share of the studies focused on the therapeutic effects and potential pharmacological action by medicinal plants/ natural products. (B) The same term map with a different color coding to show 4 clusters of terms. The clustering was done with the default method by VOSviewer, and each cluster was set to have at least 10% (n = 27) of the 263 terms. The 4 clusters were related to the use of plant species for traditional medicine (red, 104 terms), the chemical assay and evaluation of activities of plant extracts against bacteria, fungi, microbiota, etc (green, 75 terms), the treatment efficacy and toxicity evaluation using animal and cell models (blue, 60 terms), and the various parts of plants used, such as seed, leaf, and shoot (grey, 24 terms).

(A)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herb
therapy
child
mouse
vitro
mechanism
system
man
woman
contraction
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mixture
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role
relation
practice
group
ethanol
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person
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aerial part
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basis
traditional use
medicinal use
stem bark
plant extract
antifungal activity
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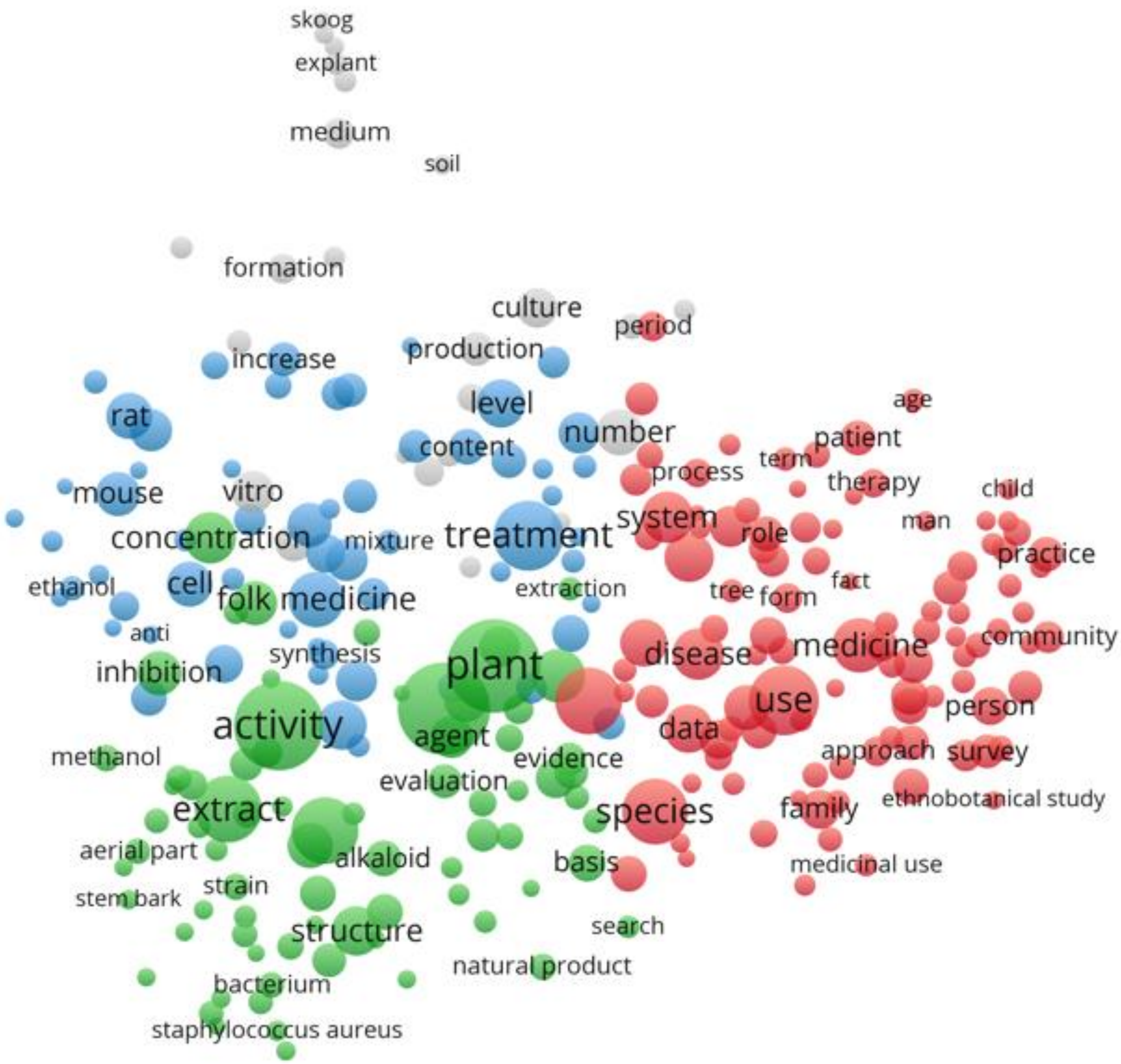
(B)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mouse
vitro
man
system
role
concentration
mixture
treatment
practice
ethanol
cell
folk medicine
extraction
tree
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anti
synthesis
disease
medicine
community
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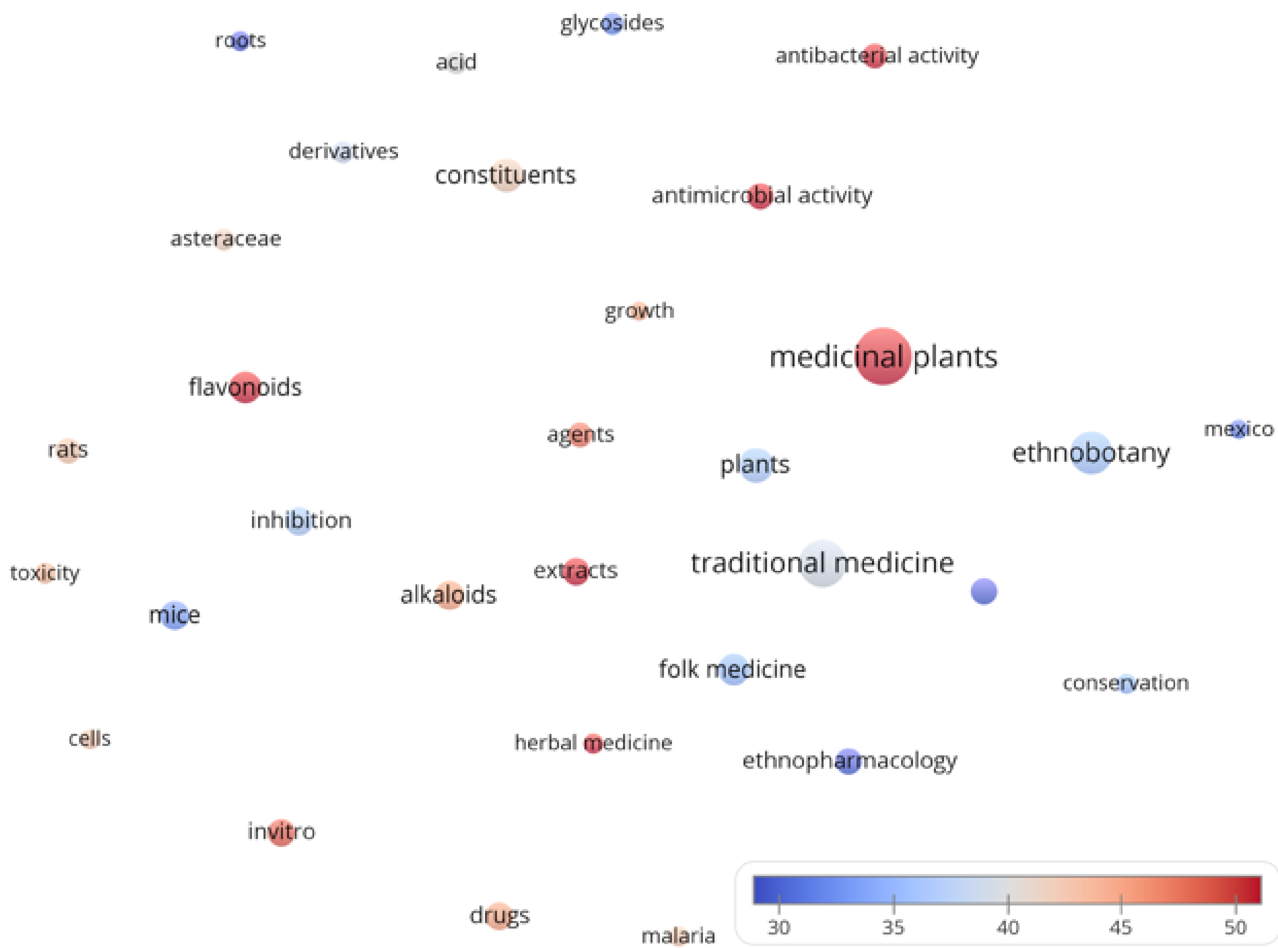
aerial part
alkaloid
basis
medicinal use
stem bark
strain
structure
search
natural product
bacterium
staphylococcus aureus

Figure 4. Term map using keywords of ethnopharmacology publications of 1991–2000. (A) Keywords were analyzed and visualized by VOSviewer, a bibliometric software that relates the terms with the citation data, resulting in a term map that shows their frequency of occurrence by bubble size, their frequency of co-occurrence among the publications by the distance between bubbles, and the averaged citation counts of publications containing them by bubble color. There were 31 keywords that appeared in at least 1.0% (n = 36) of the 3,545 publications and are hence visualized. Publications focusing on antibacterial/antimicrobial activity were highly cited. (B) The same term map with a different color coding to show 4 clusters of keywords. The clustering was done with the default method by VOSviewer, and each cluster was set to have at least 10% (n = 4) of the 31 keywords. The 4 clusters were related to the potential use of alkaloids and flavonoids to treat malaria (red, 12 terms), the glycosides derived from plants of the Asteraceae family (green, 7 terms), the conservation of ethnobotany especially in Mexico (blue, 6 terms), and the antibacterial and antimicrobial activities of traditionally used medicinal plants (yellow, 6 terms).

(A)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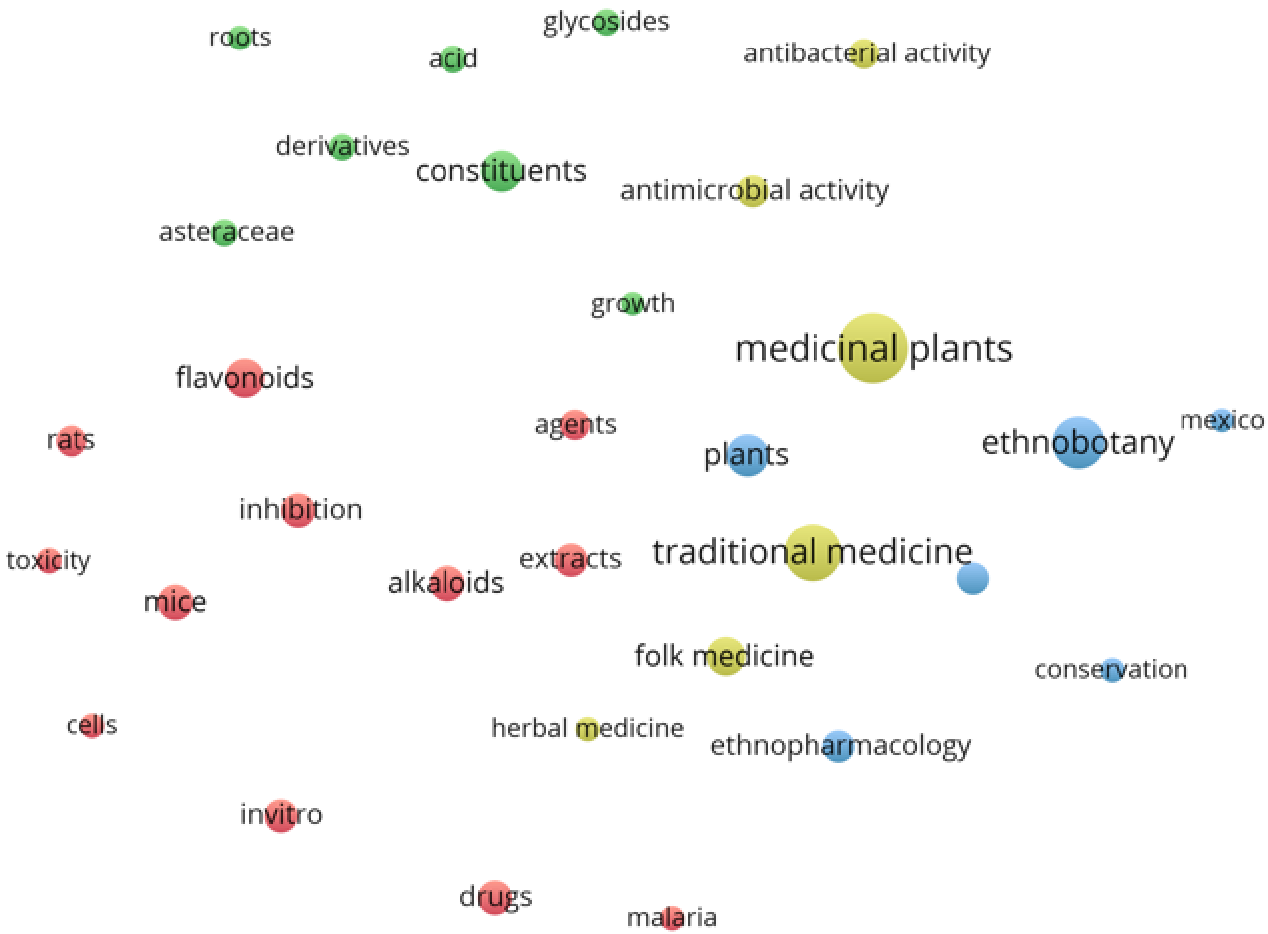
(B)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traditional medicine
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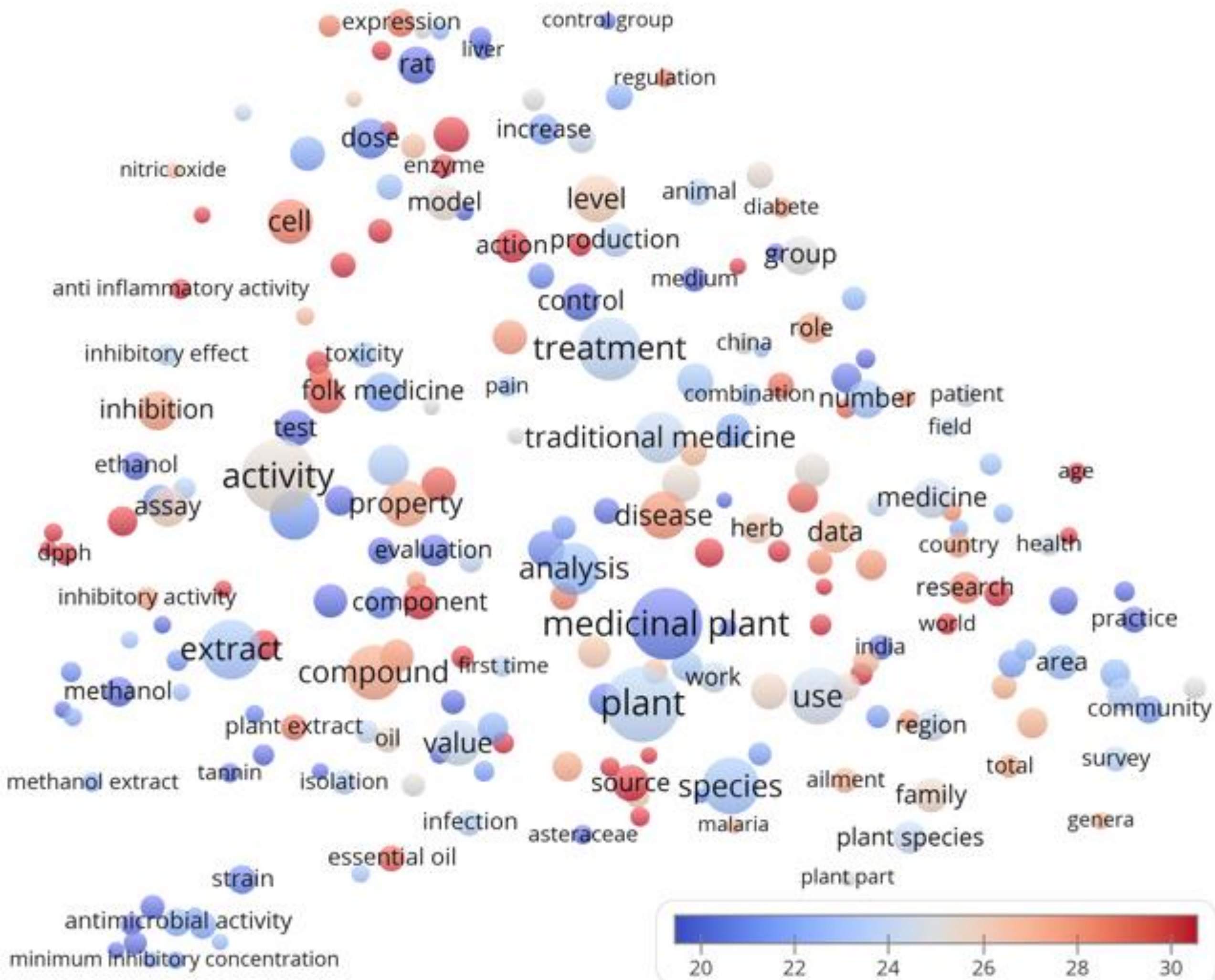
extracts
alkaloids
mice
folk medicine
conservation
cells
herbal medicine
ethnopharmacology
invitro
drugs
malaria

Figure 5. Term map using words from titles and abstracts of ethnopharmacology publications of 2001–2010. (A) Words from titles and abstracts were analyzed and visualized by VOSviewer, a bibliometric software that relates the terms with the citation data, resulting in a term map that shows their frequency of occurrence by bubble size, their frequency of co-occurrence among the publications by the distance between bubbles, and the averaged citation counts of publications containing them by bubble color. There were 220 terms that appeared in at least 1.0% (n = 159) of the 15,875 publications and are hence visualized. Publications concerning antioxidant activity of medicinal plants/ natural products and their mechanism of interaction with enzyme systems were highly cited. (B) The same term map with a different color coding to show 3 clusters of terms. The clustering was done with the default method by VOSviewer, and each cluster was set to have at least 10% (n = 22) of the 220 terms. The 3 clusters were related to the use and applications of medicinal plant for traditional medicine (red, 89 terms), the chemical assay and evaluation of activities of plant extracts (green, 77 terms), and the testing of treatment dose, mechanism, and toxicity evaluation using animal and cell models (blue, 54 terms).

(A)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infection
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essential oil
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plant part
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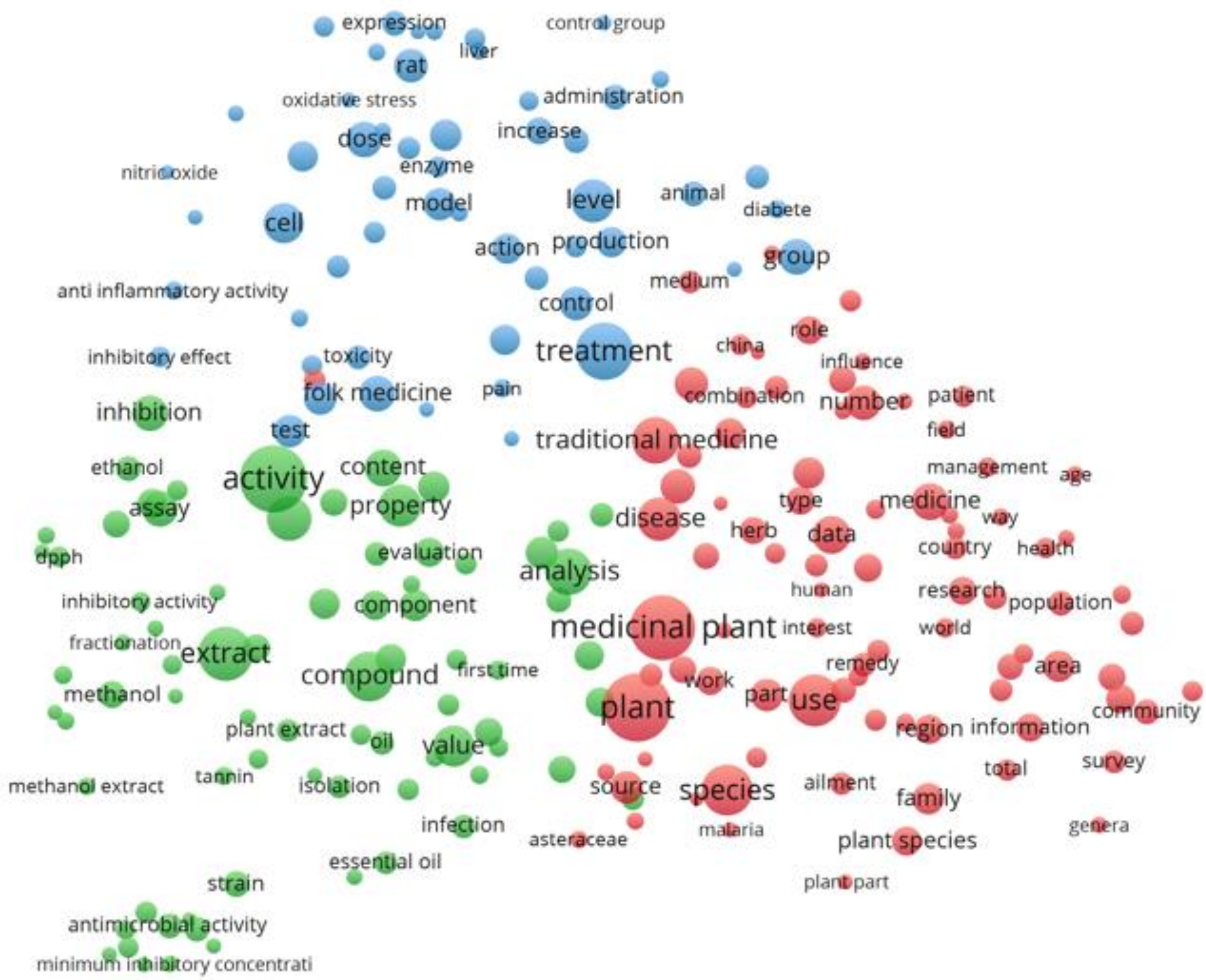
(B)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asteraceae
malaria
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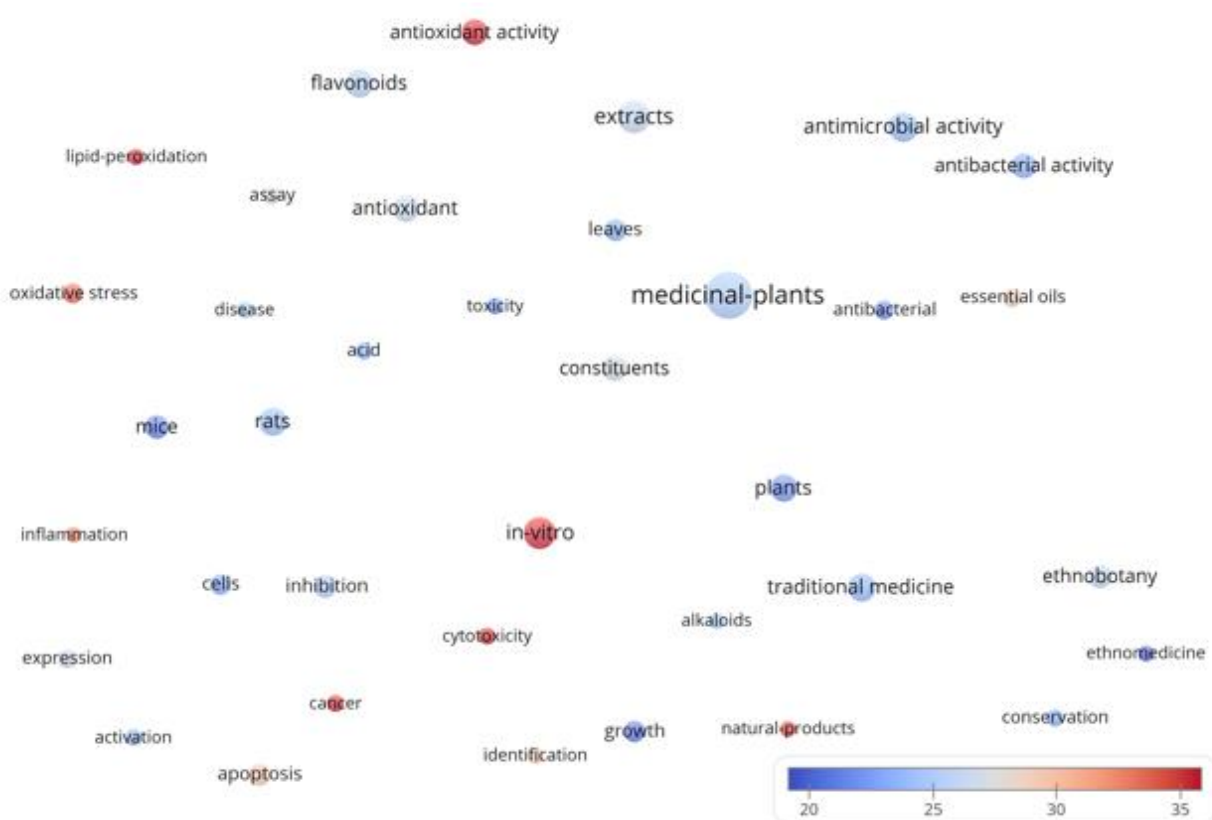
minimum inhibitory concentrati

Figure 6. Term map using keywords of ethnopharmacology publications of 2001–2010. (A) Keywords were analyzed and visualized by VOSviewer, a bibliometric software that relates the terms with the citation data, resulting in a term map that shows their frequency of occurrence by bubble size, their frequency of co-occurrence among the publications by the distance between bubbles, and the averaged citation counts of publications containing them by bubble color. There were 36 keywords that appeared in at least 1.0% (n = 159) of the 15,875 publications and are hence visualized. Publications focusing on antibacterial/antimicrobial activity were highly cited. (B) The same term map with a different color coding to show 4 clusters of keywords. The clustering was done with the default method by VOSviewer, and each cluster was set to have at least 10% (n = 4) of the 36 keywords. The 4 clusters were related to oxidative stress and cytotoxicity (red, 18 terms), identification of alkaloids in plants (green, 9 terms), various activities of essential oils (blue, 6 terms), and antioxidant activity of flavonoids (yellow, 4 terms).

(A)



(B)

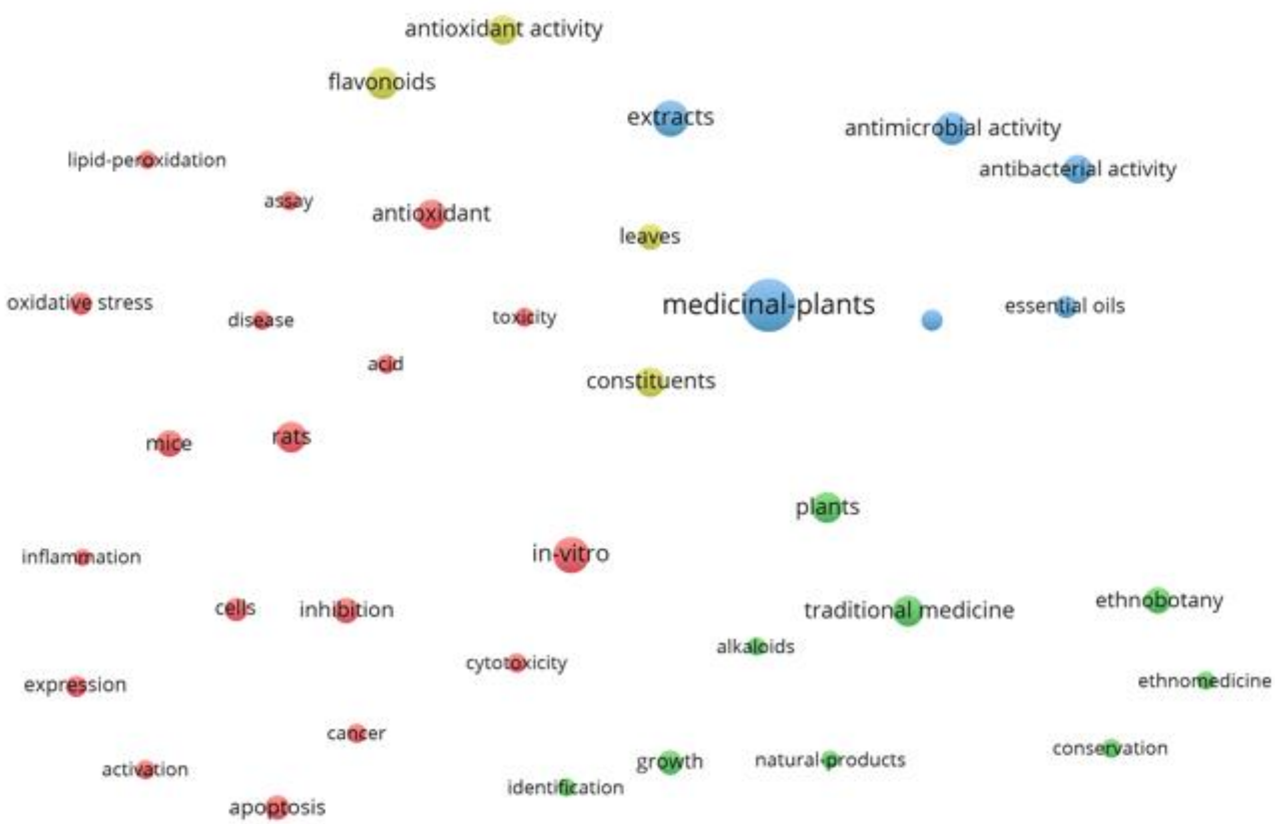
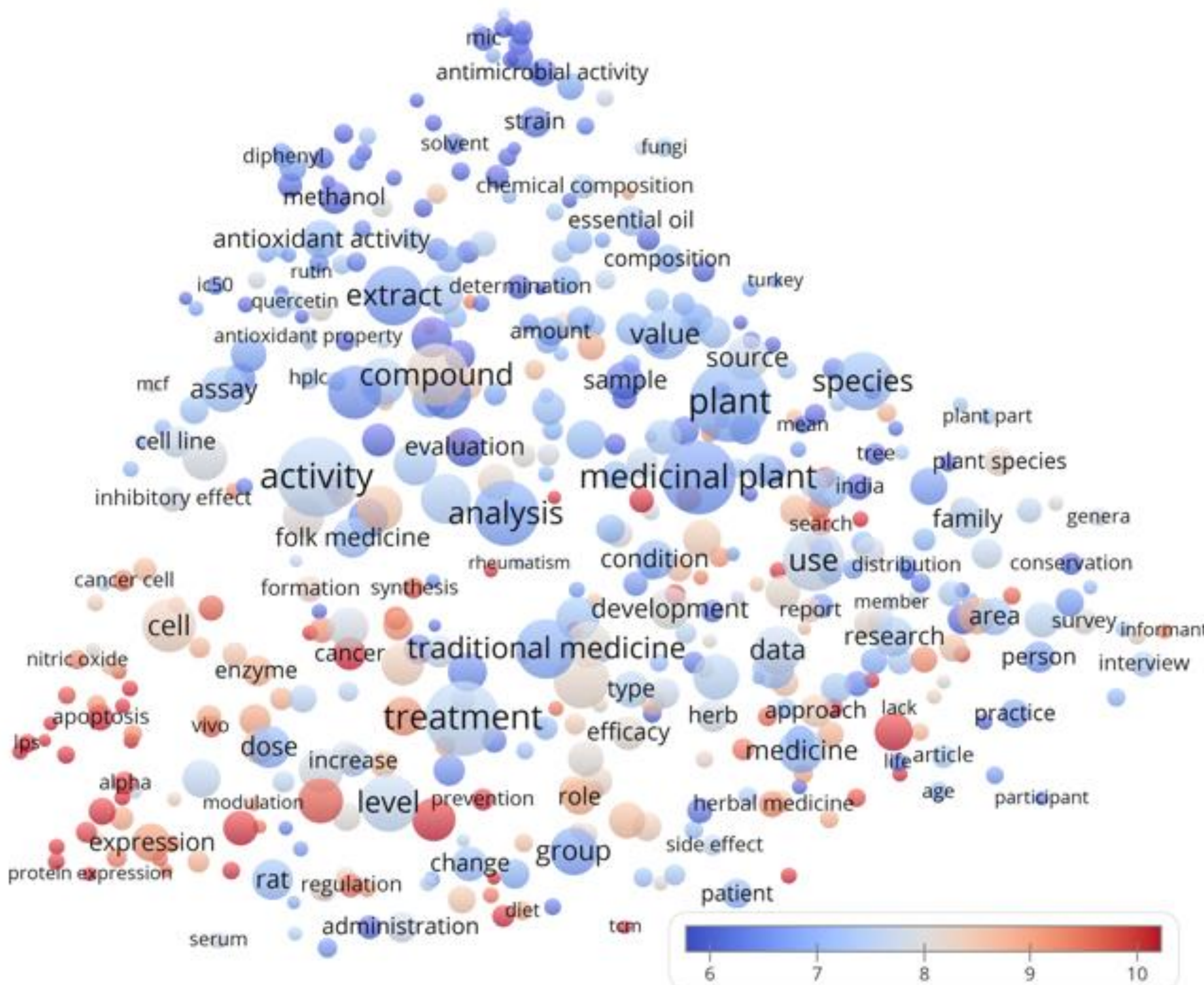

antioxidant activity
flavonoids
extracts
antimicrobial activity
lipid-peroxidation
antibacterial activity
assay
antioxidant
leaves
oxidative stress
disease
toxicity
medicinal-plants
essential oils
acid
constituents
mice
rats
plants
inflammation
in-vitro
cells
inhibition
traditional medicine
ethnobotany
alkaloids
cytotoxicity
expression
ethnomedicine
cancer
conservation
activation
growth
natural-products
identification
apoptosis

Figure 7. Term map using words from titles and abstracts of ethnopharmacology publications of 2011–2018. (A) Words from titles and abstracts were analyzed and visualized by VOSviewer, a bibliometric software that relates the terms with the citation data, resulting in a term map that shows their frequency of occurrence by bubble size, their frequency of co-occurrence among the publications by the distance between bubbles, and the averaged citation counts of publications containing them by bubble color. There were 481 terms that appeared in at least 1.0% (n = 387) of the 38,604 publications and are hence visualized. Publications concerning cancer and related concepts were highly cited (red bubbles in the lower left corner). (B) The same term map with a different color coding to show 3 clusters of terms. The clustering was done with the default method by VOSviewer, and each cluster was set to have at least 10% (n = 49) of the 481 terms. The 3 clusters were quite similar to those from the preceding time period, related to the use and applications of medicinal plant for traditional medicine (red, 193 terms), the chemical assay and evaluation of activities of plant extracts (green, 151 terms), and the testing of treatment dose, mechanism, and toxicity evaluation using animal and cell models (blue, 137 terms).

(A)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article
alpha
modulation
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prevention
role
herbal medicine
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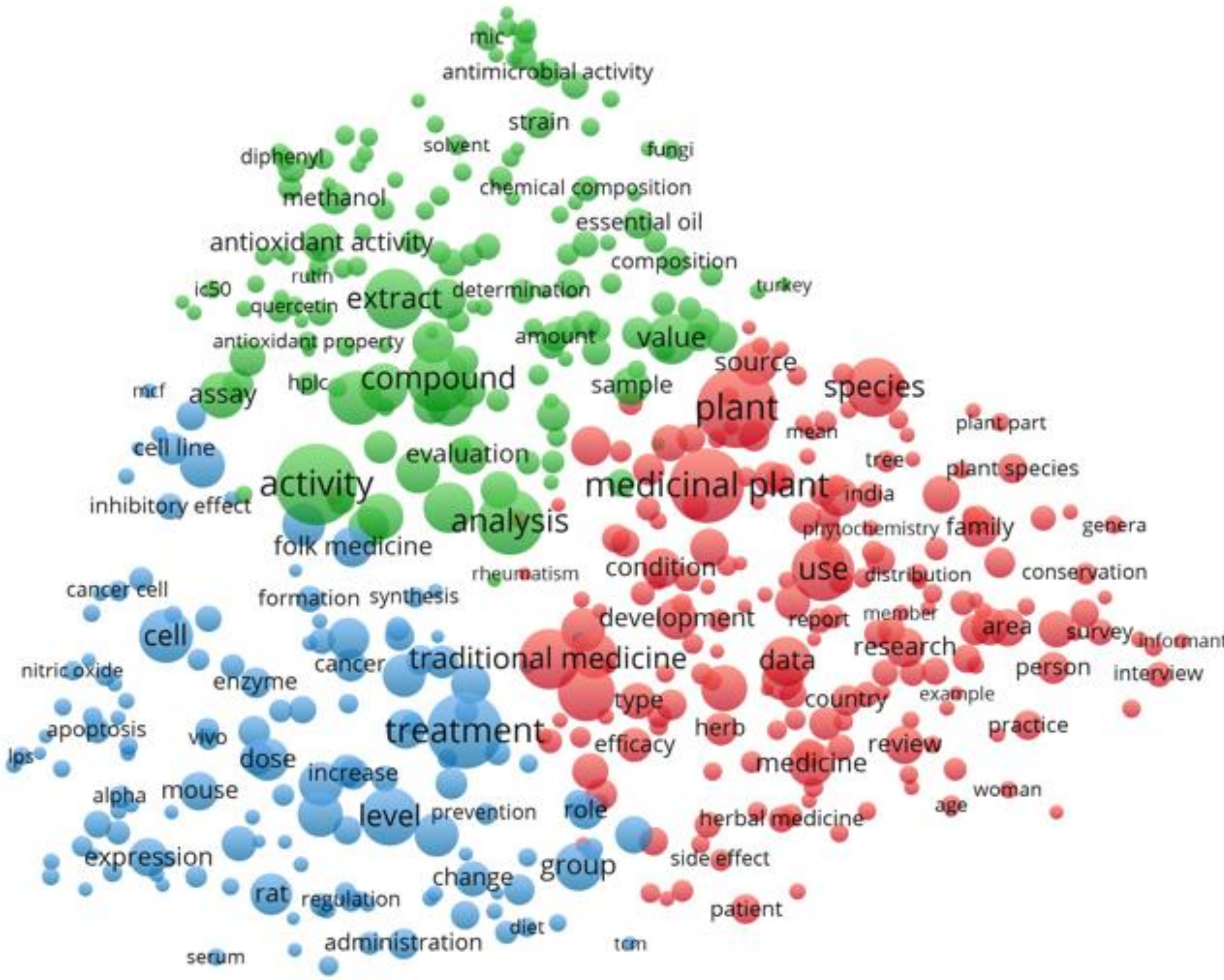
(B)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antioxidant property
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evaluation
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activity
medicinal plant
india
inhibitory effect
analysis
phytochemistry
family
genera
folk medicine
rheumatism
condition
use
distribution
conservation
cancer cell
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synthesis
development
report
member
area
survey
informant
cell
research
nitric oxide
cancer
traditional medicine
data
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example
apoptosis
treatment
herb
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review
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medicine
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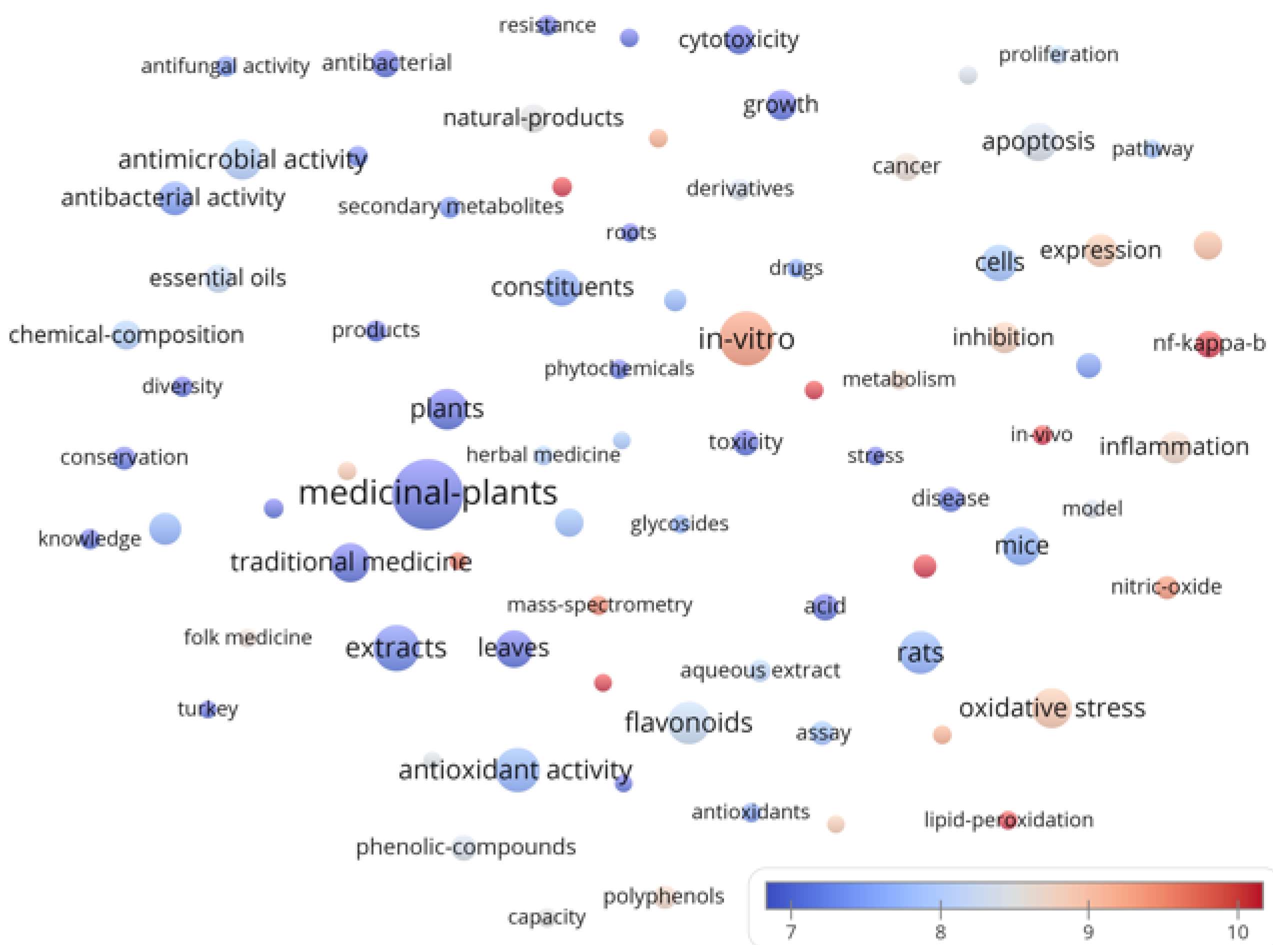
woman
level
prevention
role
age
herbal medicine
expression
side effect
group
change
rat
regulation
patient
diet
administration
tcm
serum

Figure 8. Term map using keywords of ethnopharmacology publications of 2011–2018. (A) Keywords were analyzed and visualized by VOSviewer, a bibliometric software that relates the terms with the citation data, resulting in a term map that shows their frequency of occurrence by bubble size, their frequency of co-occurrence among the publications by the distance between bubbles, and the averaged citation counts of publications containing them by bubble color. There were 81 keywords that appeared in 1.0% (n = 387) of the 38,604 publications and hence visualized. Publications focusing on inflammation and oxidative stress were highly cited. Publications of biosynthesis and drug discovery were also highly cited. (B) The same term map with a different color coding to show 4 clusters of keywords. The clustering was done with the default method by VOSviewer, and each cluster was set to have at least 10% (n = 9) of the 81 keywords. The 4 clusters were related to oxidative stress and inflammation (red, 30 terms), antioxidant activity of phytochemicals (green, 20 terms), ethnobotany and conservation (blue, 17 terms), and various activities of plants, their extracts, and essential oils (yellow, 14 terms).

(A)


resistance
cytotoxicity
antifungal activity
antibacterial
proliferation
natural-products
growth
antimicrobial activity
apoptosis
pathway
cancer
antibacterial activity
secondary metabolites
derivatives
roots
essential oils
drugs
cells
expression
constituents
chemical-composition
products
in-vitro
inhibition
nf-kappa-b
phytochemicals
metabolism
diversity
plants
in-vivo
conservation
herbal medicine
toxicity
stress
inflammation
medicinal-plants
disease
model
knowledge
glycosides
traditional medicine
mice
nitric-oxide
mass-spectrometry
acid
folk medicine
extracts
leaves
aqueous extract
rats
turkey
flavonoids
assay
oxidative stress
antioxidant activity
antioxidants
lipid-peroxidation
phenolic-compounds
polyphenols
capacity
7
8
9
10

(B)

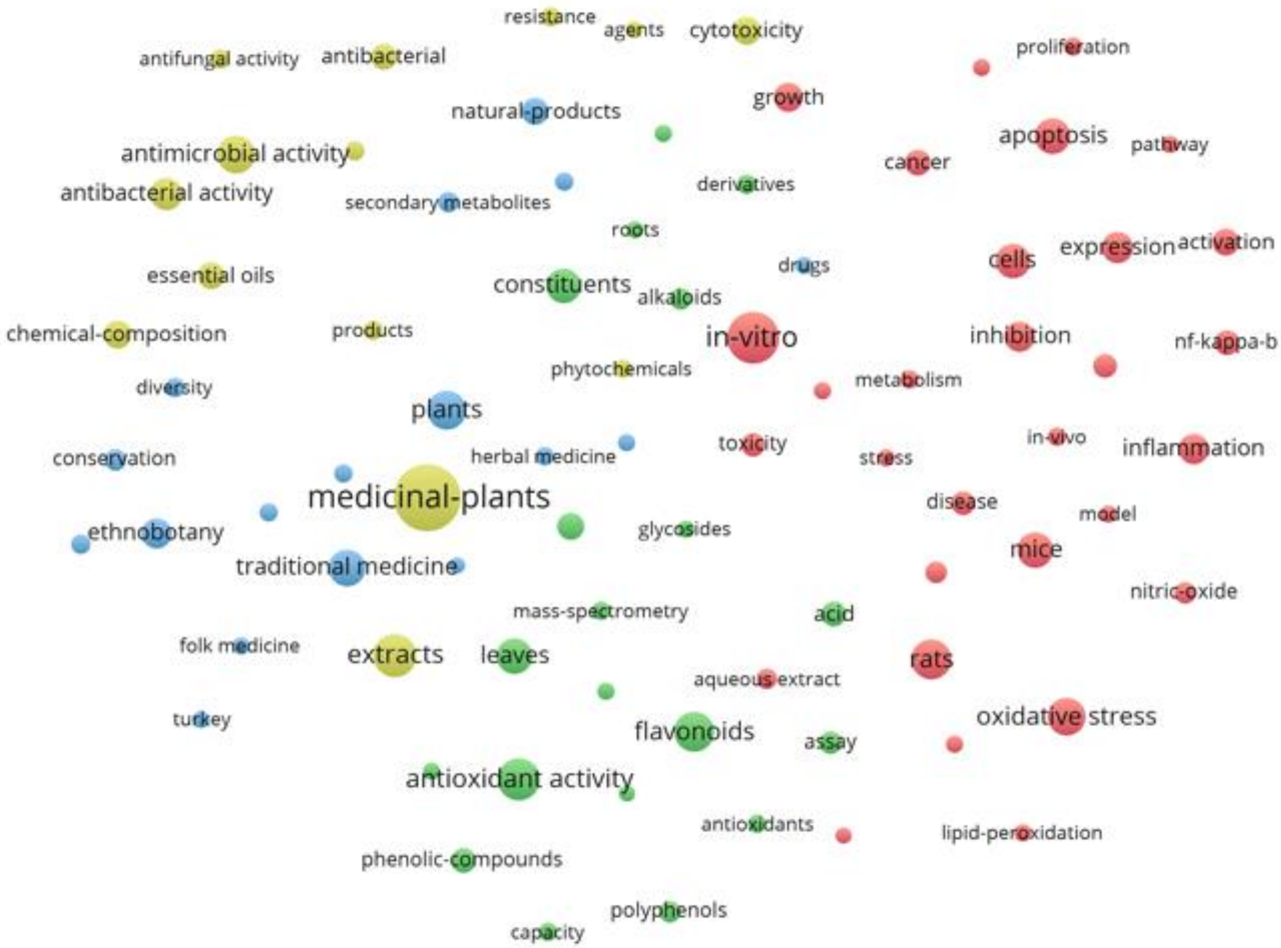

resistance
agents
cytotoxicity
antifungal activity
antibacterial
proliferation
growth
natural-products
apoptosis
pathway
antimicrobial activity
cancer
antibacterial activity
secondary metabolites
derivatives
roots
expression
activation
cells
drugs
essential oils
constituents
alkaloids
chemical-composition
products
in-vitro
inhibition
nf-kappa-b
phytochemicals
metabolism
diversity
plants
in-vivo
conservation
herbal medicine
toxicity
stress
inflammation
medicinal-plants
disease
model
ethnobotany
glycosides
mice
traditional medicine
nitric-oxide
mass-spectrometry
acid
folk medicine
extracts
leaves
rats
aqueous extract
turkey
oxidative stress
flavonoids
assay
antioxidant activity
antioxidants
lipid-peroxidation
phenolic-compounds
polyphenols
capacity

Figure 9. Phytochemical classes and natural compounds often investigated in the ethnopharmacology field.

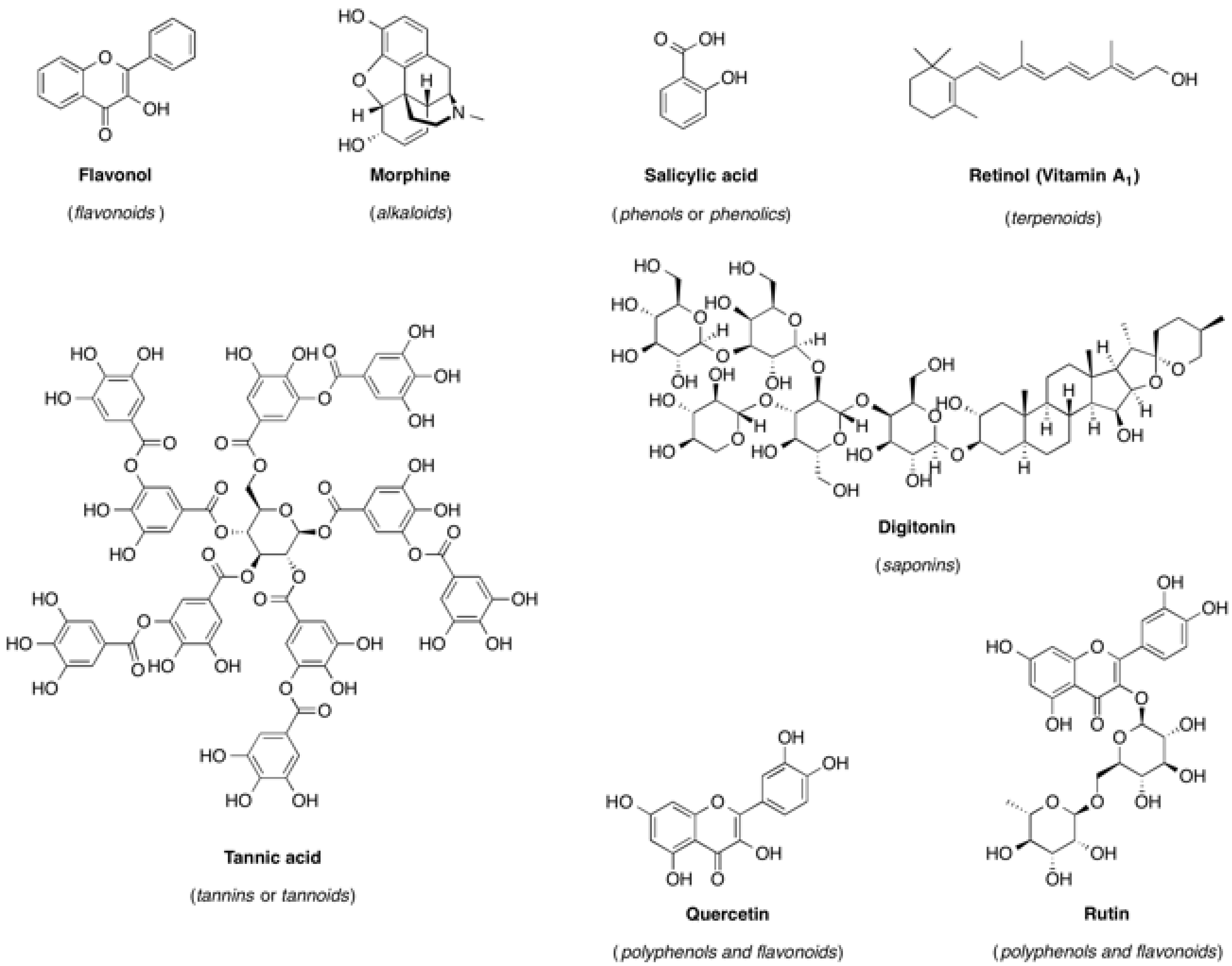


Figure 10. Temporal changes in publication shares of selected countries/regions. It should be noted that a publication could have contributions from multiple countries/regions. Regarding the major contributors, the shares of Japan and USA have declined while those of China and Brazil have increased.

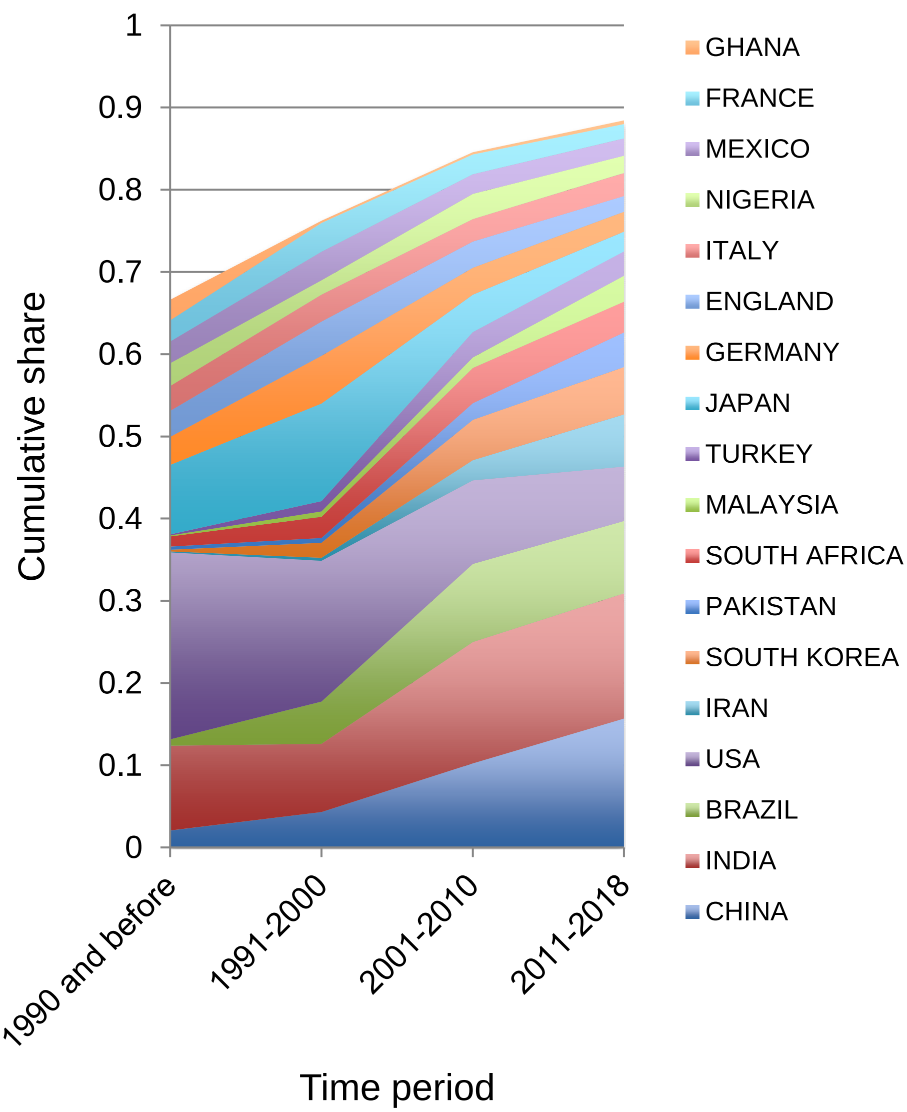
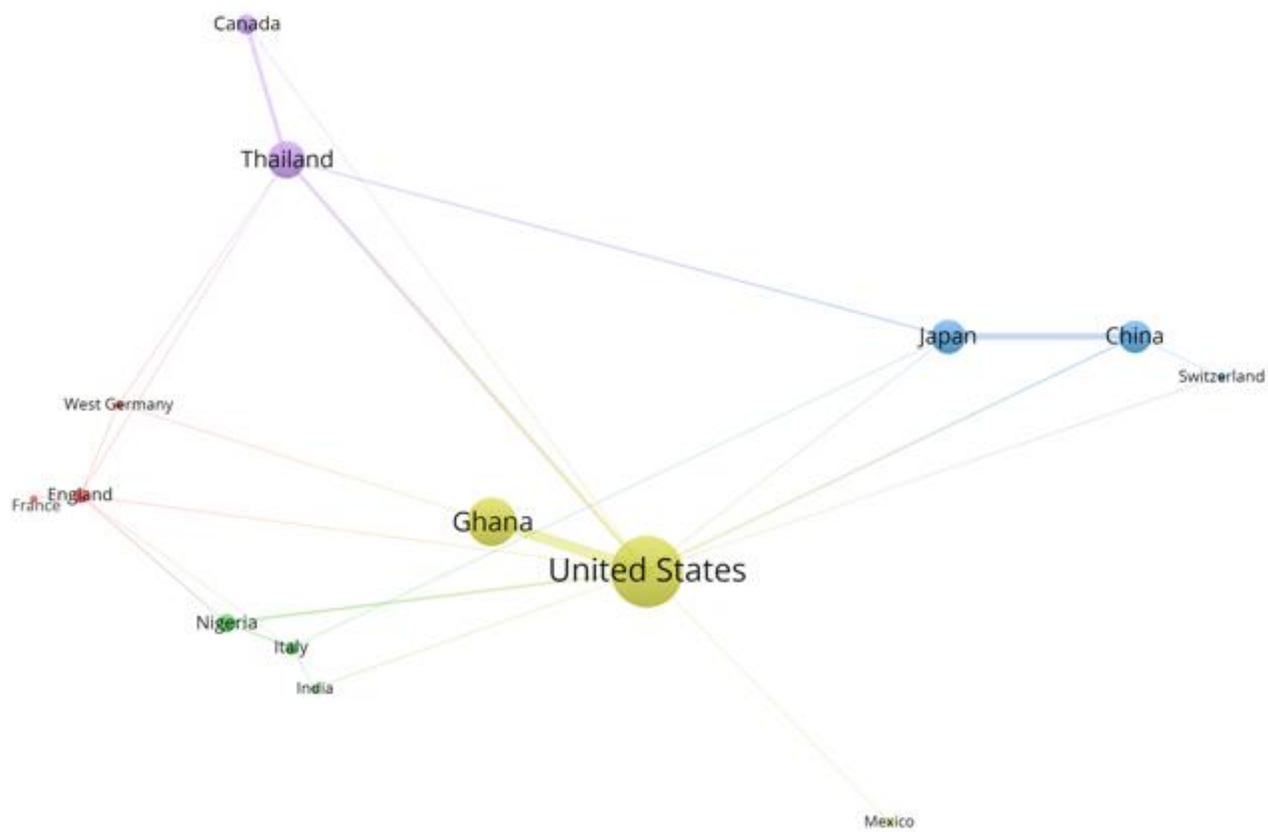


Figure 11. Temporal changes in the extent international collaborations. The bubble size indicates the total link strength of a country, which is calculated as the sum of international collaborations involved, adjusted by fractional counting. Bubbles are closer to each other if the countries/regions collaborated more frequently, hence a thicker connecting line, and clustered together (with the default clustering parameters by VOSviewer). For each time period, we only considered countries/regions with >1% contributions to the total number of publications in that period. (A) In 1990 and before, the collaboration network of 14 countries/regions, in 5 clusters with 24 links and total link strength of 83.5 was visualized. The United States-Ghana and China-Japan collaborations were strongest. (B) In 1991–2000, the collaboration network of 21 countries/regions, in 5 clusters with 89 links and total link strength of 267 was visualized. England, the United States, and China were in the center of the network. (C) In 2001–2010, the collaboration network of 20 countries/regions, in 4 clusters with 135 links and total link strength of 832.5 was visualized. Again, England, the United States, and China were in the center of the network. (D) In 2011–2018, the collaboration network of 28 countries/regions, in 4 clusters with 360 links and total link strength of 5489 was visualized. They formed a tight network and collaborated with each other. From these illustrations, it could be shown that co-authored publications increased over the years.

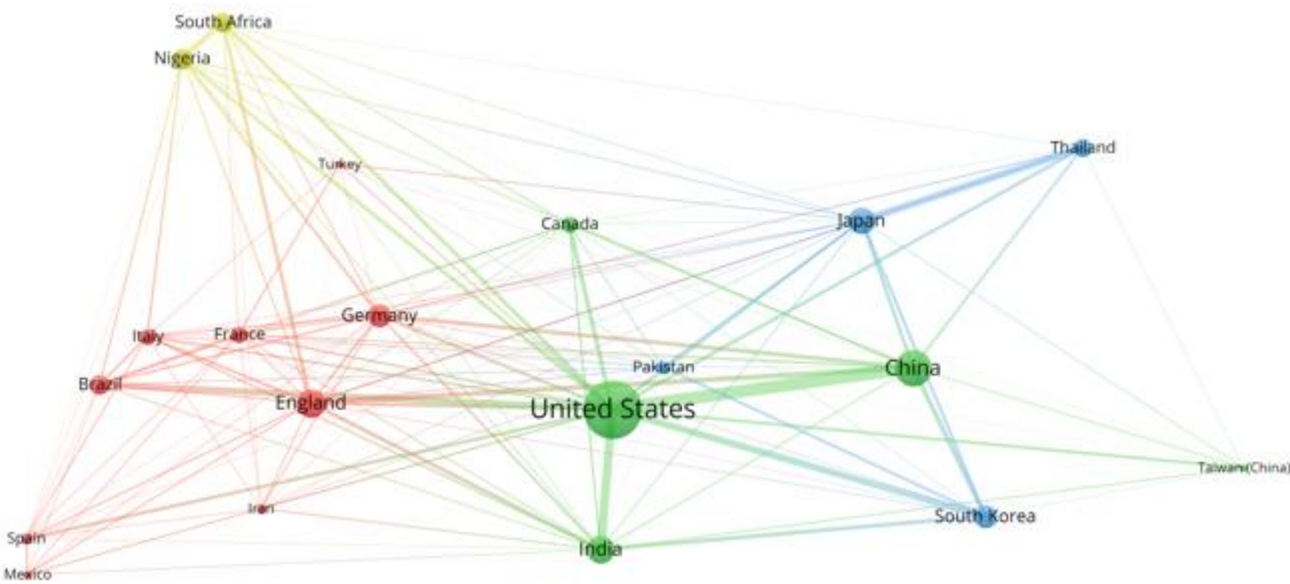
(A)


Canada
Thailand
Japan
China
Switzerland
West Germany
France
England
Ghana
United States
Nigeria
Italy
India
Mexico

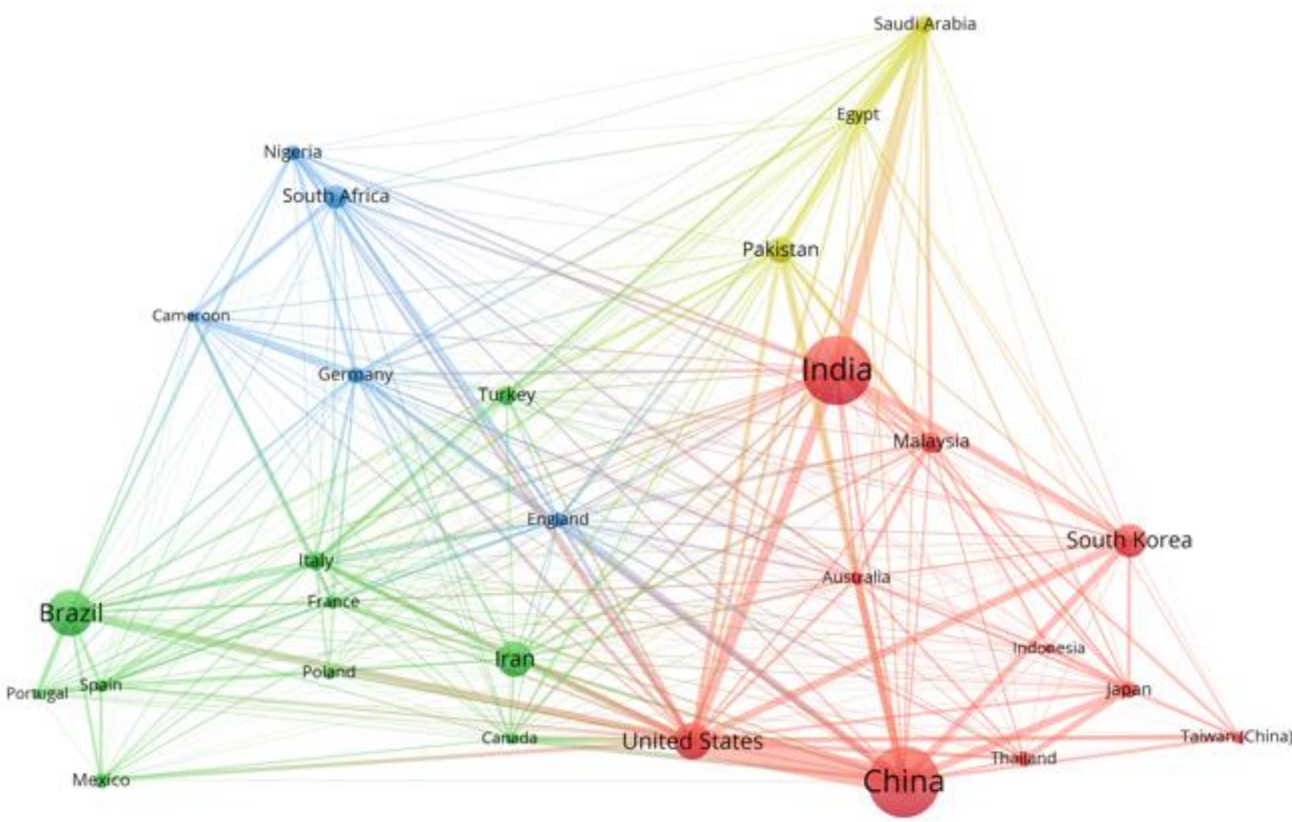
(B)


Belgium
Italy
India
China
Taiwan (China)
Brazil
Japan
Argentina
France
Spain
South Africa
Germany
England
United States
South Korea
Switzerland
Nigeria
Turkey
Canada
Thailand
Mexico

(C)


South Africa
Nigeria
Turkey
Thailand
Canada
Japan
Germany
Italy
France
Pakistan
China
Brazil
England
United States
Taiwan (China)
Iran
South Korea
Spain
India
Mexico

(D)


Saudi Arabia
Egypt
Nigeria
South Africa
Pakistan
Cameroon
India
Germany
Turkey
Malaysia
England
South Korea
Italy
Australia
Brazil
France
Indonesia
Iran
Poland
Portugal
Spain
Japan
Canada
United States
Taiwan (China)
Thailand
Mexico
China