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Three decades of research on *Centella asiatica*: Insights and future trends from bibliometric analysis

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ABSTRACT

Introduction: *Centella asiatica* (L.) Urb. (CA; Family: Apiaceae) remains a major herb in the indigenous medicines of many Asian and African countries. Scientists have been delving deeper to fully understand the rationale for the various anecdotal therapeutic claims ascribed to its usage. Here, we present a comprehensive analysis of the published research on CA within the past three decades.

Methods: The original articles and conference papers on CA research between 1991 and 2021 indexed on the Scopus® database were retrieved and analyzed by VOSviewer® software.

Results: The ~2000 published research articles have been cited > 38,000 times in the period under study. The dominance of India, Malaysia, China, Thailand, and Indonesia out of the 81 countries that contributed to CA research is obvious. These Asian countries altogether contributed more than two-thirds of the publication count. However, the Italian scientist, Belcaro GV affiliated with the Università Degli Studi "G. d'Annunzio" Chieti – Pescara, Italy led the individual pack with 26 publications on CA while Kim OT of the Rural Development Administration, South Korea is the most cited author with 532 citations. The Thai universities – Chulalongkorn, Mahidol, Khon Kaen, Prince of Songkla, and Chiang Mai are actively involved in the research on CA having published ~7 % of the total outputs and citations within the last 31 years.

Conclusions: The primary focus of the research on CA has been its efficacy in the management of wound healing and other chronic conditions. Recent investigations are expanding into cosmetics, phytoremediation, and food packaging.

1. Introduction

Centella asiatica (L.) Urb. (CA) belongs to the Apiaceae plant family (subfamily Mackinlayoideae) which was re-allocated from the subfamily Hydrocotyloideae (genus: Hydrocotyle). As such, CA was previously known as *Hydrocotyle asiatica* using the old Hydrocotyle nomenclature (Nicolas and Plunkett, 2009). The plant has different local names given by various cultures, but the most common names are "Indian Pennywort", "Asian Pennywort" and "Gotu kola". Popularly touted as one of the "Miracle elixirs of life," CA has been an integral component of the ancient Ayurvedic, Chinese, and African traditional medicinal systems (Gohil et al., 2010). The perennial creeping plant grows in a variety of soils with moist, sandy, or clayey loam that is richer in humus than clay (Devkota and Jha, 2009) and is found in most tropical and subtropical regions of the world. Although historically native to Southeast Asia and the Pacific Island, the plant is now grown in many other countries; notably, South Africa, Madagascar and Seychelles, USA, Mexico, and Ecuador (Orhan, 2012; Wright et al., 2022).

CA is widely known for its culinary use as a salad vegetable or in juices (Hashim, 2011); however, its versatile medicinal properties have been the main factor driving its growth in the global herbal market (Sun et al., 2020). It is traditionally used to treat neurological diseases such as dementia, Alzheimer's disease, anxiety, and depression in Ayurveda (Orhan, 2012). The demand for the CA plant has increased over the past

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three decades and is expected to continue to rise into the next decade (Transparency Market Research, 2021). In India for example, where it is sold under the trade name "Brahmi booti", it is listed among the 178 species of medicinal plants consumed in quantity > 100 metric tonnes per year with an annual trade estimated between 500 and 1000 metric tonnes (Ved and Goraya, 2007). It is also sold in the form of liposomal tablets, creams, or powders and as a component of many herbal formulations (Prasad et al., 2019). The inclination of consumers towards organic products and the growing demand for botanicals in cosmetics and personal care products are also driving the growth in demand. Nevertheless, the unrestricted exploitation of CA coupled with inadequate cultivation to restore its natural abundance may place it at an increased risk of extinction (Sardrood et al., 2019).

The scientific research on CA in the past three decades has focused mainly on its vast medicinal potential and the broad-spectrum bioactivity of its derived phyto-compounds. Depending on the demographic region and place of collection, the ursane- and oleanane-type pentacyclic triterpenoid saponins account for about 8% of the plant compounds (James and Dubery, 2011). The triterpenoid saponins; asiaticoside, madecassoside, asiatic acid, and madecassic acid are responsible for most of its pharmacological activity and have been used as biomarkers to assess the quality of the CA plant (Hashim, 2011; James and Dubery, 2011; Maulidiani et al., 2014). Flavonoids, phenolic acids, steroids, amino acids, vitamins, and essential oils are some other constituents of CA (Mohd Zainol et al., 2009). The CA plant is widely reputed for its wound-healing properties and the treatment of various skin conditions. Basic and clinical research investigations have shown the beneficial effects of CA and its triterpenoids in this regard, hence, their inclusion in some skincare products (Bylka et al., 2014; Ratz-Lyko et al., 2016). Asiaticoside and madecassoside, which are mainly credited for their potent wound-healing activities, are believed to act by increasing the synthesis of glycosaminoglycan and increasing hydroxyproline and collagen contents in the wound tissue (Idris and Mohd Nadzir, 2021). Besides facilitating wound healing, CA extracts have demonstrated other medicinal activities. For example, they can be effective in the management of accelerated aging (Karsono et al., 2021), diabetes ShanmugaPriya et al. (2023)) cancer (Hussin et al., 2014), and cardiovascular diseases (Razali et al., 2019). Additionally, the neuroprotective (Puttarak et al., 2017; Wright et al., 2022), antimicrobial (Idris and Mohd Nadzir, 2021), anti-inflammatory (Arribas-López et al., 2022; Hafiz et al., 2020), and antioxidant (Buranasudja et al., 2021) characteristics of CA have been well-described in the literature as summarized in Table 1. However, CA has also been implicated as a component of some herbal and dietary supplements with hepatotoxicity concerns during human consumption to induce weight loss (Bessone et al., 2021; Santos et al., 2021) urging the need for caution for use in such indications.

In the present study, a special emphasis was placed on the contributors (researchers, institutions, countries, and journals) to the ethnopharmacological research advancements made on the plant in more than 30 years. The common areas, trends, and prospects of CA research are critically analyzed in a bid to highlight the major influencers of this important medicinal plant.

Table 1
Key pharmacological potentials of *Centella asiatica* as shown in recent studies.

Pharmacological actions	Specific biochemical or molecular mechanisms	Reference
Wound healing	• Improves angiogenesis via inflammatory mechanisms. • Elicits better pigmentation of split-thickness skin grafts. • Decreases trans-epidermal water loss and skin erythema.	(Arribas-López et al., 2022; Ratz-Lyko et al., 2016; Jenwitheesuk et al., 2018)
Anti-aging	• Preserves telomere length. • Reduces the expression of pro-aging genes e.g., *TERT*, *C-MYC*, *SIRT*, etc. • Upregulates calorie restriction	(Karsono et al., 2021)
Antidiabetic	• Reduces blood glucose and elevates insulin secretion and signaling • Ameliorates the dry skin condition in type 2 diabetic patients. • Improves the oral hygiene of hyperglycaemic patients. • Reduces the symptoms of neuropathy in type 2 diabetic patients	(Legiawati et al., 2020; Lou et al., 2018; ShanmugaPriya et al., 2023)
Anticancer	• Inhibits cell proliferation, apoptosis and DNA damage in HepG2 cells	(Hussin et al., 2014)
Cardio-protective	• Decreases serum myocardial marker enzymes implicated in cardiomyopathy.	(Razali et al., 2019)
Neuroprotective	• Improves behavioral performance and mitochondrial function. • Boosts working memory, mood and alertness. • Eases anger	(Hambali et al., 2021; Puttarak et al., 2017; Wright et al., 2022)
Antimicrobial	• Shows positive effects against *B. subtilis*, *L. monocytogenes*, *E. coli*, *V. cholera*, *S. paratyphi*, *A. niger*, *C. albicans*, *S. aureus*, etc.	(Idris and Mohd Nadzir, 2021)
Antioxidant	• Scavenges tissue reactive oxygen species (e.g. $O_2^{\cdot-}$, H_2O_2, $OH^{\cdot}$) • Elevates transcription and activities of antioxidant enzymes such as SOD, CAT, GPx, GST	(Buranasudja et al., 2021)
Anti-inflammatory	• Inhibits nitrite level, PGE_2, TNF-α expressions in LPS-induced RAW264.7 cells	(Hafiz et al., 2020)

NRF2 – Nuclear factor-erythroid factor 2-related factor 2; O2-. – superoxide anion; H2O2 –
hydrogen peroxide; $OH^{\cdot}$ – hydroxyl radical; GPx – glutathione peroxide, GST – glutathione
S-transferase; HO-1 – Heme oxygenase 1; PGE_2 – prostaglandin E2; TNF-α – tumor necrosis factor-alpha;
LPS – lipopolysaccharide

2. Materials and methods

The Scopus database was selected for the collection of research outputs on *Centella asiatica* (L.) Urb. over the last 31 years in this study. This is primarily due to its comparative ease of navigation, multidisciplinary focus, and global acceptance among scientific researchers (Felice and Polimeni, 2020; Mishra et al., 2021; Salmeron-Manzano et al., 2020). Scopus is the largest known peer-reviewed and citation abstracting database which covers a wide range of subjects thus allowing for in-depth analyses of previous research findings and possible predictions of future research trends (Md Khudzari et al., 2018).

The method used in the collection of data from the Scopus database is illustrated in the flow chart in Fig. 1. The query type used for the data search initially carried out on the 8th of March 2021 and later on the 14th of November 2022 was: (TITLE-ABS-KEY ("Centella asiatica or Gotu kola")) AND LIMIT-TO DOCTYPE ("ar") OR LIMIT-TO DOCTYPE ("cp") AND PUBYEAR > 1990 AND PUBYEAR < 2022. The search was limited to original research and conference papers as they represent accurately the output form of most scientific research activities and as we have done previously (George et al., 2021). All the articles retrieved from the database were then further scrutinized using Microsoft Excel® version 2013 (Washington, USA). This was done to ensure the accuracy of collected data to be used for analysis and to preclude any duplicates (Omoregbe et al., 2020). The scrutinized documents were further imported into the VOSviewer software version 1.6.16 (Leiden,

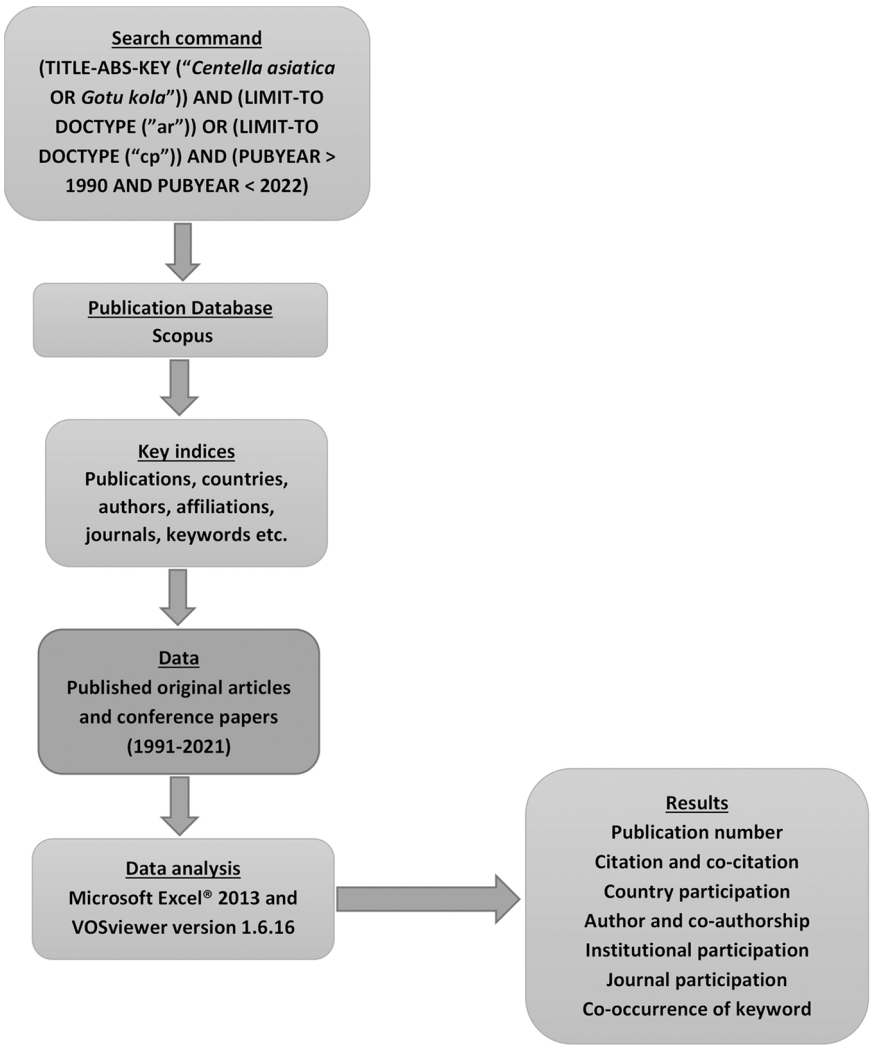

Fig. 1. A flow chart of the study methodology. Scopus is the largest known peer-reviewed and citation abstracting database, therefore, was selected for this study. The data obtained were then analyzed using widely accepted analysis tools; Microsoft Excel® 2013 and VOSviewer® version 1.6.16.

Netherlands) where they were used for the mapping of important information on co-authorship of countries, co-authorship of authors, co-authorship of institutions, journal participation, co-occurrence of authors, co-citation analysis, occurrence of keywords, etc.

3. Results and discussion

3.1. The growth trend in the number of publications

The analysis of the published research data on *Centella asiatica* (CA) between 1991 and 2021 indexed and mined from Scopus yielded a total of 1970 published original articles and conference papers that have been cited a total of 38,469 times with an average annual publication rate of ~66. Of the total documents, only a meager 104 were papers presented at conferences representing approximately 5% compared to the remaining 95 % that were published as original articles within the period. As shown in Fig. 2, the number of publications per year was less than 20 from 1991 to 2000 with an average yearly publication of 9.9; a continuous rise in the number of publications was observed from 2002 onwards reaching a peak of 202 in 2021. The average annual rate of publications on CA research increases per decade with the second and third decades posting 44.6 and 122.3, respectively. This indicates a growing research interest in the plant by scientists all over the world which can be related mostly to its pharmacological, medicinal, and nutritional importance as researchers continue to find viable natural therapies for lifestyle diseases.

3.2. Citations of Centella asiatica publications (1991 – 2021)

For the citation analysis in this study, the threshold of publication citations was set at ≥ 100. A total of 77 publications on CA research within the period met this criterion and the most cited article with 600 citations was published by Wong and colleagues (Wong et al., 2006). The high citation count of this study may be partly due to the inclusion of other traditional plants in addition to CA in the investigation of their antioxidant activities. The second most-cited (363 citations) CA publication was authored by Logeswari and others (Logeswari et al., 2015) where they described the antimicrobial potentials of silver nanoparticles made from CA and other plant extracts. Other publications with high citations are presented in Table 2.

3.2.1. Co-citation of cited authors

The co-citation analysis of cited authors in publications is a viable way of identifying and visualizing connections among different authors within a given niche field (Mora et al., 2019). The total link strength (TLS) indicates the level of cordiality between different nodes in the author citation interconnections (Van Eck and Waltman, 2013). In this study, the co-citation analysis of authors with at least 100 co-cited

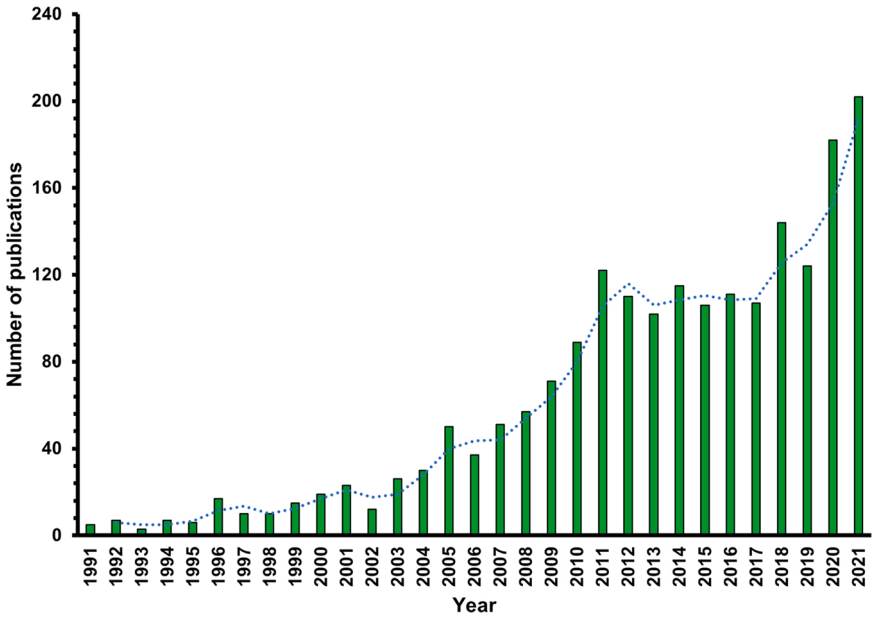

Fig. 2. Research outputs on *Centella asiatica* as indexed on the Scopus® database. A total of 1770 published original articles and conference papers were indexed on the Scopus database with an average annual publication rate of 59 in the period 1991–2021.

Table 2
Centella asiatica publications (in vitro studies) with the most citations (1991 – 2021).

Publication	Number of citations	Reference
Antioxidant activities of aqueous extracts of selected plants	600	(Wong et al., 2006)
Synthesis of silver nanoparticles using plant extracts and analysis of their antimicrobial activity	363	(Logeswari et al., 2015)
Anti-collagenase, anti-elastase and anti-oxidant activities of extracts from 21 plants	337	(Thring et al., 2009)
Phenolic and antioxidant activity of some food and medicinal plants	274	(Bajpai et al., 2005)
Antioxidative activity and total phenolic compounds of leaf, root and petiole of four accessions of *Centella asiatica* (L.) Urban	264	(Zainol et al., 2003)
Preliminary assessment of nutritional value of traditional leafy vegetables in KwaZulu-Natal, South Africa	250	(Odhav et al., 2007)
Total phenolics and antioxidant activities of fenugreek, green tea, black tea, grape seed, ginger, rosemary, Gotu kola, and Ginkgo extracts, vitamin E, and tert-butylhydroquinone	239	(Rababah et al., 2004)
Antimicrobial effects of Thai medicinal plants against acne-inducing bacteria	216	(Chomnawang et al., 2005)
In vitro screening of five local medicinal plants for antibacterial using dsc diffusion method	215	(Zaidan et al., 2005)

documents was considered for analysis. Of the 118,148 co-cited authors, only 85 met the set threshold. Fig. 3 presents the visualization network of these authors which are grouped into four different clusters.

Cluster 1 (red) contains 26 co-cited authors; Gupta YK has the highest TLS of 2330 and 242 co-cited documents. This author is closely followed by Li Y (TLS, 2170 and co-cited documents, 201) and Tantisira MH (TLS, 1966 and co-cited documents, 161), respectively. Cluster 2 (green) is composed of 19 co-cited authors with Shukla A having the highest TLS of 2482 and 203 co-cited documents. This author is closely followed by Dhawan BN (TLS, 2405 and co-cited documents, 200) and Rasik AM (TLS, 2279 and co-cited documents, 178). Clusters 3 (blue) and 4 (yellow) have nine and five co-cited authors, respectively. In the former, Kim OT (TLS, 2380 and co-cited documents, 164) had the highest connection and is followed by Hwang B (TLS, 2125 and co-cited documents, 134). Belcaro GV (TLS, 5368 and co-cited documents, 384) and Cesarone MR (TLS, 4176 and co-cited documents, 204) had the most interconnections in cluster 4. Many of the co-citations of these authors were received in areas of shared research interests.

3.3. Country participation in Centella asiatica research

A total of 81 countries participated in *Centella asiatica* (CA)-related research over the last three decades based on the publications indexed on the Scopus database information and as analyzed by VOSviewer®. It is noteworthy to mention that some country affiliations are undefined since some authors did not include the details about their countries or affiliations in publications which may result in false positives during the data mining from the database. Hence, we performed a painstaking screening of all documents with undefined locations to remove any incorrect assignment of countries.

India has the highest number of publications (601) and citations (12,088) followed by Malaysia (213), China (200), Thailand (179), and Indonesia (160) as listed in Table 3. Unsurprisingly, almost half (9) of the top 20 leading countries are from the Asian continent where the plant originates and derived its name (Gohil et al., 2010) and the list is completed with countries in Europe (6), North America (2), Africa (1), Australia (1) and South America (1). Only five of the countries have 100 publications or more on CA research within the period under study. The domination of India regarding the number and citations of CA outputs may be attributed to their age-long widespread dependence on their traditional medicines commonly referred to as Ayurveda which utilizes medicinal plants and other natural therapies against diseases (Pandey et al., 2013).

Despite the naturalization of CA in Africa, mainly in South Africa, Madagascar, and Tanzania, only the first country is featured in the top 20 leading countries with 36 publications and 1069 citations within the stipulated period under review. The herb which is commonly referred to as “icudwane” or “Bolila-balinku” by the Zulu and Sotho populations in South Africa is traditionally utilized for the relief of wounds, leprosy, and syphilis (Long et al., 2012) and is routinely available as a dietary supplement in stores. This may account for the increased research activity compared to other countries in Africa.

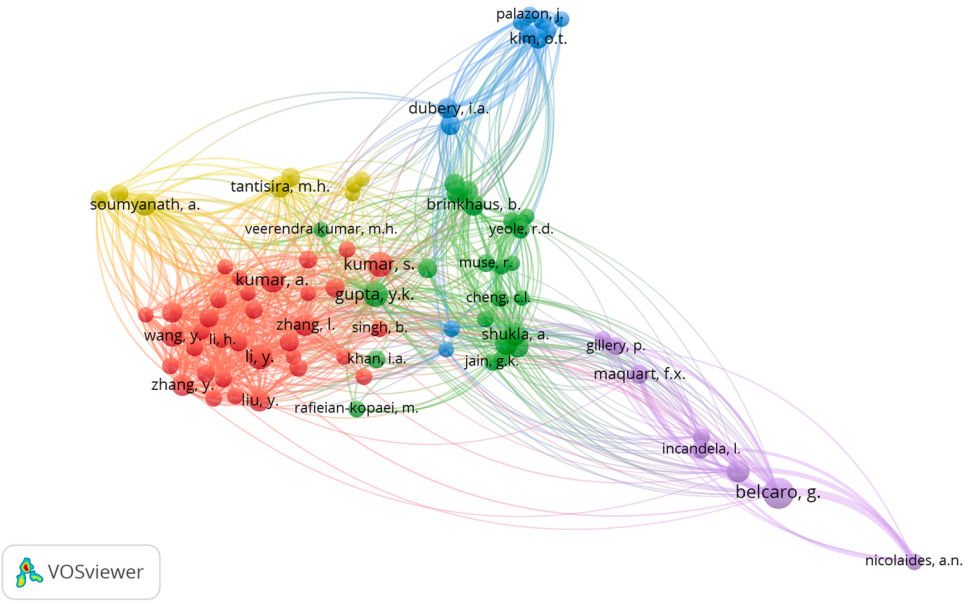

Fig. 3. Visualization network of co-citation of cited authors of *Centella asiatica* publications. The co-citation analysis of authors with at least 100 co-cited documents yielded 59 co-cited authors that were grouped into 4 different clusters.

Table 3
Countries (top 20) with the highest number of publications on *Centella asiatica*.

Country	Total publications	Total citations	TC:TP
India	601	12,088	20.11
Malaysia	213	4369	20.50
China	200	3773	18.87
Thailand	179	3133	17.50
Indonesia	160	527	3.29
United States	93	2880	30.97
South Korea	92	2134	23.20
Italy	82	1282	15.63
Japan	46	1165	25.33
South Africa	36	1069	29.69
Australia	34	1014	29.82
Brazil	34	702	20.65
United Kingdom	31	1137	36.68
France	29	708	24.41
Germany	26	649	24.96
Spain	26	579	22.27
Canada	24	850	35.42
Pakistan	22	162	7.36
Turkey	22	361	16.41
Iran	22	275	12.50

TC – Total citations; TP – Total publications

In terms of international collaborations on CA research, VOSviewer analysis identified 29 countries with a minimum of 10 publications together that were subsequently divided into 7 clusters (Fig. 4). Cluster one (red) contains eight countries with active research collaborations on the plant and high TLS. They include Australia (TLS – 23), United Kingdom (TLS – 19), South Korea (TLS – 17), Brazil (TLS – 11), Pakistan (TLS – 10), Bangladesh (TLS – 9), Vietnam (TLS – 9), and South Africa (TLS – 6). The five countries grouped based on their inter-collaborations and co-authorship in cluster two (green) are Belgium (TLS – 8), China (TLS – 16), France (TLS – 13), Germany (TLS – 9), and Madagascar (TLS – 10). Cluster three consists of four countries: Indonesia (TLS – 11), Japan (TLS – 27), Taiwan (TLS – 6), and Thailand (TLS – 39). In cluster four (yellow), four countries were grouped, namely, Italy (TLS – 12), Nepal (TLS – 3), Turkey (TLS – 7), and the United States (TLS – 32) while cluster 5 (purple), has India (TLS – 43), Malaysia (TLS – 37) and Saudi Arabia (TLS – 17). Finally, clusters six and seven have two countries each: Iran (TLS – 4) and Spain (TLS – 6), Canada (TLS – 21), and Sri Lanka (TLS – 6), respectively.

3.4. Participation of authors in Centella asiatica research outputs

The number of research outputs is usually considered an indicator of the level of expertize of an author on a particular research subject. The publication count, together with the number of citations amassed, can reflect the author's expertize on a subject over a given time. Although this general notion is not always an accurate interpretation of the quality of research since other factors such as the popularity of the area of research and the publication model (subscription or open access) influence publication citations. Therefore, an author's productivity and influence may sometimes not reflect expertize, yet it is the major yardstick commonly used for promotions in many academic institutions (Parmar et al., 2019). In this study, only the top 10 authors with at least 12 publications on CA research within the last three decades are listed in Table 4.

The most productive author in terms of the number of publications on CA research is Belcaro GV, who is affiliated with the Università degli Studi "G. d'Annunzio" Chieti - Pescara in Italy with 26 publications. This author is followed by Tantisira MH from Mahidol University, Bangkok, Thailand with 21 publications. The top-cited author is Kim OT (Rural Development Administration, South Korea) with 532 citations from 15 publications followed by Soumyanath A (Oregon Health & Science University, USA) with 467 citations from 16 publications.

3.4.1. Co-authorship of authors

A co-authorship analysis of authors of CA research within the last three decades was conducted with the set threshold of one publication and 200 citations on VOSviewer. The data showed that only 125 authors of the total 6735 participants met these criteria (Fig. 5). Again, the productive authors, Belcaro GV, Tantisira MH, Soumyanath A, and Dai Y, have the highest number of co-authored publications demonstrating the strength of their collaborations.

3.5. Institutional participation in Centella asiatica research (1991 – 2021)

The participation of universities, research centers, and other institutions in the research outputs on CA was investigated. A total of 160

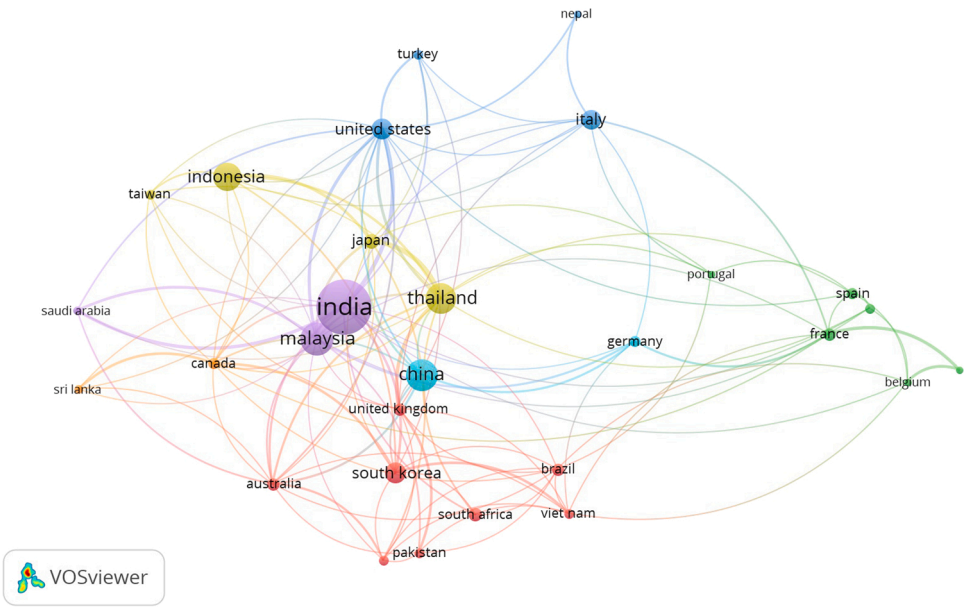

Fig. 4. Visualization network of countries involved in the research on *Centella asiatica.* The international collaboration analysis resulted in 29 countries with a minimum of 10 co-publications that were divided into 7 clusters.

Table 4
Authors of *Centella asiatica* research with at least 10 publications indexed on Scopus within the 1991 – 2021 period.

Name	No of Documents	No of Citations	Affiliation	Country
Belcaro G.V	26	417	Università degli Studi "G. d'Annunzio" Chieti - Pescara	Italy
Tantisira M. H	21	396	Bourapha University, Chimbouri	Thailand
Cesarone M. R	20	391	Università degli Studi "G. d'Annunzio" Chieti - Pescara	Italy
Soumyanath A.	16	467	Oregon Health & Science University, Portland	United States
Dai Y.	15	444	China Pharmaceutical University, Nanjing	China
Kim O.T	15	532	Rural Development Administration, Jeollabuk-do	South Korea
Quinn J.F	14	355	Oregon Health & Science University, Portland	United States
Gray N.E	14	294	Oregon Health & Science University, Portland	United States
De Sanctis M. T	13	346	Università degli Studi "G. d'Annunzio" Chieti - Pescara	Italy
Dugall M.	13	109	Università degli Studi "G. d'Annunzio" Chieti - Pescara	Italy

institutions reported on the research publications on the plant in the last three decades. However, only 10 of these institutions with 20 or more publications are listed in Table 5. An overwhelming 90 % of the leading institutions on CA research are based in Asia; this may not be far-fetched as the plant is native to these countries where it is a foremost traditional medicine (Gohil et al., 2010). Thailand, specifically, has contributed immensely to the knowledge and research outputs of CA by hosting up to five out of 10 of the leading institutions. The institution with the highest number of publications is however Universiti Putra Malaysia with 68 published articles and 1876 citations, recording an average of 27.6 citations per publication. The institution is followed by Chulalongkorn University, Thailand with 45 published articles and 861 citations. Other institutions actively conducting scientific research on CA are Universiti Teknologi Mara, Malaysia (31 publications cited 477 times), Università degli Studi "G. d'Annunzio" Chieti – Pescara, Italy (26 publications cited 390 times), Mahidol University, Thailand (26 publications cited 811 times) (Table 5).

3.6. Journal participation in Centella asiatica research (1991 – 2021)

The participation of scientific journals in CA publications over the years was assessed by the quantity, influence, and bibliographic connections. In all, 868 journals have published original research articles and conference papers on CA research. The top 10 journals that have published the greatest number of CA manuscripts are presented in Table 6. Predictably, given the interdisciplinary nature and the core focus on medicinal plants, the Journal of Ethnopharmacology hosts the most publications (73) and citations (4519), accounting for about 3.7% of the total publications on the plant within the stated time frame. It is followed by AIP Conference proceedings (26), Phytotherapy Research (22), Evidence-based Complementary and Alternative Medicine (22), and Fitoterapia (20), which together accounted for 4.6 % of total publications. Notably, Food Chemistry with just 18 publications garnered the highest total citations/total publications ratio of 98.8, a testament to its superior impact factor over the other journals on the list (Table 6). These journals, though with the common theme of medicinal plants, publish articles on broad research subjects such as Pharmacology, Botany, Chemistry, Biology, and Medicine. Furthermore, most of the influential journals on CA research are hosted on the Elsevier publishing platform signifying its significant impact in this genre compared to other publishers.

To evaluate the bibliographic coupling and the collaborative strength among journals with publications on CA, the network visualization (Fig. 6) of journals with a minimum of 10 publications was examined. Only 26 journals met this threshold, and they were divided into four clusters. Cluster one (red) is composed of AIP Conference Proceedings, Angiology, Contact Dermatitis, Food Chemistry, International Food Research Journal, Phytomedicine, and Phytotherapy Research. The seven journals in cluster 2 (green) include the Asian Journal of Pharmaceutical and Clinical Research, Evidence-based

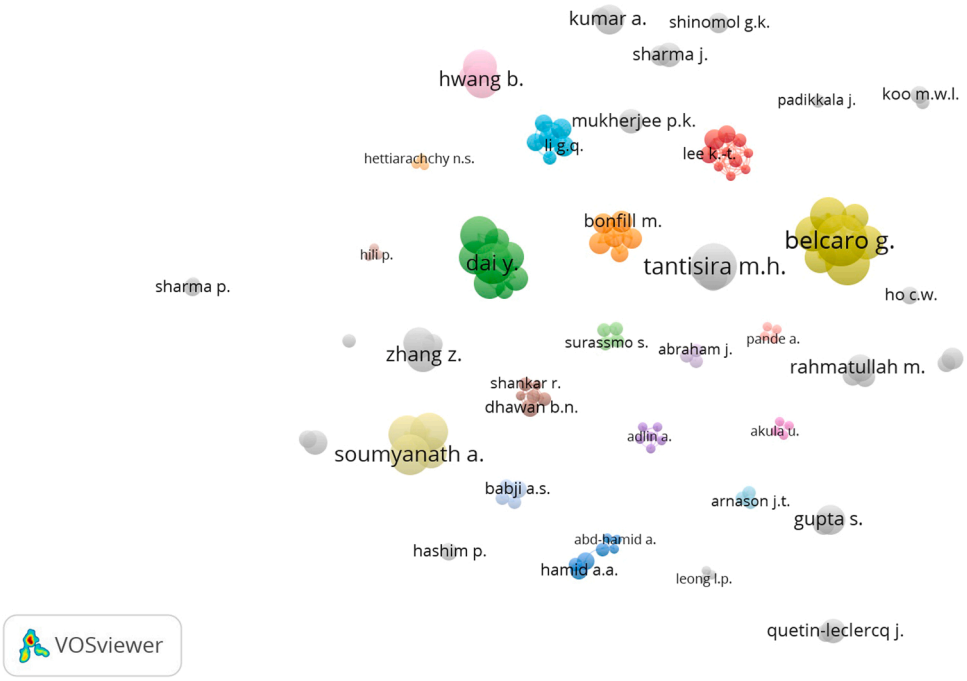

Fig. 5. Visualization network of co-authorship of authors of *Centella asiatica* publications. Co-authorship analysis with a minimum of one publication and 200 citations gave 92 authors with co-cited documents.

Table 5
The top-10 leading institutions on *Centella asiatica* publications (1991–2021).

Institution	Total publications	Total citations	TC: TP
Universiti Putra Malaysia	68	1876	27.59
Chulalongkorn University, Thailand	45	861	19.13
Universiti Teknologi Mara, Malaysia	31	477	15.39
Università degli Studi "G. d'Annunzio" Chieti – Pescara, Italy	26	390	15.00
Mahidol University, Thailand	26	811	31.19
Universiti Kebangsaan Malaysia	25	565	22.60
China Pharmaceutical University, China	25	687	27.48
Khon Kaen University, Thailand	25	420	16.80
Prince of Songkla University, Thailand	23	172	7.48
Chiang Mai University, Thailand	22	450	20.45

TC – Total citations; TP – Total publications

Complementary and Alternative Medicine, International Journal of Pharma and Biosciences, International Journal of Pharmaceutical Sciences Review and Research, International Journal of Pharmacy and Pharmaceutical Sciences, Journal of Ethnopharmacology and Research Journal of Pharmacy and Technology. Cluster three (blue) also has seven journals: Acta Horticulturae, Fitoterapia, Industrial Crops and Products, Journal of Applied Pharmacy, Journal of Natural Remedies, Pharmacology Online, and Research Journal of Pharmaceutical, Biological and Chemical Sciences. In cluster 4 (yellow), five journals are grouped, the Asian Pacific Journal of Tropical Biomedicine, BMC Complementary and Alternative Medicine, International Immunopharmacology, Molecules, and Planta Medica. Almost all these journals specialize in publishing research on the medicinal, pharmacological, or pharmaceutical investigations of plants and natural products which further emphasizes the growing interest in CA as a natural therapy against many human diseases. The visualization network of journals (Fig. 6) shows that the Journal of Ethnopharmacology has the best collaborative network with a total link strength of 1332. It is followed by Phytotherapy Research and Evidence-based Complementary and Alternative medicine with 970 and 823 total link strengths, respectively, indicating that these journals are actively involved in influencing the citations of publications on CA in other journals.

Table 6
Journals with the highest number (top 10) of publications on *Centella asiatica* research.

Name	Publisher	Total publications	Total citations	TC: TP
Journal of Ethnopharmacology	Elsevier	73	4519	61.90
AIP Conference proceedings	American Institute of Physics	26	45	1.73
Phytotherapy Research	Elsevier	22	1100	50.00
Evidence-based Complementary and Alternative Medicine	BMC	22	454	20.64
Fitoterapia	Elsevier	20	899	44.95
Food Chemistry	Elsevier	18	1778	98.78
Phytomedicine	Elsevier	18	968	53.78
International Journal of Pharmacy and Pharmaceutical Sciences	Innovare Academic Sciences	16	137	8.56
IOP Conference Series Earth and Environmental Science	IOP Publishing	16	13	0.81
International Journal of Pharmaceutical Sciences Review And Research	Global Research Online	15	109	7.27

TC – Total citations; TP – Total publications.

3.7. Co-occurrence of all keywords

The co-occurrence of all keywords analysis was carried out to understand the most frequently used keywords in CA research manuscripts published between 1991 and 2021. Keywords help to identify research hotspots, concentration, focus, and possible future trends on a research subject as well as research gaps (Elisha and Viljoen, 2021; Obileke et al., 2020). In this study, the threshold for the co-occurrence of keywords was set at ≥ 60; that is, keywords that occurred at least 60 times in all publications during the period under study. A total of 19,856 keywords

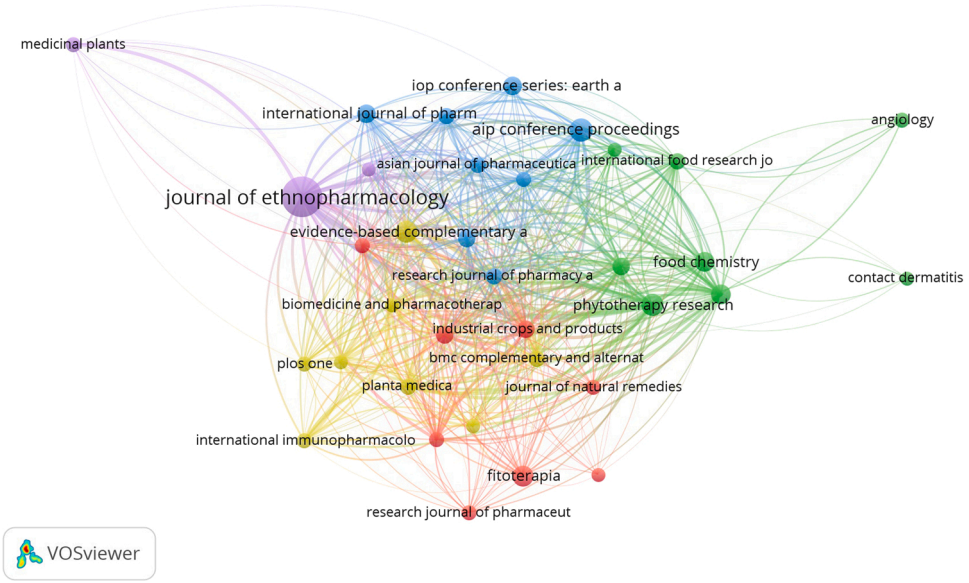

Fig. 6. Visualization network of bibliometric coupling of journals publishing *Centella asiatica* research. Inter-journal collaboration analysis with a minimum of 10 publications resulted in a total of 35 journals that were divided into four clusters.

was used so far in publications but only 104 meet the requirement representing about 0.5 % of all used keywords. These were divided into four clusters as listed in Table 6 and used for the visualization network shown in Fig. 7. The keywords are mostly related to the in vitro and in vivo pre-clinical experimental studies of the potentials of CA in models of diseases. The antioxidant qualities of CA especially have been the focus of many research investigations and have attracted the interests of many researchers (Buranasudja et al., 2021; Gray et al., 2017; Hafiz et al., 2020; Karsono et al., 2021; Sun et al., 2020). Expectedly, the most co-occurring keyword is '*Centella asiatica*'' with 1361 occurrences. Other top co-occurring keywords with their frequency of occurrences are 'non-human' (817), 'controlled study' (762), '*Centella asiatica* extracts' (709), 'unclassified drug' (527) 'human' (494), 'male' (444), 'plant extract' (434), and 'medicinal plants' (383). Most of the keywords associated with CA research indicate that the plant is mostly being exploited for its medicinal importance for use as an alternative to conventional orthodox therapeutic drugs targeted against chronic diseases and as a preventative health supplement.

3.8. Conclusions

The research publications on *Centella asiatica* as indexed on the Scopus database continue to grow in tandem with its heightened importance in the traditional management of wound healing and chronic diseases. Asian institutions and countries especially those of India, Malaysia, Thailand, and China, as well as the scientists; Belgaro GV and Tantisira MH have established their research authority on the plant in the last 31 years. The research articles and conference papers over this period on the plant, promoted quite convincingly, its vast potential as a viable therapeutic for humans which can only be limited

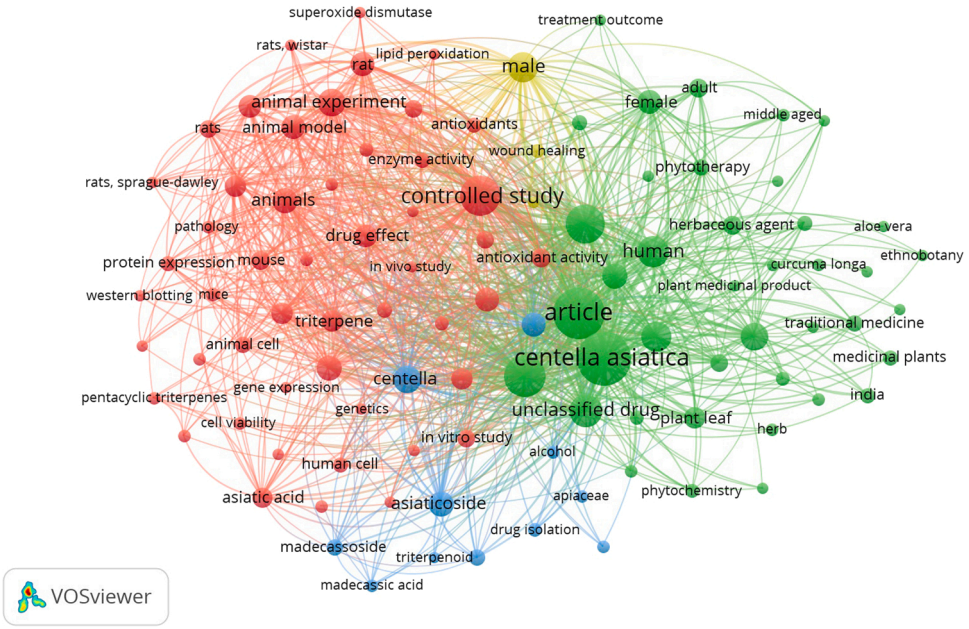

Fig. 7. Visualization network of co-occurrence of all keywords used in *Centella asiatica* publications. A co-occurrence analysis involving a minimum of 60 keywords was performed and the 104 most common keywords that emerged were grouped into 4 clusters.

by the fewer clinical studies available on its safety profile. This, together with the emerging research interests in the applications for bioremediation and food packaging purposes may dominate the publications of *Centella asiatica* in the next decade.

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CRediT authorship contribution statement

ABO – Conceptualization, Formal analysis, Methodology, Writing - original draft. **TTG** – Data curation, Formal analysis, Methodology, Writing - original draft. **ORO** – Writing - original draft. **AOO** – Writing - review & editing. **MO** – Writing - review & editing.

Declaration of Competing Interest

None to declare.

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