Global research progress on reproductive behavior and ethnobotany of the *Saussurea* genus: Literature review-based-bibliometric analysis.

Pooja Singh, Baby Gargi, Vijaylaxmi Trivedi, Ashish Thapliyal and Prabhakar Semwal

Correspondence

Pooja Singh[1], Baby Gargi[1], Vijaylaxmi Trivedi[2], Ashish Thapliyal[3] and Prabhakar Semwal[1,4,*]

[1]Department of Biotechnology, Graphic Era (Deemed to be University), 566/6 Bell Road, Clement Town, Dehradun-248002, India; PS (poo.ja80066@gmail.com); BG (gargimogha46@gmail.com).
[2]High Altitude Plant Physiology Research Centre, H. N. B. Garhwal University, Srinagar Garhwal, India; VLT (vijaylaxmitrivedi@gmail.com).
[3]Department of Microbiology, Graphic Era (Deemed to be University), 566/6 Bell Road, Clement Town, Dehradun-248002, India; AT (ashish.thapliyal@gmail.com).
[4]Research and Development Cell, Graphic Era Hill University, Society Area, Clement Town, Dehradun-248002, India.

[*]Corresponding Author: semwal.prabhakar@gmail.com

Ethnobotany Research and Applications 26:25 (2023) - http://dx.doi.org/10.32859/era.26.25.1-15
Manuscript received: 02/05/2023 – Revised manuscript received: 05/08/2023 - Published: 14/08/2023

Review

Abstract

Background. Saussurea is the most diverse genus of the Asteraceae family generally found in temperate areas of Eurasian countries. This genus comprises approximately 27 ethnologically important species such as *Saussurea laniceps, S. costus, S. medusa, S. obvallata, S. involucrata*, etc. which are traditionally used for treatment of various ailments and also have aesthetic and religious importance.

Methods. This study integrated two separate approaches for the literature review, first we reviewed research work conducted on ethnobotany, morphology, pollinators, breeding systems, and the development of fruits of the genus *Saussurea*. Second, bibliometric analysis for quantitative analysis of published documents on the Scopus database to identify research status and publication trends emerging in the field of reproductive biology and ethnobotany of the *Saussurea* genus.

Results and Conclusion. According to our findings, all *Saussurea* species use entomophily as their primary method of pollination. In this genus, outcrossing is typically observed, and this breeding system appears to have been responsible for the success in terms of ecology and evolution of this genus. India is one among the top nations having the most published literature on the reproductive biology of the *Saussurea* genus and its ethnobotanical uses. The top three journals where the manuscripts have been published are the "*Journal of Ethnopharmacology*", "*Plos One*", "*Journal of Ethnobiology and Ethnomedicine*". Research topics such as conservation, ethnopharmacology and *Saussurea lappa* are highly cited topics, indicating the usage of *Saussurea* species especially in the pharmaceutical industries. This study provides a snapshot of the research progress in the field of reproductive biology and ethnobotanical studies on the *Saussurea* genus at the global level and opens doors to future research.

Keywords: Saussurea, pollen, breeding system, entomophily, phenology, pollinators.

Background

The family Asteraceae is considered as the largest family among angiosperms comprising over 1600 genera and 10% (25,000) of total species with worldwide distribution, while from India nearly 177 genera and 1052 species were recorded (Rolnik & Olas 2021; YU *et al.* 2022). The genus *Saussurea* encompasses temperate areas of Asia, Europe, America, and Australia as geographical range of their habitat (Barres *et al.* 2013; Chen 2016; Dickoré 2001). This genus includes about 493 species globally (Raab-Straube 2017) and around 62 species are reported from the Indian Himalayan Region (Butola & Samant 2010; Hajra 1995). The Eastern and Middle Asia are the center of origin and the epicenter of species diversity of this genus (Butola & Samant 2010; Dickoré 2001; Gailite & Rungis 2012). Members of the *Saussurea* genus are perennial herbs, found in stony places, open slopes, forest cleared patches or waste land at high elevations up to 6000 m above mean sea level (a.s.l.) (Kasana *et al.* 2020). Although maximum species of this genus are found between 1600-3600 m a.s.l., but few species such as *Saussurea gnaphalodes* was even recorded at elevation of 6200 m a.s.l. in Mount Everest (Bakhtaulova *et al.* 2022; Dentant 2018; Yang *et al.* 2008; Yoshida 2002). The genus is characterized by unarmed leaf margins, entire to pinnately divided leaves, which are usually lanuginose, dimorphic pappus bristles, recurved apex of phyllaries, linear style branches and basally connate pappus (Bremer 1994; Häffner 2000; Raab-Straube 2003). Several species such as *Saussurea costus, S. medusa, S. involucrata* and *S. obvallata* belonging to this genus; possess therapeutic properties and religious applications, therefore they have economic value. Some species of the *Saussurea* genus are also a rich source of food, flavoring products, rubber, essential oil, insecticides, and dyes, etc. (Butola & Samant 2010). Several species in this genus exhibit remarkable adaptations to their adverse habitats, and some species exceed their upper limit of distribution beyond 6000 meters' elevation. The most remarkable species groups are the "snowball plants" or "snow hares", *S. gossipiqqphora* and allies, *S.* subg. *Eriocoryne,* with a thick woolly indumentum, and the also referred to as "greenhouse plants" or "snow lotuses", plants belonging to *S.* subg. *Amphilaena* including *Saussurea obvallata*, have their synflorescence covered by semi-transparent bracts varying from white, yellow, and purple in color (Semwal *et al.* 2020; Shi *et al.* 2011; Sun *et al.* 2014). Due to lotus like appearance many species like *S. involucrata* are even grown as ornamental plants (Chen & Wang 2018).

Since most of the high altitude *Saussurea* species in the Himalaya are habitat-specific and distributed over a narrow geographic range, hence require the conservation measures due to their higher risk of the climate change driven extinctions (Klein 2004). According to an assessment conducted in India about 48 species were recorded as threatened species (out of the 62 species) (Butola & Samant 2010). Among these, total 44 sp. have been recognized as rare, two species as critically endangered and two species reported as endangered (Butola & Samant 2010). The species is classified as threatened, when deaths outnumber births over an extended period of time due to several factors including habitat loss, anthropogenic activities, introduction of parasites and diseases and restrictions in reproduction (Kapoor & Usha 2020; Mir *et al.* 2020).

Information on reproductive biology of any plant species is crucial to their successful conservation and sustainable utilization (Rashid *et al.* 2023). In the absence of data on species is considered to be threatened when mortality surpasses births for a significant period of time because of limitations on their reproduction. Management, conservation, and sustainable use of a species requires a detailed understanding of its reproductive biology, and conservation. Without information on reproductive biology, any conservation attempts would be ineffective (Shivanna & Tandon 2014).

Bibliometric analysis is a multidisciplinary science that uses mathematical and statistical techniques used by scientists to analyze the results, impact of journals, and authors, keywords within particular fields of research. With the help of these information researchers are able to analyze the research trends in a particular research field. In this review, the literature analysis has been done in two ways: first, by reviewing the published literature, and second by conducting a quantitative analysis of the data using bibliometric analysis of the literature published in Scopus database. With the help of this review, we intend to comprehensively assemble, analyze, and discover the most recent developments and trends in the area of reproductive biology for this genus.

Materials and Methods

A search was conducted in the following search engines: Science Direct, Scopus, Google Scholar, Research Gate, PubMed, Willey, SpringerLink, and Taylor and Francis, using terms: "Reproductive biology of *Saussurea*", "Pollination biology of *Saussurea*", "Phenology of *Saussurea*", "Breeding systems of *Saussurea*", and "Ethnomedicinal applications of *Saussurea* genus". The articles published till date were screened on the basis of language, duplicate articles were removed, and relevant articles were selected for the review.

For the bibliometric analysis, published data on reproductive biology have been retrieved from the Scopus database in April 2023 and covers the year 2000 to 2023 defined in the following query: ((TITLE-ABS-KEY ("*Saussurea*") AND TITLE-ABS-KEY ("*Reproductive biology*") OR TITLE-ABS-KEY ("*Pollination biology*") OR TITLE-ABS-KEY ("*Seed germination*") OR TITLE-ABS-KEY ("*Ethnobotany*") OR TITLE-ABS-KEY (*Phenology*) OR TITLE-ABS-KEY ("*Medicinal applications*") OR TITLE-ABS-KEY ("*Ethnopharmacology*")OR TITLE-ABS-KEY ("*Ethnomedicine*")). Exclusion on the basis of language is not applied due to the small size of data in our study. The retrieved data was saved as [.CVS] file and analyzed using the VOSviewer software in order to gather information on keywords, journals, and cooperation among countries.

Results and Discussion

Literature based screening

Ethnobotanical applications of Saussurea genus

Ethnobotany is the study of utilization of native plants by people of a particular culture and region, and includes traditional knowledge about indigenous cultures, the surrounding plant diversity (Kunwar *et al.* 2021). The *Saussurea* genus has remarkable ethnobotanical applications in Ayurvedic, Siddha, Unani, Tibetan (Amchi), and Chinese traditional medicinal practices (Kumar & Pundir 2022). For a very long time, several rural communities residing in Himalayan region, utilized *Saussurea* species for the treatment against several conditions associated with respiratory disorders, gastrointestinal disorders, skin disorders, dental disorders, excretory disorders, paralysis, cardiac disorders, snake bite and reproductive disorders (Table 1). Species like *S. costus, S. heteromalla*, and *S. obvallata* are used to treat skin disorders such as leukoderma (Batool *et al.* 2019; Butola & Samant 2010). Several respiratory disorders such as bronchitis, lung infections, asthma, pneumonia are treated by *S. costus, S. obvallata, S. bracteata, S. gnaphalodes,* and *S. gossypiphora* (Ballabh & Caurasia 2007; Butola & Samant 2010; Gupta *et al.* 2013; Kandari *et al.* 2012). The species *S. auriculata* and *S. gossypiphora* promotes blood circulation, and *S. gnaphalodes*, *S. graminifolia*, and *S. simpsoniana* have been reported to be used to purify blood (Butola & Samant 2010; Rajbhandari *et al.* 2009; Tamang *et al.* 2017). In China, Naxi/ Nakshi people use the plant of *S. leucoma* as a source of healthy food (Zhang *et al.* 2019). The most prevalent species, *S. costus,* has been significantly used as medicine in India, Japan, Korea and China. The plant is reported to treat various ailments ranging from common ailments such as cold, cough, flatulence, tooth ache, earache to complicated disorders related to kidney, lungs, heart and brain. The roots are strong source of aromatic oils and widely used as perfume (Ahmad *et al.* 2019; Ballabh & Chaurasia 2007; Butola & Samant 2010; Gairola *et al.* 2014; Houghton & Osibogun 1993; Kandari *et al.* 2012; Kumar & Pundir 2022; Kayani *et al.* 2015; Shah 1982; Yang *et al.* 2017). Species such as *S. obvallata* and *S. gossypiphora* have their own religious significance as they are offered to the temples as religious offerings (Budha-Magar *et al.* 2020; Mishra *et al.* 2021; Pant & Semwal 2013; Semwal *et al.* 2019). Detailed description of traditional applications of *Saussurea* genus is presented in Table 1.

Flower initiation

Most of *Saussurea* species are polycarpic, perennial herbs with a height range of 10 cm to 3 m. floral development in *Saussurea* species is described by Raab-Straube in 2017, sterile leaf rosette development takes place after germination. Followed by the development of flowering stem simultaneously with the secondary leaf rosette caused by branching of the main axis near the ground level. The apical meristem cell of previous year's sterile leaf give rise to further flowering stem. After fruiting, the apical meristem of the flowering stem is consumed. In the heads of *Saussurea*, flowering starts in the outermost row of florets and proceeds towards the central inner ones. The style branches remain open for several days, many-flowered capitula can extend flowering to 14 days. Within a synflorescence, the central or terminal capitulum matures first, gradually followed by the outer or lower ones, so that the flowering period of one plant can last up to one month or more (Raab-Straube 2017).

Floral structure

Flowers of *Saussurea* are clustered in capitula, a distinguishing trait of the Compositae. Capitulum consists of many florets and phyllaries, usually surrounded by dense white woolly hairs. The wool is densest in the high-altitude species, and aids in the thermoregulation of the flowers, minimizing frost damage at night and also preventing ultraviolet light damage from the intense high-altitude sunlight (Parmar *et al.* 2012). The plants of this genus develop a simple sterile leaf rosette after germination (Tsukaya *et al.* 2002). Genus *Saussurea* displays a variety of morphological structures such as woolly trichomes (snow rabbits), in *S*. subg. *Eriocoryne*, and leafy bracts, (snow lotuses) in S. subg. *Amphilaena* (Shi *et al.* 2011). A broad variety of inflorescence types (corymbiform, hemispheric, paniculiform, or racemiform synflorescence, sessile or pedunculate) are observed in *Saussurea*, and the number of capitula per individual vary from one to several hundred.

Table 1. Ethnomedicinal applications of few species of *Saussurea* genus.

Species	Parts used	Ethnobotanical Applications	Country	References
S. auriculata (spreng. ex DC.) Schi.Bip.	Leaf, roots, whole plant	Laxative, venereal diseases, blood circulation	India, Nepal, Pakistan	(Arshad *et al.* 2021; Butola & Samant 2010; Rajbhandari *et al.* 2009)
S. bracteate Decne.	Roots	Boils, headache, cough, fever, lung infection, cold	India	(Butola & Samant 2010; Ballabh & Chaurasia 2007)
S. ceratocarpa Decne.	Whole plant	Headache, lumbar pain, menorrhea, renal pain	India	(Butola & Samant 2010)
S. costus (Falc.) Lipsch.	Roots	Dysentery, skin disorder, cold, cough, bronchitis, rheumatism, cholera, flatulence, jaundice, leprosy, phlegm, tooth and earache, stomachache, wound healing, ulcer, spice, perfume, diuretic, antiseptic, aphrodisiac, insecticide, pesticide, anthelmintic, bronchial asthma, heart problems, headache, hysteria, menstrual irregularities, scabies, toothache, snakebite.	India, China, Japan, Korea	(Butola & Samant 2010; Kumar & Pundir 2022; Shah 1982; Yang *et al.* 2017; Ballabh & Chaurasia, 2007; Gairola *et al.* 2014; Houghton & Osibogun 1993; Kayani *et al.* 2015)
S. fastuosa (Decne). Sch.Bip.	Aerial parts	Wound healing	Nepal	(Rajbhandari *et al.* 2009)
S. glacialis Herder.	Flower, leaf	Liver disorders, throat ache, heart ailments, mental disorders	India, Tibet	(Butola & Samant 2010)
S. gnaphalodes (Royle) Schi. Bip.	Aerial parts	Kidney disorders, urinary disorders, cough, cold, backache, pulmonary disorders, blood purification.	India	(Butola & Samant 2010; Ballabh *et al.* 2008)
S. gossypiphora D. Don.	Roots,	Religious offering, hysteria, gynecological disorders, menstrual disorders, perfume, asthma pneumonia, stomach disorders, wound healing, headache, blood circulation	India	(Butola & Samant 2010; Mishra *et al.* 2021; Samant & Shreekar 2003; Tamang *et al.* 2017; Wali *et al.* 2019)
S. graminifolia Wall. ex. DC.	Whole plant	Cough, blood purification, increase menstrual flow, menstrual cramps due to renal disorders.	India, Tibet	(Butola & Samant 2010)
S. heteromalla (D. Don) Hand.-MazzD.	Roots, seed, leaf	Leukoderma skin disease, wound healing, fever, colic pain, horse-bite disease	India, Pakistan	(Batool *et al.* 2019; Butola & Samant 2010; Malik *et al.* 2015)
S. involucrata (Kar. et Kir.) Sch.Bip.	Aerial parts	Rheumatoid arthritis, infertility, inflammation, ornamental	China, Kazakhstan, Magnolia	(Chik *et al.* 2015; Kumar & Pundir 2022; Chen & Wang 2018)
S. jacea (KL) C.B.Clarke	Whole plant	Urinary disorders	India	(Ballabh *et al.* 2008)
S. leucoma Diels	Whole plant	Food source	China	(Zhang *et al.* 2016)
S. medusa Maxim.	Whole plant	Arthritis, weakness, headache, high blood pressure, menstrual disorders	China, Tibet	(Butola & Samant 2010)
S. obvallata (DC.) Edgew.	Roots, leaves, flower, buds	Paralysis, wounds healing, leukoderma, fever, cold, cough, cardiac disorders, hydrocele, reproductive disorders,	Tibet, India, Pakistan, Nepal	(Butola & Samant 2010; Kumar & Pundir 2022; Mishra *et al.* 2021; Semwal *et al.* 2020; Bano *et*

		religious purpose, cerebral ischemia, conjunctivitis, headache, rheumatism, intestinal ailments, urinary track problems, insect repellent, cardiac disorders, mental disorders		*al.* 2014; Bisht *et al.* 2013; Budha-Magar *et al.* 2021; Dhar *et al.* 2002; Gupta *et al.* 2013; Kala, 2005; Kandari *et al.* 2012; Kumar *et al.* 2009; Kumar *et al.* 2011; Malik *et al.* 2015; Negi *et al.* 2006; Phondani *et al.* 2010; Pant & Semwal 2013; Sharma & Singh 2018; Sharma & Samant 2014; Singh & Rawat 2011; Tsarong 1986; Wanga *et al.* 2010)
S. roylei (DC.) Schi. Bip.	Whole plant	Wound healing, inflammation, excessive bleeding, joint ache	Tibet, India	(Butola & Samant 2010)
S. simpsoniana (Field and Guard) Lipsch.	Roots	Snakebite, period cramps, plague, insecticide, cough, cold, blood purification	India	(Butola & Samant 2010)
S. stella Maxim.	Whole plant	Toxin, fever, rheumatic pain, bone fractures	Tibet	(Chen *et al.* 2018)
S. taraxacifolia Wall. ex. DC.	Leaves	Ulcers and cold	Tibet	(Butola & Samant 2010)

The simplest type of inflorescence is a single capitulum that can be found at the end of a stem or in the middle of a rosette of leaves. One such type is prevalent across many species, including *S. bracteata, S. hookeri, S. linearifolia, S. longifolia, S. muliensis, S. pilinophylla, S. polycolea, S. pubifolia, S. sunhangii*. A capitulum consists of three main structures that are involucre, receptacle, and florets. The involucre is composed of multiple rows, lacks spines, and occasionally has a mucronate or membrane appendage that is green or purplish in color. Receptacle has short scales and is generally covered in thick, subulate bristles, and sometimes reduced to minute papillae and naked receptacle condition which is observed in several species such as *S. dorogostaiskii* and *S. involucrata*.

Florets are bisexual, having tubular morphology consisting of narrow tube campanulate limbs terminating in five corolla lobes. Commonly observed flower color in *Saussurea* is purple, however pink and white flowers are also observed in this genus (Chen 2016). As is generally the case in the Compositae, stamens form an anther tube in which the pollen is released. The species of *Saussurea* show no exception to this general pattern of stamen morphology and anther tube has a fertile part, consisting of two linear thecae per anther, and two sterile appendages, a basal one and an apical one. The basal anther appendages are elongated and may be sagitted, entire, lacinated, or woolly (Häffner 2000). The five stamens with free filaments are imbedded in the corolla tube and the anthers are dithecous, forming a ring around style. Gynoecium consists of two fused carpels, two stigmas. Style branches are usually carduoid type and divergent at the end with inferior ovary. Nectar is present in the tube of the flower. Achene is the fruit developed in *Saussurea*. It is normally glabrous, occasionally glandular, pubescent or papillose, with an inconspicuous apical rim or a developed crenulate or denticulate crown. Homomorphic or heteromorphic pappus is found, with single or multiple rows of bristles (Shi *et al.* 2011).

Anthesis

In *Saussurea* species anthesis begins in the early morning simultaneously in several florets, with presentation of white pollen at the tip of the anther tubes. On the following day, the style finishes its growth through the anther tube, and the diverging style branches are expanded, presenting pollen on their abaxial surface. At the same time, the next inner row of florets is presenting pollen at the tips of their anther tubes (Raab-Straube 2017).

Pollination

For reproduction in angiosperms pollination is an essential stage, and pollinators are required for genes transfer within and among populations of wild plant species (González-Varo *et al.* 2013). The flowering period in *Saussurea* can last up to more than a month. The flowers are tubular and bisexual, the corolla is mostly violet, often bluish or reddish, sometimes brownish, blackish or pink, white is also rarely observed, anthers are dark purple, dark blue, or black. Anthers tails sagitted, entire, lacerated, or lanate. Achene is smooth or transversely wrinkled, mostly glabrous, rarely with glands, papillae, or hair. Apical margin is inconspicuous, entire or sometimes forming a short crown (Shi *et al.* 2011).

Pollination in the *Saussurea* genus is predominated by insects. In trans-Himalayan region, bumblebees are reported to be main pollinators of the different species of *Saussurea* genus including *S. jacea*, *S. lappa*, *S. albescens, S. auriculata, S. fastuosa* along with other species of *Butterflies, Diptera, Aphids* and *Coccinellid* beetles are labeled as the accidental pollinators (Chandra *et al.* 2019). Features such as abundant hairs or muscles generating heat made the bumblebees the most efficient pollinators in alpine ecosystems (Bingham & Ranker 2000; Heinrich 1975; Osborne *et al.* 1999). Law *et al.*, 2010 investigated the reproductive biology, pollination biology and population dynamics of *S. laniceps* and *S. medusa* and observed that both species are pollinated by two bumble bees *i.e. Bombus rufofasticatus* Smith and *B. festivus* species and flowers are unable to produce seed in the absence of pollinators (Law *et al.* 2010). The reproductive biology of *S. obvallata* has been investigated in India and the study revealed that this species is naturally self-compatible and preferred for mixed mating (Semwal *et al.* 2019).

Breeding system

Breeding system is the means of transfer of genes from one generation to the next through sexual reproduction (Shivanna & Tandon 2014). Breeding systems are fundamental and an important part of plant biology, which influence many aspects of their biology, such as genetic diversity and genome evolution (Charlesworth 2006). Limited studies have been conducted in *Saussurea* species, indicating the condition called self-incompatibility, most prevalent among *Saussurea* species. Species such as *S. weberi, S. laniceps, S. medusa,* and *S. lappa,* were found to be self in-compatible with an exception of *Saussurea obvallata* which was recorded to be self-compatible species with facultative xenogamy breeding system (Table 2) (Abbott *et al.* 2017; Law *et al.* 2010; Mohi-Ud-Din *et al.* 2006; Semwal *et al.* 2019).

Table 2. Compatibility and breeding system of some *Saussurea* species.

Species	Compatibility	Breeding system	References
Saussurea weberi	Self-incompatible	Obligate-outcrossing	(Abbott Jr, 1998)
Saussurea laniceps	Self-incompatible	Outcrossing	(Law *et al.* 2010)
Saussurea medusa	Self-incompatible	Outcrossing	(Law *et al.* 2010)
Saussurea lappa	Self-incompatible	Outcrossing	(Mohi-Ud-Din *et al.* 2006)
Saussurea obvallata	Self-compatible	Facultative xenogamy	(Semwal *et al.* 2019)

Fruits

The members of *Saussurea* produce a type of fruit called an achene. In *Saussurea* species achene is obovoid, cylindrical to tetragonal in shape with a pericarp. In *Saussurea*, the pericarp surface is normally smooth and glabrous, but occasionally transversely wrinkled, sometimes glandular, papillose or rarely hairy. In *S.* subg. Amphilaena, only *S. linearifolia* has very small papillose trichomes near the apical rim of the achene; all other species have entirely glabrous achenes. This kind of achene trichomes also occurs occasionally in different other groups of *Saussurea,* especially in *S.* subg. Eriocoryne, *e.g.,* in *S. medusa* (Fujikawa 2010). The color of ripe achene ranges from straw-colored to black (Bremer 1994; Häffner 2000). The pappus is found in two rows and is heteromorphic. Many traits such as pappus form, anatomical and other morphological features of achene played a significant role in taxonomic classification at the tribal level of Asteraceae family (Cron *et al.* 1993; Kasana *et al.* 2020; Roque & Funk 2013; Singh and Pandey 1984; Stebbins 1953; Tomb 1977; Zarembo and Boyko 2008; Zhang *et al.* 2013; Shi *et al.* 2011). Scan electron microscopy characterization of 23 Indian *Saussurea* spp. provided key for the identification of species studied, which is based on the micromorphological characters of achene (Saklani *et al.* 2000). In Korea, achene morphology of 23 *Saussurea* spp. investigated, and results highlighted that record of achene anatomical characteristics and micromorphology proved to be a useful tool for taxonomic reassessment (Ghimire *et al.* 2016). Generally, the outer and inner pappus bristles fall off at the time of the achene maturity (*S.* subg. Amphilaena) except in some species (*S. medusa*), which is an adaptation to wind dispersal. Achene lacks structures such as claiosomes. prickles, hairs or glutinosa glands that aid in other methods of dispersal preventing long distance seed dispersal (atelochory dispersal) (Raab-Straube 2017).

Bibliometric analysis

Annual growth of publication

The 71 publications were retrieved from the Scopus database, out of which 68 were in English, 2 in Chinese and 1 was written in French language. The publication trend is represented in Fig. 1, and this publication trend can be divided into two distinct periods. First ten years (2000-2010) not more than 5 publications have been recorded which represents the initial stage of growth of publications in this field. The next decade represents the steady growth period particularly between the years 2017 and 2022. The maximum number of articles (n=9) were published during the year 2020.

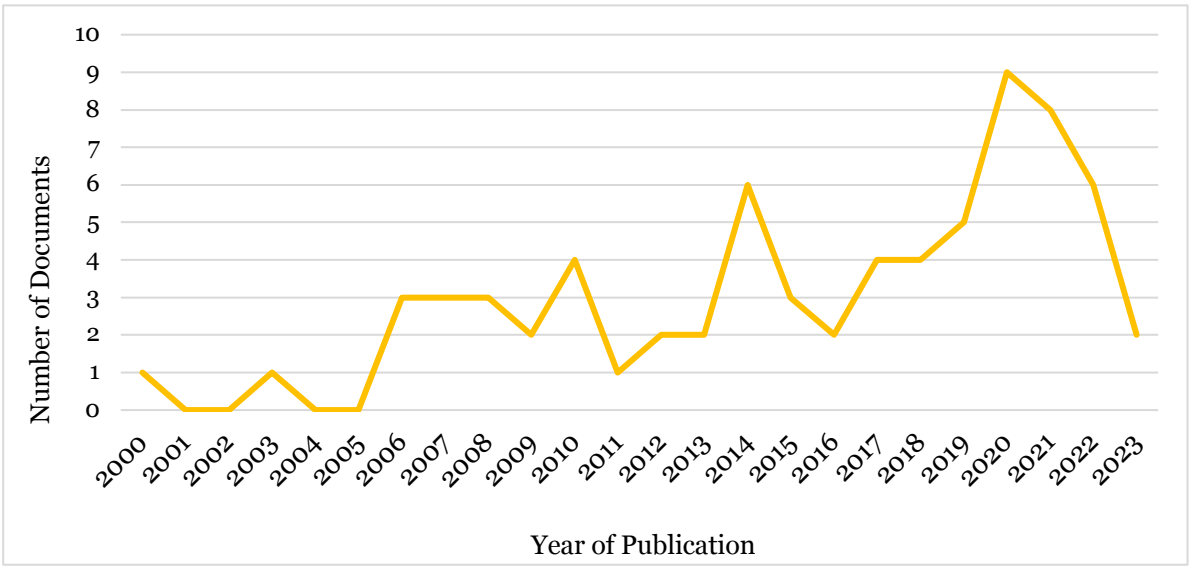

Figure 1. Publication trends per year

Countries of publications

Table 3 lists top ten contributing countries in descending order of the total number of documents that were published. According to the retrieved published literature from the Scopus database, India is the country with the maximum number of publications (n=29) out of the 71 studies, other countries have also contributed in compiling the data China (n=16) occupied the second position followed by Pakistan (n=13), and Germany (n=4). In all, only 30 countries have participated in the research related on this genus.

Table 3. Contributing countries ranked by the total number of the Publications.

S. No.	Country	Documents	Citations
1	India	29	1073
2	China	16	250
3	Pakistan	13	370
4	Germany	4	15
5	United Kingdom	3	16
6	Georgia	2	1
7	Italy	2	66
8	Nepal	2	173
9	Thailand	2	34
10	Austria	1	6

Journal of publications

The "*Journal of Ethnopharmacology*" had the highest number of published articles (n=15) followed by "*Plos One*" (n=3) and "*Journal of Ethnobiology and Ethnomedicine*" (n=3) but in terms of number of citations "*Journal of Ethnopharmacology*" still occupied the first ranking with maximum frequency (n=1166) followed by "*Journal of Ethnobiology and Ethnomedicine*" (n=108) and "*Journal of Herbal Medicine*" (n=71). The "*Journal of Ethnopharmacology* "had the highest impact factor (5.195) as per the Journal Citation Report 2022. Top 10 productive journals and related information are listed in Table 4.

Table 4. List of top 10 productive Journals.

SOURCE	QUARTILE	DOCUMENTS	CITATIONS	AVERAGE CITATIONS	IF*
Journal of Ethnopharmacology	Q1	15	1166	233.2	5.195
Plos One	Q2	3	57	19	3.752
Journal of Ethnobiology and Ethnomedicine	Q2	3	108	36	3.404
Journal of Herbal Medicine	Q3	3	71	23.6	2.542
Journal of Applied Research on Medicinal and Aromatic Plants	Q1	2	13	6.5	3.945
International Journal of Pharma and Bio Sciences	-	2	26	13	-
European Journal of Integrative Medicine	Q4	2	37	18.5	1.813
Saudi Pharmaceutical Journal	Q2	2	45	22.5	4.562
Plant Cell Reports	Q1	1	71	71	4.964
Current Science	Q3	1	40	40	1.169

*Journal Citation Report 2022

Co-authorship of countries

The co-operation between countries is represented in Fig. 2, the node size indicates number of published documents and line thickness indicates the strength link, larger the node, the greater the number of citations of author, and the thicker the line, the greater the link strength. Network visualization of co-authorship of countries is divided into three different clusters, cluster 1 (green) representing collaboration between countries China, Nepal, Macau Austria, and Czech Republic. Clusters 2 (pink) represents collaboration of countries like India, UK, Germany, Canada, Qatar, Georgia, Mongolia, South African and Thailand were observed, while three cooperating countries including the USA, Pakistan, and Italy are in cluster 3 (blue).

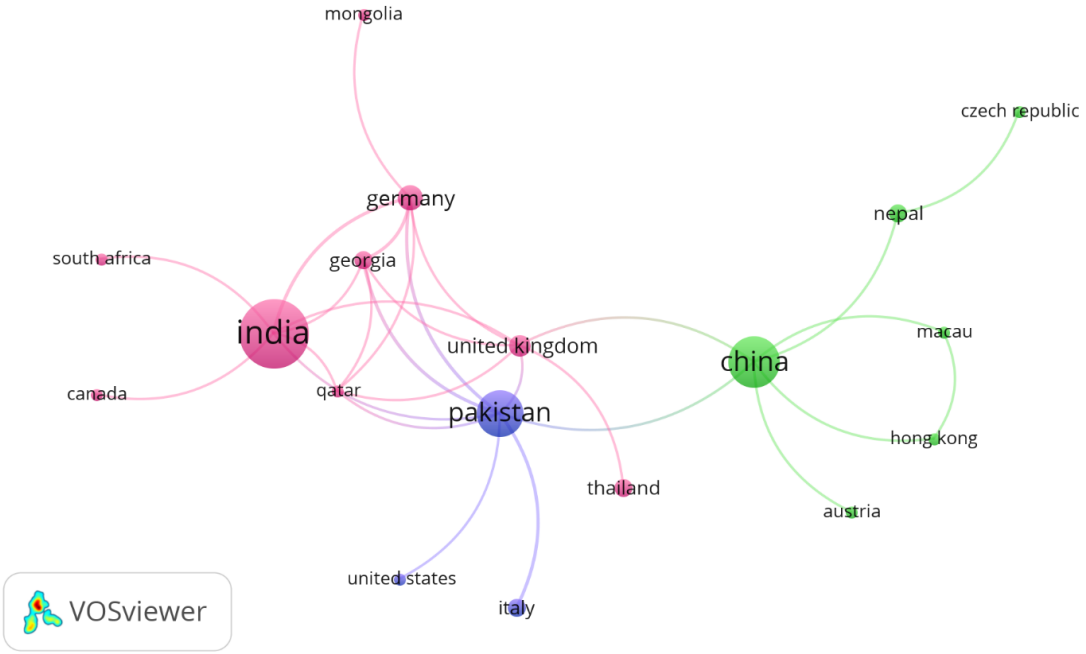

Figure 2. Network visualization of co-authorship between the Countries.

Keywords analysis

Figure 3 represents the density visualization of keywords in this font size and yellow color positively correlated with the frequency of occurrence of keywords. Our analysis showed that “Medicinal plants (n=17)”, “Ethnopharmacology (n=9)”, “Ethnobotany (n=7)”, “Conservation (n=6)” and “Seed germination (n=5)” were the top five Keyword words with the highest frequency. The Density visualization reveals the majority of the research fields in which scientists are most interested and the topics that are frequently investigated. The overlay visualization network (Fig 4) indicates the average year of occurrence of keywords suggestion the trend of keywords used over the years. Figure 4 shows the size and color of the node, respectively, indicate the frequency of the keyword and the average year of publication. According to our observations based on the occurrence of keywords, the genus *Saussurea* contains species that are significant from an ethnobotanical perspective and have a significant risk of being overused for their therapeutic applications and there is a lack of research on conservation from the perspective of reproductive biology has been clearly observed.

Conclusion

On the basis of literature review and bibliometric analysis, it can be concluded that the genus *Saussurea* is a group of an important, annual-flowering, evergreen herbs which are mainly pollinated by bumblebees because they are well adapted for covering long distances in the extreme environment of alpine regions. Most studies conducted for evaluation of the breeding system showed that the members of this genus showed partially self-incompatibility. Self-incompatibility is the most common method used by plants for the prevention of inbreeding and promote outcrossing. Outcrossing system is the basis of genetic diversity which ultimately leads to the evolution of species and also explain the reason behind the high species diversity in *Saussurea* genus. Climate change's effects have been discussed several times in this genus, with evidence that changes in various biochemical processes can alter plant morphology and phenological events like the flowering period (this is the most important stage), and can have a big impact on a species' population dynamics. Many species of this genus have been pushed into the "threatened" category due to their medicinal virtues, high demand, and effect of climate change. Apart from this, this study has demonstrated the ethnobotanical applications of a few species within the genus; it also widely paves the way for the identification of yet-undiscovered ethnobotanical uses for other species, and the botanists/ ethno-botanists would greatly benefit from this. Currently there is a huge requirement for investigation of reproductive biology of such threatened species belonging to this genus, which can provide information of the basic requirements and conditions for re-establishment, propagation and restoration of the threatened population in their natural and artificial habitats.

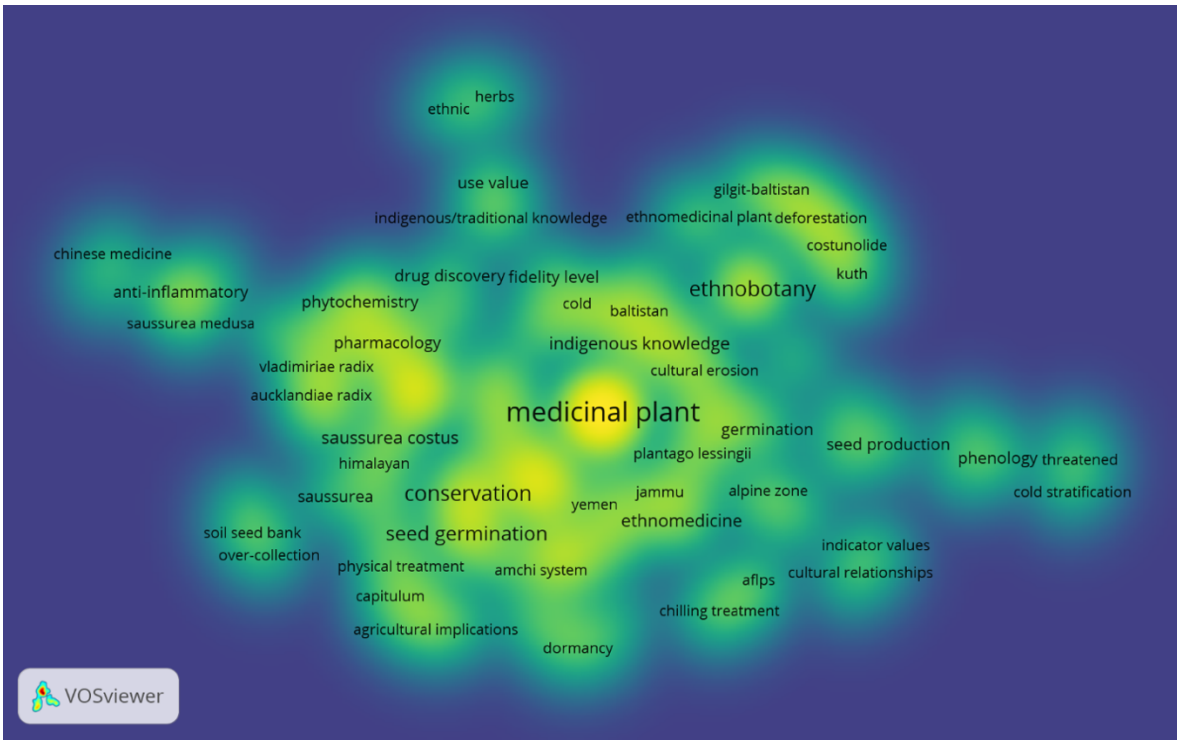

Figure 3. Density visualization of co-occurrence of keywords. Font size and background color (blue<green<yellow), represents the frequency of occurrence of keywords. Keywords with highest frequency have largest font size and yellow background color. The space between each of the keywords demonstrate the association of these research topics.

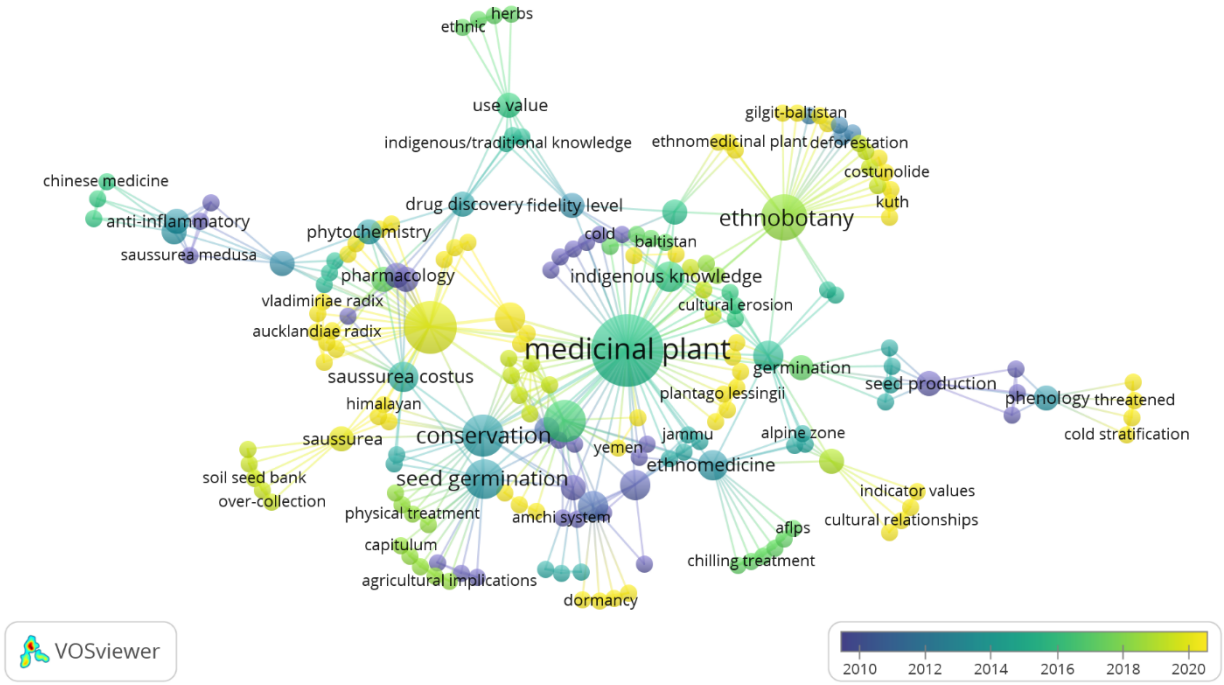

Figure 4. Overlay visualization of co-occurrence of keywords. The node size represents the frequency of occurrence of keyword and color of the node , indicates the average year in which keywords are generally used.

Future prospects and limitations

Considering that little studies have been done on the reproductive biology of the *Saussurea* genus regardless of the fact that a number of species are classified as threatened, there is a lot of scope for research in the future. For the bibliometric analysis, the use of a single database is a significant drawback in our bibliometric analysis, even if Scopus database provided considerably more extensive data. The published literature on plant reproductive biology was not entirely gathered because databases like Web of Sciences, Dimension, PubMed, etc. were excluded. Data generated from various databases may be used in future follow-up research to compare with the findings provided in this study.

Declarations

Ethical approval and consent to participate: Not applicable

Consent for publication: Not applicable

Availability of data and materials: All data generated during this study has been included in this manuscript**.**

Competing interests: The authors declared that they have no conflict of interest.

Funding: Not applicable

Author's contributions: Prabhakar Semwal: Project administration, Concept, Review and edit; Pooja Singh and Baby Gargi: data collection, draft preparation, and analysis; VLT: Review and edits, AT: Review and edits

Acknowledgements

Pooja Singh acknowledges the Graphic Era Deemed to be University for PhD fellowship.

Literature cited

Abbott RE, Doak DF, DeMarche ML. 2017. Portfolio effects, climate change, and the persistence of small populations: analyses on the rare plant *Saussurea weberi*. Ecology 98:1071-1081.

Arshad N, Ishtiaq S, Jahangir M, Akbar S. 2021. Evaluation of antioxidant, antimicrobial and anticancer activities of compounds reported *Saussurea hypoleuca* Spreng. roots. Pakistan Journal of Pharmaceutical Sciences 34:819-824.

Bakhtaulova A, Kenzhekhanova ZS, Karasholakova L. 2022. Distribution of *Saussurea* species on the territory of Zhongar-Alatau State National Natural Park. IOP Conference Series: Earth and Environmental Science, vol. 1112. IOP Publishing, p 012118.

Ballabh B, Chaurasia O, Ahmed Z, Singh SB. 2008. Traditional medicinal plants of cold desert Ladakh—used against kidney and urinary disorders. Journal of Ethnopharmacology 118:331-339.

Ballabh B, Chaurasia O. 2007. Traditional medicinal plants of cold desert Ladakh—Used in treatment of cold, cough and fever. Journal of Ethnopharmacology 112:341-349.

Bano A, Ahmad M, Zafar M, Sultana S, Rashid S, Khan MA. 2014. Ethnomedicinal knowledge of the most commonly used plants from Deosai plateau, Western Himalayas, Gilgit Baltistan, Pakistan. Journal of Ethnopharmacology 155:1046–52. doi: 10.1016/j.jep.2014.05.045.

Barres L, Sanmartín I, Anderson CL, Susanna A, Buerki S, Galbany-Casals M, Vilatersana R. 2013. Reconstructing the evolution and biogeographic history of tribe Cardueae (*Compositae*). American Journal of Botany 100:867-882.

Batool A, Miana GA, Muddassir M, Khan MA, Zafar S. 2019. In vitro cytotoxic, antioxidant, antibacterial and antifungal activity of *Saussurea heteromalla* indigenous to Pakistan. Pakistan Journal of Pharmaceutical Sciences 32:2771-2777.

Bingham RA, Ranker TA. 2000. Genetic diversity in alpine and foothill populations of *Campanula rotundifolia* (Campanulaceae). International Journal of Plant Sciences 161:403-411.

Bisht VK, Kandari LS, Negi JS, Bhandari AK, Sundriyal RC. 2013. Traditional use of medicinal plants in district Chamoli, Uttarakhand, India. Journal of Medicinal Plants Research 7:918–29. doi: 10.5897/JMPR13.2599.

Bremer K. 1994. Asteraceae: Cladistics and Classification, Timber Press, Portland.

Budha-Magar S, Sher H, Kunwar RM, Bussmann RW, Ur Rahman I. 2021. *Saussurea albescens* (DC.) Sch.; *Saussurea lappa* (Decne.) Sch. Bip; *Saussurea obvallata* (DC.) Sch. Bip. A steraceae. Ethnobotany of the Himalayas. doi: 10.1007/978-3-030-45597-2_217-1.

Butola JS, Samant SS. 2010. *Saussurea* species in Indian Himalayan Region: diversity, distribution and indigenous uses. International Journal of Plant Biology 1:e9.

Chandra K, Sidhu A, Raghunathan C, Sharma I, Kubendran T. 2019. Fauna of Indian trans-Himalaya: an overview. Faunal Diversity of Biogeographic Zones: Indian Trans-Himalaya: 1-225:1-22.

Charlesworth D. 2006. Evolution of plant breeding systems. Current Biology 16:R726-R735.

Chen C, Wei Y, Tian Y, Qiu X. 2018. Research progress on *Saussurea* Tibetan Medicine-Taking *Saussurea stella* Maxim. for example. Agricultural Biotechnology 7:232-237.

Chen J, Wang YJ. 2018. New *Saussurea* (Asteraceae) species from Bogeda Mountain, eastern Tianshan, China, and inference of its evolutionary history and medical usage. PLoS One 13:e0199416.

Chen Y. 2016. Asteraceae II (*Saussurea*): Part 2: Flora of the Pan-Himalaya. Institute of Botany, Chinese Academy of Science.

Chik W-I, Zhu L, Fan L-L, Yi T, Zhu G-Y, Gou X-J, Tang Y-N, Xu J, Yeung W-P, Zhao Z-Z. 2015. *Saussurea involucrata*: A review of the botany, phytochemistry and ethnopharmacology of a rare traditional herbal medicine. Journal of Ethnopharmacology 172:44-60.

Cron GV, Robbertse PJ, Vincent PL. 1993. The anatomy of the cypselae of species of *Cineraria* L.(Asteraceae—Senecioneae) and its taxonomic significance. Botanical Journal of the Linnean Society 112:319-334.

Dentant C. 2018. The highest vascular plants on Earth. Alpine Botany 128:97-106.

Dhar U, Manjkhola S, Joshi M, Bhatt A, Bisht AK, Joshi M. 2022. Current status and future strategy for development of medicinal plants sector in Uttaranchal, India. Current Science 83:956–964.

Dickoré W. 2001. Observations on some *Saussurea* (Compositae–Cardueae) of W Kunlun, Karakorum and W Himalaya. Edinburgh Journal of Botany 58:15-29.

Fujikawa K. 2010. Taxonomic study of the genus *Saussurea* section Eriocoryne (Asteraceae) in the Himalayas. Makinoa N.S. 8:25-80.

Gailite A, Rungis D. 2012. An initial investigation of the taxonomic status of *Saussurea esthonica* Baer ex Rupr. utilising DNA markers and sequencing. Plant Systematics and Evolution 298:913-919.

Gairola S, Sharma J, Singh Bedi Y. 2014. A cross-cultural analysis of Jammu, Kashmir and Ladakh (India) medicinal plant use. Journal of Ethnopharmacology 155:925-986.

Ghimire B, Jeong MJ, Lee KM, Heo K, Lee CH, Suh GU. 2016. Achene morphology of *Saussurea* species (Asteraceae, Cardueae) in Korea and its systematic implications. Botanical Journal of the Linnean Society 181:692-710.

González-Varo JP, Biesmeijer JC, Bommarco R, Potts SG, Schweiger O, Smith HG, Steffan-Dewenter I, Szentgyörgyi H, Woyciechowski M, Vilà M. 2013. Combined effects of global change pressures on animal-mediated pollination. Trends in Ecology & Evolution 28:524-530.

Häffner E. 2000. On the phylogeny of the subtribe Carduinae (tribe Cardueae, Compositae). Berlin: Botanic Garden and Botanical Museum Berlin, Freie Universität Berlin. – Englera 21. doi: 10.2307/3776757.

Hajra PK, Rao, RR, Singh DK, Uniyal BP. 1995. Flora of India. Botanical Survey of India, Calcutta, India.

Heinrich B. 1975. Thermoregulation in bumblebees. Journal of Comparative Physiology 96:155-166.

Houghton PJ, Osibogun IM. 1993. Flowering plants used against snakebite. Journal of Ethnopharmacology 39:1–29.

Hussain MA, Tyub S, Kamili AN. 2020. Ecology, distribution mapping and conservation implications of four critically endangered endemic plants of Kashmir Himalaya. Saudi Journal of Biological Sciences, 27(9):2380–2389. doi: 10.1016/j.sjbs.2020.05.006.

Kala CP. 2005. Indigenous uses, population density, and conservation of threatened medicinal plants in protected areas of the Indian Himalayas. Conservation Biology, 19:368-378.

Kandari LS, Phondani PC, Payal KC, Rao KS, Maikhuri RK. 2012. Ethnobotanical study towards conservation of medicinal and aromatic plants in upper catchments of Dhauli Ganga in the central Himalaya. Journal of Mountain Science 9:286-296.

Kapoor L, Usha S. 2020. Biodiversity and Conservation: India's Panoramic View. In: Roy N, Roychoudhury S, Nautiyal S, Agarwal S, Baksi S. (Eds) Socio-economic and Eco-biological Dimensions in Resource use and Conservation. Environmental Science and Engineering. Springer, Cham. doi: 10.1007/978-3-030-32463-6_16.

Kasana S, Dwivedi M, Uniyal P, Pandey A. 2020. An updated circumscription of *Saussurea* (Cardueae, Asteraceae) and allied genera based on morphological and molecular data. Phytotaxa 450:173–187.

Kayani S, Ahmad M, Sultana S, Khan Shinwari ZM, Yaseen G, Hussain M, Bibi T. 2015. Ethnobotany of medicinal plants among the communities of alpine and sub-alpine regions of Pakistan. Journal of Ethnopharmacology 164:186-202.

Klein R. 2004. Phytoecdysteroids, Journal of American Herbalists Guild 18–28.

Kumar G, Gupta S, Murugan M, Bala Singh S. 2009. Ethnobotanical studies of Nubra Valley-a cold arid zone of Himalaya. Ethnobotanical Leaflets 2009:9.

Kumar GP, Kumar R, Chaurasia OP, Singh SB. 2011. Current status and potential prospects of medicinal plant sector in trans-Himalayan Ladakh. Journal of Medicinal Plants Research 5:2929-2940.

Kumar J, Pundir M. 2022. Phytochemistry and pharmacology of *Saussurea* genus (*Saussurea lappa, Saussurea costus, Saussurea obvallata, Saussurea involucrata*). Materials Today: Proceedings 56:1173-1181.

Kunwar RM, Sher H, Bussmann RW. 2021. Ethnobotany of the Himalayas. Springer International Publishing: Cham. doi: 10.1007/978-3-030-57408-6.

Law W, Salick J, Knight TM. 2010. The effects of pollen limitation on population dynamics of snow lotus (*Saussurea medusa* and *S. laniceps*, Asteraceae): threatened Tibetan medicinal plants of the eastern Himalayas. Plant Ecology 210:343-357.

Malik ZA, Bhat JA, Ballabha R, Bussmann RW, Bhatt AB. 2015. Ethnomedicinal plants traditionally used in health care practices by inhabitants of Western Himalaya. Journal of Ethnopharmacology 172:133-144.

Mishra AP, Saklani S, Parcha V, Nigam M, Coutinho HD. 2021. Antibacterial activity and phytochemical characterisation of *Saussurea gossypiphora* D. Don. Archives of Microbiology 203:5055-5065.

Mohi-Ud-Din GG, Dr.Irshad A N, Wafai BA. 2006. Mating and pollination mechanisms in *Saussurea costus* (falc.) lipsch. - A critically endangered medicinal plant of N.W. Himalaya. Phytomorphology 56:41-46.

Negi CS, Koranga PR, Ghinga HS. 2006. Yar tsa Gumba (*Cordyceps sinensis*): a call for its sustainable exploitation. The International Journal of Sustainable Development and World Ecology 13:165-172.

Osborne J, Clark S, Morris R, Williams I, Riley J, Smith A, Reynolds D, Edwards A. 1999. A landscape-scale study of bumble bee foraging range and constancy, using harmonic radar. Journal of Applied Ecology 36:519-533.

Pant M, Semwal P. 2013. Brahma Kamal – the spiritually revered, scientifically ignored medicinal plant. Current Science 104:685-686.

Parmar M, Negi LS, Ramola S. 2012. Seeds germination and seedlings analysis of *Saussurea costus* Royle Ex Benth. In high and low altitudinal villages of district Uttarkashi (Uttarakhand). Seeds 2:25-30.

Phondani PC, Maikhuri RK, Rawat LS, Farooquee NA, Kala CP, Vishvakarma SCR, Rao KS, Saxena KG. 2010. Ethnobotanical uses of plants among the Bhotiya tribal communities of Niti Valley in central Himalaya, India. Ethnobotany Research and Applications 8:233-244.

Raab-Straube Ev. 2003. Phylogenetic relationships in *Saussurea* (Compositae, Cardueae) sensu lato, inferred from morphological, ITS and trnL-trnF sequence data, with a synopsis of *Himalaiella* gen. nov., *Lipschitziella* and *Frolovia.* Willdenowia Bd. 33, H.2:379-402.

Raab-Straube Ev. 2017. Taxonomic revision of *Saussurea* subgenus Amphilaena (Compositae, Cardueae). – Berlin: Botanic Garden and Botanical Museum Berlin, Freie Universität Berlin. – Englera 34.

Rajbhandari M, Mentel R, Jha PK, Chaudhary RP, Bhattarai S, Gewali MB, Karmacharya N, Hipper M, Lindequist U. 2009. Antiviral activity of some plants used in Nepalese traditional medicine 6:517-522. doi: 10.1093/ecam/nem156.

Rashid S, Rashid K, Wani BA, Ganie AH, Nawchoo IA, Khuroo AA. 2023. Reproductive biology of *Actaea kashmiriana*, an endemic medicinal plant species from the Himalaya: Implications for conservation and sustainable utilisation. Journal of Applied Research on Medicinal and Aromatic Plants 34:100461. doi: 10.1016/j.jarmap.2023.100461.

Rolnik A, Olas B. 2021. The plants of the Asteraceae family as agents in the protection of human health. International Journal of Molecular Sciences 22:3009.

Roque N, Funk VA. 2013. Morphological characters add support for some members of the basal grade of Asteraceae. Botanical Journal of the Linnean Society 171:568-586.

Saklani A, Rao R, Chaudhary L. 2000. SEM-characterisation of achene morphology towards the taxonomy of Indian species of *Saussurea* DC. (Asteraceae). Rheedea 10:1-18.

Samant S, Shreekar P. 2003. Diversity, distribution pattern and traditional knowledge of sacred plants in Indian Himalayan Region. Indian Journal of Forestry 26:222-234.

Semwal P, Painuli S, Tewari D, Bussmann RW, Palni LMS, Thapliyal A. 2020. Assesment of non-timber Brahma Kamal (*Saussurea obvallata* (DC.) Edgew.), an important Himalayan medicinal plant: Ethnomedicinal, phytochemical and pharmacological overview. Ethnobotany Research and Applications 19:1-15.

Semwal P, Pauw A, Palni LMS, Verma S, Thapliyal A. 2019. Bumblebees (*Bombus rufofasciatus* Smith) pollinate the enclosed inflorescences of the endangered Brahma's lotus (*Saussurea obvallata*: Asteraceae) of the Indian Himalaya. South African Journal of Botany 121:435-441.

Shah N. 1982. Herbal folk medicines in Northern India. Journal of Ethnopharmacology 6:293-301.

Sharma A, Singh R. Himalayan Herbal Plant: Bhramkamal. International Journal of Science and Research 8:2319–7064.

Sharma P, Samant SS. 2014. Diversity, distribution and indigenous uses of medicinal plants in Parbati Valley of Kullu district in Himachal Pradesh, northwestern Himalaya. Asian Journal of Advanced Basic Sciences 2:77–98.

Shi Z, Chen YL, Chen YS, Lin YR, Liu SW, Ge XJ, *et al.* 2011. Asteraceae (Compositae). In: Wu ZY, Raven PH, & Hong DY (eds) Flora of China, Volume 20-21 (Asteraceae). Science Press (Beijing) & Missouri Botanical Garden Press (St. Louis).

Shivanna K, Tandon R. 2014. Reproductive ecology of flowering plants: a manual. Springer New Delhi. doi: 10.1007/978-81-322-2003-9.

Singh G, Rawat GS. 2011. Ethnomedicinal survey of Kedarnath wildlife sanctuary in Western Himalaya, India. Indian Journal of Fundamental and Applied Life Sciences 1:35-46.

Singh R, Pandey A. 1984. Development and structure of seeds and fruits in compositae-Cynareae. Phytomorphology 34: 1–10.

Stebbins GL. 1953. Chromosomes and phylogeny in the Compositae, tribe Cichorieae. University of California Publications in Botany 26:401-430.

Sun H, Niu Y, Chen Ys, Song B, Liu Cq, Peng Dl, Chen Jg, Yang Y. 2014. Survival and reproduction of plant species in the Qinghai–Tibet Plateau. Journal of Systematics and Evolution 52:378-396.

Tamang M, Pal K, Kumar Rai S, Kalam A, Rehan Ahmad S. 2017. Ethnobotanical survey of threatened medicinal plants of West Sikkim. International Journal of Botany 2:116-125.

Tomb AS. 1977. Lactuceae-systematic review. -In: Heywood, J. B. Harborne 8: B. L. Turner (eds) The biology and chemistry of the Cornpositae, Volume 11. Academic Press, London, pp. 1067-1079.

Tsarong T. 1986. Handbook of Traditional Tibetan Drugs: Their Nomenclature, *Composition, Use and Dosage, Tibetan Medical Publication, Kalimpong*, 100-102.

Tsukaya H, Fujikawa K, Wu S-G. 2002. Thermal insulation and accumulation of heat in the downy inflorescences of *Saussurea medusa* (Asteraceae) at high elevation in Yunnan, China. Journal of Plant Research 115:263-268.

Wali S, Ahmad Jan H, Bussmann RW. 2019. Quantitative ethnomedicinal study of indigenous medicinal plants used for digestive disorders of Laspur Valley, Chitral, Northern Pakistan. Ethnobotany Research and Applications 18:1-18.

Wanga YF, Nib ZY, Dong M, Cong B, Shi QW, Gua YC, Kiyota H. 2010. Secondary metabolites of plants from the genus *Saussurea*: chemistry and biological activity. Chemistry & Biodiversity 7:2623–2659.

Yang HJ, Kim MJ, Kang S, Moon NR, Kim DS, Lee NR, Kim KS, Park S. 2017. Topical treatments of *Saussurea costus* root and *Thuja orientalis* L. synergistically alleviate atopic dermatitis-like skin lesions by inhibiting protease-activated receptor-2 and NF-κB signaling in HaCaT cells and Nc/Nga mice. Journal of Ethnopharmacology 199:97-105.

Yang Y, Körner C, Sun H. 2008. The ecological significance of pubescence in *Saussurea medusa*, a high-elevation Himalayan "woolly plant". Arctic, Antarctic, and Alpine Research 40:250-255.

Yoshida T. 2002. Adaptive strategies of alpine plants in Nepal. In: Noshiro S and K R Rajbhanselari (eds.) Himalayan Botany in the Twentieth and Twenty-First Centuries Tokyo, The Society of Himalayan Botany. 105–111.

Yu S, Yang X, Tian X, Liu X, Lu X, Huang C, Fu Z. 2022. The complete chloroplast genome sequence of the monotypic and enigmatic genus *Cavea* (tribe Gymnarrheneae) and a comparison with other species in Asteraceae. Journal of Genetics 101:1-9.

Zarembo E, Boyko E. 2008. Carpology of some East Asian Cardueae (*Asteraceae*). Anales del Jardín Botánico de Madrid 65: 129-134. doi: 10.3989/ajbm.2008.v65.i1.250.

Zhang J-W, Boufford DE, Sun H. 2013. Systematic significance of achene morphology in *Soroseris, Syncalathium* and *Parasyncalathium* (*Asteraceae*: Cichorieae). Botanical Journal of the Linnean Society 173:476-486. doi: 10.1111/boj.12046.

Zhang L, Chai Z, Zhang Y, Geng Y, Wang Y. Ethnobotanical study of traditional edible plants used by the Naxi people during droughts. Journal of Ethnobiology and Ethnomedicine 12:39. doi: 10.1186/s13002-016-0113-z