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

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**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 lanceps*, *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-Streuβe 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 conuate pappus (Bremer 1994; Häffner 2000; Raab-Streuβe 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. gossipiqaphora 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, Wiley, 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 [.CSV] 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. gaphnolades, 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. gaphnolades, 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 & Caurasia 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>
<thead>
<tr>
<th>Species</th>
<th>Parts used</th>
<th>Ethnobotanical Applications</th>
<th>Country</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>S. bracteate</strong> Decne.</td>
<td>Roots</td>
<td>Boils, headache, cough, fever, lung infection, cold</td>
<td>India</td>
<td>(Butola &amp; Samant 2010; Ballabh &amp; Chaurasia 2007)</td>
</tr>
<tr>
<td><strong>S. ceratocarpa</strong> Decne.</td>
<td>Whole plant</td>
<td>Headache, lumbar pain, menorrhrea, renal pain</td>
<td>India</td>
<td>(Butola &amp; Samant 2010)</td>
</tr>
<tr>
<td><strong>S. costus</strong> (Falc.) Lipsch.</td>
<td>Roots</td>
<td>Dysentery, skin disorder, cold, cough, bronchitis, rheumatism, chloera, 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.</td>
<td>India, China, Japan, Korea</td>
<td>(Butola &amp; Samant 2010; Kumar &amp; Pundir 2022; Shah 1982; Yang et al. 2017; Ballabh &amp; Chaurasia, 2007; Gairola et al. 2014; Houghton &amp; Osibogun 1993; Kayani et al. 2015)</td>
</tr>
<tr>
<td><strong>S. fastuosa</strong> (Decne.). Sch.Bip.</td>
<td>Aerial parts</td>
<td>Wound healing</td>
<td>Nepal</td>
<td>(Rajbhandari et al. 2009)</td>
</tr>
<tr>
<td><strong>S. glacialis</strong> Herder.</td>
<td>Flower, leaf</td>
<td>Liver disorders, throat ache, heart ailments, mental disorders</td>
<td>India, Tibet</td>
<td>(Butola &amp; Samant 2010)</td>
</tr>
<tr>
<td><strong>S. gnaphalodes</strong> (Royle) Schi. Bip.</td>
<td>Aerial parts</td>
<td>Kidney disorders, urinary disorders, cough, cold, backache, pulmonary disorders, blood purification.</td>
<td>India</td>
<td>(Butola &amp; Samant 2010; Ballabh et al. 2008)</td>
</tr>
<tr>
<td><strong>S. gossypiphora</strong> D. Don.</td>
<td>Roots,</td>
<td>Religious offering, hysteria, gynecological disorders, menstrual disorders, perfume, asthma pneumonia, stomach disorders, wound healing, headache, blood circulation</td>
<td>India</td>
<td>(Butola &amp; Samant 2010; Mishra et al. 2021; Samant &amp; Shreekar 2003; Tamang et al. 2017; Wali et al. 2019)</td>
</tr>
<tr>
<td><strong>S. graminifolia</strong> Wall. ex DC.</td>
<td>Whole plant</td>
<td>Cough, blood purification, increase menstrual flow, menstrual cramps due to renal disorders.</td>
<td>India, Tibet</td>
<td>(Butola &amp; Samant 2010)</td>
</tr>
<tr>
<td><strong>S. heteromalla</strong> (D. Don) Hand.-Mazz.D.</td>
<td>Roots, seed, leaf</td>
<td>Leukodermia skin disease, wound healing, fever, colic pain, horse-bite disease</td>
<td>India, Pakistan</td>
<td>(Batrool et al. 2019; Butola &amp; Samant 2010; Malik et al. 2015)</td>
</tr>
<tr>
<td><strong>S. involucrata</strong> (Kar. et Kir.) Sch.Bip.</td>
<td>Aerial parts</td>
<td>Rheumatoid arthritis, infertility, inflammation, ornamental</td>
<td>China, Kazakhstan, Magnolia</td>
<td>(Chik et al. 2015; Kumar &amp; Pundir 2022; Chen &amp; Wang 2018)</td>
</tr>
<tr>
<td><strong>S. jacea</strong> (KL) C.B.Clarke</td>
<td>Whole plant</td>
<td>Urinary disorders</td>
<td>India</td>
<td>(Ballabh et al. 2008)</td>
</tr>
<tr>
<td><strong>S. leucoma</strong> Diels</td>
<td>Whole plant</td>
<td>Food source</td>
<td>China</td>
<td>(Zhang et al. 2016)</td>
</tr>
<tr>
<td><strong>S. medusa</strong> Maxim.</td>
<td>Whole plant</td>
<td>Arthritis, weakness, headache, high blood pressure, menstrual disorders</td>
<td>China, Tibet</td>
<td>(Butola &amp; Samant 2010)</td>
</tr>
<tr>
<td><strong>S. obvallata</strong> (DC.) Edgew.</td>
<td>Roots, leaves, flower, buds</td>
<td>Paralysis, wounds healing, leukodermia, fever, cold, cough, cardiac disorders, hydrocele, reproductive disorders,</td>
<td>Tibet, India, Pakistan, Nepal</td>
<td>(Butola &amp; Samant 2010; Kumar &amp; Pundir 2022; Mishra et al. 2021; Semwal et al. 2020; Bano et</td>
</tr>
</tbody>
</table>

Table 1. Ethnomedicinal applications of few species of *Saussurea* genus.
<table>
<thead>
<tr>
<th>Species</th>
<th>Part Used</th>
<th>Uses</th>
<th>Location</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>S. roylei</em> (DC.) Schi. Bip.</td>
<td>Whole plant</td>
<td>Wound healing, inflammation, excessive bleeding, joint ache</td>
<td>Tibet, India</td>
<td>Butola &amp; Samant 2010</td>
</tr>
<tr>
<td><em>S. simpsoniana</em> (Field and Guard) Lipsch.</td>
<td>Roots</td>
<td>Snakebite, period cramps, plague, insecticide, cough, cold, blood purification</td>
<td>India</td>
<td>Butola &amp; Samant 2010</td>
</tr>
<tr>
<td><em>S. stella</em> Maxim.</td>
<td>Whole plant</td>
<td>Toxin, fever, rheumatic pain, bone fractures</td>
<td>Tibet</td>
<td>Chen et al. 2018</td>
</tr>
<tr>
<td><em>S. taraxacifolia</em> Wall. ex. DC.</td>
<td>Leaves</td>
<td>Ulcers and cold</td>
<td>Tibet</td>
<td>Butola &amp; Samant 2010</td>
</tr>
</tbody>
</table>
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. pilliphila*, *S. polycolea*, *S. pubifolia*, *S. suihangii*. 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. dorogostaikii* 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, lacerated, or woolly (Häffner 2000). The five stamens with free filaments are imbedded in the corolla tube and the anthers are ditheccous, 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. albensens*, *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 rufofastacus* 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.
Fruits
The members of *Saussurea* produce a type of fruit called an achene. In *Saussurea* species achene is ovoid, 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](image)

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.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Country</th>
<th>Documents</th>
<th>Citations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>India</td>
<td>29</td>
<td>1073</td>
</tr>
<tr>
<td>2</td>
<td>China</td>
<td>16</td>
<td>250</td>
</tr>
<tr>
<td>3</td>
<td>Pakistan</td>
<td>13</td>
<td>370</td>
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<td>4</td>
<td>Germany</td>
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<tr>
<td>10</td>
<td>Austria</td>
<td>1</td>
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</table>

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.

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

*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).
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 suggesting 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-estabishment, 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

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