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REVIEW ARTICLE

Exploration of the descriptive phyto-geography of genus *Rubus*: A systematic review with global and Indian perspectives

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Abstract

The genus *Rubus* L., belonging to the family *Rosaceae*, subfamily *Rosoideae* and tribe *Potentilleae*, with over 1454 species worldwide, plays a crucial role in ecological systems and is considered one of the most invasive groups of species in the world. Along with its invasive nature, different species of this genus are valued for their nutritional and medicinal benefits. Despite its importance, the phyto-geographical distribution of *Rubus* remains underexplored, particularly in terms of its global and regional (Indian) biodiversity. *Rubus* species are predominantly distributed across the temperate regions of the Northern Hemisphere, with their natural range extending from sea level to elevations of approximately 4500 meters. This review investigates the phyto-geographical distribution patterns of *Rubus* species, exploring their ecological adaptations and distribution across diverse global landscapes. We synthesize findings from a wide range of biogeographical studies, examining key determinants and factors influencing species distribution, climate resilience and spread across different continents. Ecological aspects are also addressed, emphasizing their role in pollination as well as their pharmaceutical benefits. Additionally, the review focuses on *Rubus* species in India, a region known for its distinct ecosystems and high levels of endemism. By integrating global and regional perspectives, this review provides a comprehensive understanding of the phyto-geographical dynamics of *Rubus*, offering valuable insights for future research on this genus.

Keywords: genus *Rubus;* Indian Himalayan region; phyto-geography; systematic review

Introduction

The genus *Rubus* L. (family *Rosaceae*), comprising approximately 700 species of shrubs, brambles and trailing plants, making it one of the most ecologically and economically important genera in both temperate and tropical regions (1). The widespread distribution and intricate taxonomy of *Rubus* render it a fascinating subject for phyto-geographical studies. This genus is best known for its edible fruits, such as blackberries and raspberries, which have considerable agricultural, medicinal and ecological value (2-5). Additionally, *Rubus* species exhibit remarkable adaptive radiation across a variety of habitats, ranging from forests to grasslands, often showing extensive local diversity and regional endemism (6). These features make *Rubus* a key player in ecosystem dynamics and an ideal candidate for investigating patterns of species distribution and evolutionary processes. The phyto-geography of *Rubus* has long been a subject of interest, characterized by its complex distribution patterns, which have been influenced by various ecological, climatic and historical factors.

Previous research has revealed that the genus is predominantly found in the Northern Hemisphere, with significant diversity in temperate regions of North America, Europe and Asia (7, 8). The biogeographical history of *Rubus* has been shaped by major climatic events, including glaciations and post-glacial warming periods, which have influenced its present distribution (9). Moreover, studies of phylogenetic relationships within the genus have highlighted both intra- and interspecific genetic divergence, reflecting the genus complex evolutionary history (10). Phyto-geographical patterns in *Rubus* are often complicated by the genus' high level of polyploidy and apomictic reproduction, which contribute to the emergence of cryptic species and local varieties. This presents challenges in taxonomic classification and species delineation, as well as in understanding the historical factors that have shaped their distribution (11).

This genus is renowned for its economic significance, primarily due to the production of blackberries, raspberries and other berry fruits, which are not only valuable in human nutrition but also offer medicinal properties, such as antimicrobial, anti-inflammatory and antioxidant effects

(12, 13). Ecologically, *Rubus* species are critical for their ability to thrive in a wide range of habitats, from temperate woodlands to disturbed areas, where they stabilize soils and provide essential habitat and food for pollinators and wildlife (9).

Recent molecular studies, including analyses of chloroplast and nuclear markers, have provided new insights into the phylogeography of *Rubus*, uncovering fine-scale population structures and revealing the roles of historical migration, hybridization and gene flow in shaping the current diversity (14, 16). The adaptability of *Rubus* species to a variety of environmental conditions, from temperate woodlands to disturbed habitats, underscores the genus' significant role in shaping ecological landscapes. Thus, the genus *Rubus* is not only a model for studying plant evolution and speciation but also a vital resource for biodiversity conservation, offering critical ecological services and potential for future agricultural innovations. Hence, understanding the phyto-geographical dynamics of it is crucial for both biodiversity conservation and sustainable agricultural practices, particularly in the face of ongoing environmental changes and habitat fragmentation (15). Below, the table incorporated provides details of species of the *Rubus* genus found in India, as listed in the IUCN red list with their conservation status (Table 1).

Therefore, this article aims to provide a systematic, comprehensive review of the descriptive phyto-geography of the genus *Rubus*, synthesizing recent findings on its species' distribution and ecological significance from both global & Indian perspective. By integrating data from different studies, we seek to contribute to a more nuanced understanding of how *Rubus* species have distributed and dispersed across various geographic regions. Furthermore, we explored the major research gaps surrounding genus *Rubus* taxonomy and classification, which remain a central issue in current phyto-geographical research.

Approach for data collection

A comprehensive literature search was performed to explore various aspects of the genus *Rubus*. For *Rubus* L. taxonomic nomenclature adhere to the International Code of Nomenclature for algae, fungi and plants (IUCN), which regulates plant classification, ensuring consistency in botanical naming worldwide. The study utilized the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (17), an internationally recognized framework for systematic review reporting. The search process utilized three key online databases: Google Scholar, Wiley and Scopus. The following keywords were employed to capture a broad spectrum of relevant literature: "Genus *Rubus*," "Himalayan raspberry," "geographic distribution," "*Rubus* L. evolutionary trends," "phytogeography," "*Rubus* species distribution," "ecology of *Rubus*," "proximate analysis of *Rubus* species," "plant distribution patterns," "ecological zones of *Rubus* species" and "geographic spread of *Rubus*."

Initially, 180 references were retrieved during the literature search. After removing 50 duplicates, 130 articles were assessed for eligibility. Articles were carefully reviewed against inclusion and exclusion criteria. Inclusion criteria focused on full-text studies investigating geographic distribution, evolutionary trends, phytogeography, habitat preferences and species richness within the *Rubus* genus. Exclusion criteria were applied to abstracts, conference posters, non-experimental studies, qualitative data and dissertations. Ultimately, 80 studies met the eligibility criteria and were selected for inclusion in this review. The literature selection process, including screening and eligibility assessment, is illustrated in Fig. 1. Notably, some studies were categorized under multiple themes, resulting in a higher article count than the number of individual papers reviewed.

Global phytogeographic prospective of genus *Rubus*

Phytogeography concerned with all aspects of plant distribution, from the controls on the distribution of species ranges (both at large & small scales), to factors that govern the composition of entire communities and floras (28). The entire globe divided into six major phytogeographic centre enlisted in Table 2 (29).

About 1454 species, 60 hybrids and 12 subgenera in the flowering plant of this genus *Rubus*; have been described throughout the world, which are called as blackberries, raspberries, dewberries and brambles (30). The species of this genus are native to six continents and their occurrence stretches at an elevation from mean sea

Table 1. The IUCN Status of different species of genus *Rubus* in India

Species	IUCN Status	References
Rubus chaerophylloides	Endangered (EN)	(18,19)
Rubus pectinellus	Vulnerable (VU)	(18,20)
Rubus macraei	Vulnerable (VU)	(18,24)
Rubus armeniacus	Near Threatened (NT)	(18,22)
Rubus niveus	Least Concern (LC)	(18,23)
Rubus ulmifolius	Least Concern (LC)	(18,21)
Rubus fruticosus	Least Concern (LC)	(18,25)
Rubus ellipticus	Least Concern (LC)	(18,26)
Rubus tridentatus	Data Deficient (DD)	(18,27)

Table 2. Phytogeographic regions of the world

S. No.	Phytogeographic regions	Contemporary geographic allocation
01	Australian kingdom	Entire Australian Continent and associated Islands (Tasmania)
02	Cape kingdom	South Africa
03	Antarctic kingdom	Antarctic Islands and Southern most region of South America (Islands of Argentina)
04	Palaeo-tropical kingdom	Entire African landmass, Middle East Arabia, South East Asia and its associating Islands (New Zealand)
05	Neo-tropical kingdom	Entire South and Central American Region Including West Indies Islands
06	Boreal kingdom	Complete North America, Europe, Eurasia, East Asian Countries

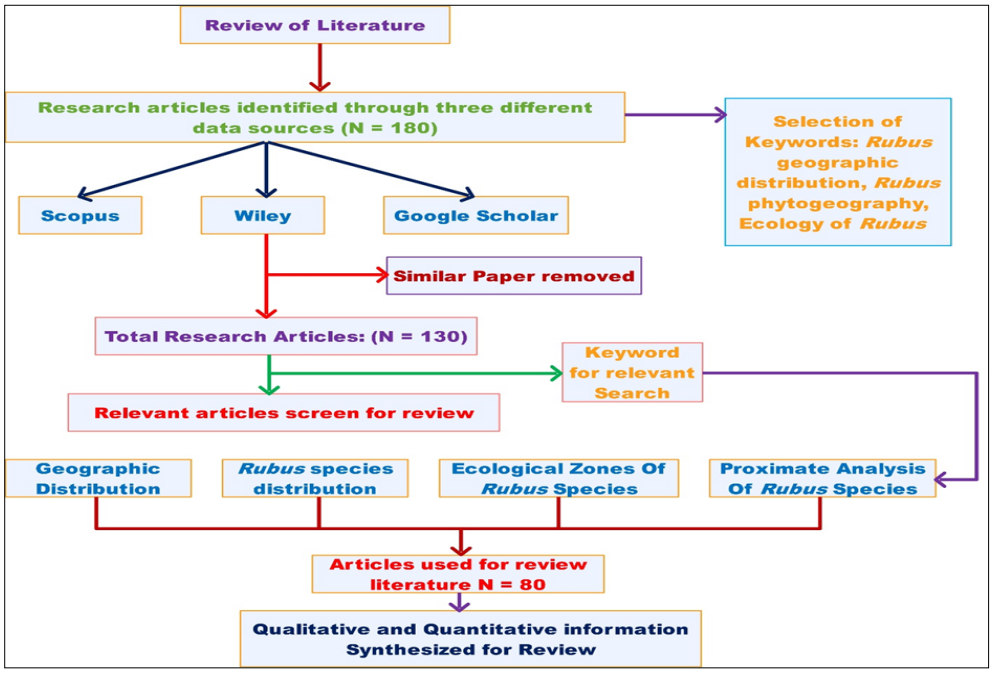

Fig. 1. Systematic workflow of literature review process.

level to 4500-meter (31). A total of 12 subgenera of *Rubus* have been recognized, among which only *Idaeobatus* (Raspberries along with Arctic Raspberries (*Cylactis*)), *Eubatus* (Blackberries (later known as *Rubus*)) and *Malachobatus* include species that produce edible fruits of commercial importance (32, 33). The 12 subgenera were recognized primarily classified based on morphology and identified three major centers of origin: East Asia (Subgenus *Idaeobatus*), Southeast Asia (Subgenus *Malachobatus*) and Europe and American Peninsula (Subgenus *Rubus*). It was further suggested that all other smaller subgenera have evolved from these three predominant groups. It was speculated that the centre of origin for *Rubus* is southwestern China, as it is geologically archaic and was not covered by glaciers during the quaternary (34). Regarding the geographic race of the genus *Rubus* showed maximum amount of hybrid varieties due to both mode of reproduction (Sexual & Asexual) and the ploidy level ranged from 2 to 7x (x=7) and the subgenus *Ideobatus* predominantly diploid (35). A detailed description of the distribution of different *Rubus* species across various continents is provided below.

3.1 North America

Jennings described the subgenera occur from the arctic (for example, *Cylactis*) to South America (for example, *Orobatus*) and this *Orobatus* is thought to be derived from the hybrid of North American subgenera *Rubus* and *Anoplobatus* (36). Himalayan Raspberry is notably invasive along the U.S. West Coast. Between 2001 and 2010, it was the most common nonnative shrub in western Oregon, covering approximately 637 square kilometers of forested lands (37). The genus *Rubus* in Iowa state of North America was studied and concluded that the three subgenera of *Rubus* represented in Iowa's flora can be easily distinguished in the field or herbarium and these were such as *Cylactis*, *Anoplobatus*, *Idaeobatus* (38). The phylogenetic development of the genus *Rubus* was explored, leading to the inference that the most recent ancestral lineage likely emerged in North America during the Miocene (circa 20 million years ago). It is hypothesized that these species spread from North America to Asia and Europe through the Bering land bridge, as well as southward across the Panamanian Isthmus. Additionally, it is proposed that *Rubus* species underwent substantial diversification in Asia during the Miocene, with the ancestral population dispersing from North America toward Asia, Europe and Central and South America in the early Miocene. This migration was followed by diversification and further spread to Oceania via long-distance avian dispersal (39).

3.2 Australia

The recently described subgenus *Micranthobatus* occurs in Australia and New Zealand (40). The subgenus *Micranthobatus* of genus *Rubus* (*Rosaceae*) in Australia was revised and two new species named *R. moorei* F. Muell. and *R. nebulosus* A.R were reported (41).

3.3 Europe

An experimental outcome on comprehensive field combined with extensive herbarium investigation conducted to assess the presence of genus *Rubus* L. representatives in the Bardo Mountain range (SW Poland). The findings revealed that this region harbors one of the highest concentrations of *Rubus* species in Poland, with a total of 50 documented species. Notably, 37 of these species were recorded in the area for the first time. Among the identified taxa, 48 species belong to the subgenus *Rubus*, one species to the subgenus *Idaeobatus* and one taxon, classified under *Nothosubgenus* × *IdaeoRubus*, represents a hybrid origin (42). The introduced species of *Rubus* in Hungary, Serbia and the Balkans, which comes under subgenus *Eubatus* (Blackberries) mostly native to Europe were studied with special aspect to their ecological distribution pattern (43, 44). Blackberries are botanically classified in the genus *Rubus* subgenus *Rubus* and European blackberries (*Rubus fruticosus* L.) have a centre of origin in the Caucasus, are well distributed throughout Europe and have been introduced into Asia, Oceania and North and South America (45). Subgenus *Idaeobatus* mostly includes the European raspberries (*Rubus idaeus* L.), the cloudberry

(*R. chamaemorus* L., which are native to southern European mountains and were named by Linnaeus for Mount Ida, Turkey).

Three taxa of the section *Rubus* were found to be most widespread in the investigated area of Western Central Italy and these species were reported as *R. ulmifolius* Schott, *R. canescens* DC. and *R. hirtus* Waldst. & Kit. based on the field survey (46). An in-depth assessment was conducted on the range, ecological preferences and potential threats posed by alien *Rubus* species in Hungary. The initial documentation of a non-native species, *R. phoenicolasius* Maxim., in the country dates to 1999. Meanwhile, *R. armeniacus* Focke was officially identified in 2014, though its presence is suspected to have extended several decades prior. Additionally, two newly observed transient alien species, *R. laciniatus* Willd. and *R. occidentalis* L., were recorded for the first time in Hungary (44). A compilation of 72 taxa from the genus *Rubus* L., subgenus *Rubus*, along with their distribution is done in Luxembourg, among which 59 taxa belong to section *Rubus* and 13 taxa to section *Corylifolii* Lindley (47).

The taxonomy and distribution of the genus *Rubus* series Radula on the Iberian Peninsula, southwestern Europe was described and interpreted that series is separated into two, distinguished by the leaflets felted beneath (ser. Radula) versus not felted (ser. Pallidi) (48). The evolution of genus *Rubus* subgenus *Rubus* was investigated and concluded that one of the main driving forces of evolution was sexuality in the series Glandulosi. The result showed that the palaeovegetation data of initial hybridizations took place over different time periods in the European regions over several millennia (49). *Rubus arcticus* L. belongs to the subgenus *Cylactis*, being one of the species of the phylogenetic Arctic group. Other members of this group are *R. acaulis* Michx., a subspecies of *R. arcticus* and *R. stellatto* Sm. (50, 51).

The occurrence of *Rubus* L. species in south-eastern Lower Silesia (SW Poland) was studied and 61 species (about 2/3 of all species growing in Poland) were documented, twenty-eight species were recorded for the first time in this area and two species were identified as new to this location (52). A new species of *Rubus* known as *Rubus kaznowskii* Kosiński & Ziel., which belongs to the series Subthyrsoidei (sect. Corylifolii) was reported from south-central Poland. *R. kaznowskii* Kosiński & Ziel has mainly been observed on rusty soils, in habitats of mixed coniferous and mixed broadleaf forests, usually in sunny places, along forest margins and roads and roadside thickets (53). Investigations were carried out in Medvednica Nature Park, central Croatia, with an aim to determine the presence of *Rubus* spp., their determination and their disposition in the Nature Park and seven types of *Rubus* sp. in the Nature Park with *Rubus discolor* L. was found to be the most prevalent (54).

3.4 Asia

In the Asian continent, South-East Asian region which cover most of the Chinese provinces is considered as one of the three major diversity point for *Rubus* species. At least 299 *Rubus* taxa are described from China and are distributed in 27 provinces (34). Vavilov considers China to occupy the “first place in all the world” as far as the “composition of wild and cultivated fruit is concerned (55).” He does not discuss in detail the center of origin for *Rubus*; however, this genus may overlap his Chinese and Indo-Malayan centers (55, 56). Previous works showed that only one *Rubus* species, *R. rosifolius* Smith, subgenus *Idaeobatus*, as originating in the Indo-Malayan center (57). This species was introduced into cultivation on Java and was found wild in the Philippines, with its range extending to southern Japan. Vavilov mentions *Rubus* in a group of fruit and berry genera typical of both the old and new worlds (56).

The species of *Rubus* in China are classified into 8 sections with 24 subsections as follows: 1. Sect. *Idaeobatus*, emend. Yü et Lu (11 subsect. 83 sp.); 2. Sect. *Lampobatus* Focke (1 sp.); 3. Sect. *Rubus* (1 sp.); 4. Sect. *Malachobatus* Focke, emend. Yü et Lu (13 subsect. 85 sp.); 5. Sect. *Dalibardastrus* (Focke)Yü et Lu (10 sp.); 6. Sect. *Chaemaebatus* Focke (5 sp.); 7. Sect. *Cylactis* Focke, emend. Yü et Lu (8 sp.); 8. Sect. *Chamaemorus* Focke (1 sp.). There are about 200 species recorded in E. Asia, of which the species in China (194) amount to 97 % of the total number. By analysis of the distribution of species in China the great majority of them inhabit the southern parts of the Yangtze River where exist the greatest number of species and endemics, especially in southwestern parts of China, namely Yunnan, Sichuan and Guizhou. In this region the characteristics of floristic elements of *Rubus* can be summarized as follows: it is very rich in composition, containing 6 sections and 94 species, about 66 % of the total number of Chinese species; there are also various complex groups, including primitive, intermediate and advanced taxa of phylogenetic importance; the proportion of endemic plants is rather high, reaching 61 species, up to 44 % of the total endemics in China (58). However, obtaining precise quantitative data on the total geographic area occupied by all *Rubus* species in square kilometers is challenging due to their widespread and varied distribution. For instance, in China alone, suitable habitats for *Rubus idaeus* L. span approximately 2373390 square kilometers, covering about 24.72 % of the country's land area (59).

Nepal exhibits a rich diversity of *Rubus* species, with 32 species and 4 varieties, including the evergreen Himalayan creeping bramble (*Rubus nepalensis* (Hook.f.) Kuntze), known locally as "Ainselu" (59). North American raspberries (*R. strigosus* Michx., *R. spectabilis* Pursh, *R. parviflorus* Nutt.), black raspberries (eastern, *R. occidentalis* L. and western, *R. leucodermis* Douglas ex Torr. & A. Gray) and Asian species (*R. chingii* Hu, *R. coreanus* Miq., *R. crataegifolius* Bunge and *R. parvifolius* L) are mainly distributed in Zhejiang, Fujian, Hubei and Guizhou provinces of China (60). The evolutionary history of *Rubus niveus* Thunb. was studied and showed that it might originated from Asia but can now be found in several non-Asian locations around the globe along with that based on the herbarium specimens studied and information from published texts and on-line databases. In Malaysia the *Rubus* distribution was investigated and reported two major

sub-genera like *Chamaebatus* & *Idaeobatus* with two and eighteen species respectively (61).

The distribution of *Rubus* species in the islands of Philippines was investigated and reported 17 species of *Rubus* in the country but concluded that five species were widely distributed across the country and these species were *R. moluccanus* L., *R. rosifolius* Sm, *R. fraxinifolius* Poir., *R. pectinellus* Maxim and *R. rolfei* Vidal (62). Several *Ideaobatus* species, widely distributed in Japan, have been recorded in the Flora of Japan (63) and twenty-eight species/varieties in Japan belong to the subgenus *Ideaobatus*, which was distributed from Hokkaido (cool temperate) to Okinawa (subtropical) climates (64). The genus *Rubus* L. in Taiwan was taxonomically revised based on morphological and phytogeographical patterns, where forty (40) taxa (34 species, 3 varieties and 3 hybrids) of the genus were recognized, including two new hybrid species *R. croceacanthus* × *corchorifolius* and *R. rosifolius* × *fraxinifolius* (35).

3.5 South America

The diversity of *Rubus* in South America is much under studied and a taxonomic framework needs to be established as a basis for future revisionary and phylogenetic work. 110 names based on South American specimens were identified which were published since 1767. In South America, the *Rubus* genus, which includes blackberries, raspberries and related plants, is represented by four subgenera, with the most species found in the Andes, including *Idaeobatus*, *Orobatus* and *Rubus* (65). Twenty-two species of genus *Rubus* were reported under three major subgenera *Idaeobatus*, *Rubus* & *Orobatus* in Andes Mountain range and Ecuador of South America(66-69).

3.6 Africa

A total of eight taxa were recognized, including the two indigenous taxa *R. pinnatus* Willd. and *R. rigidus* Sm., the four introduced species *R. armeniacus* Focke, *R. bergii* (Cham & Schltdl) Eckl & Zeyh, *R. rosifolius* Sm and *R. titanus* LH Bailey and two hybrids between indigenous and introduced taxa were reported in the Cape Floristic Region of South Africa (70).

Hence, the genus *Rubus* is broadly originated from three major phytogeographic region such as Southeast Asia (Palaeo-tropical Kingdom), South America (Neo-tropical Kingdom) & East Asia (Boreal Kingdom) and all other species of this genus originated either from these regions and distributed to other parts of the world or originated from the sexual dimorphism between species. But regarding the diversity and extent of spreading of the genus, South-East Asia (Palaeo-tropical Kingdom) region can be considered as the major point of origin of the genus.

Domestic phytogeographic prospective of genus *Rubus*

A phytogeographical region is defined as an area of uniform climatic conditions and having a distinctly recognizable type of vegetation (71). The Indian sub-continent is well known for its broad variation in climate types and greater diversity in floral wealth correspondingly. The botanical Survey of India has classified the entire nation into nine major phytogeographic centres, which can be enlisted as:

1. Western Himalaya
2. Eastern Himalaya
3. Indus plain
4. Gangetic plain
5. Central India
6. Deccan
7. Western coasts of Malabar
8. Assam
9. Bay Islands of Andaman and Nicobar

Forty-one species of *Rubus* were reported from the then British India, out of which 39 species and 15 varieties are found within the present political boundaries of India that is enlisted with their respective subgenera and phytogeographic origin center in Table 3 (72). Among the six subgenera of *Rubus* in the Indian subcontinent, *Malachobatus* exhibits the highest species richness, with 14 species, followed by *Idaeobatus* with 12 species (Fig. 2). The *Rubus* subgenus comprises 9 species, while *Cyclactis* has 2 species. The least represented subgenera, *Chamaebatus* and *Dalibardastrum*, contain only 1 species each. This distribution highlights the dominance of *Malachobatus* and *Idaeobatus* in the region, indicating their ecological adaptability and evolutionary success.

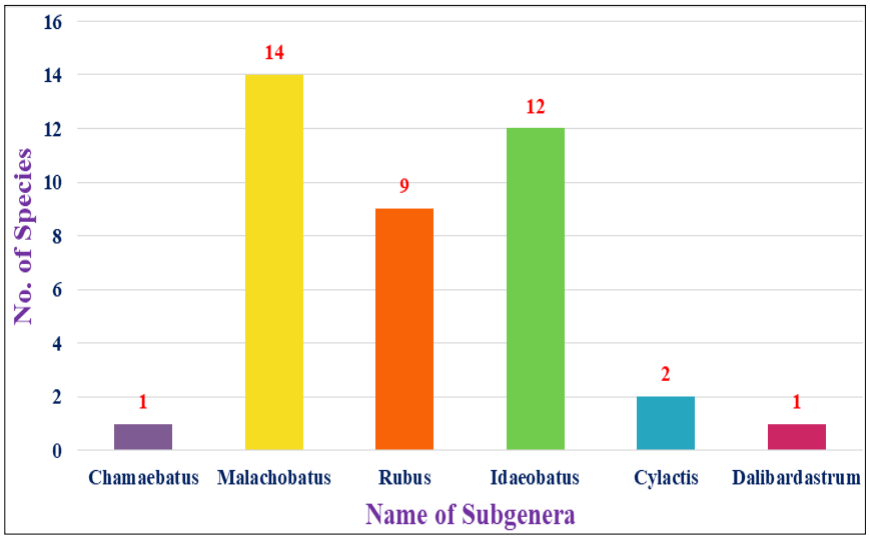

Fig. 2. Numeric distribution of *Rubus* species in different phytogeographic regions of India.

Table 3. Comprehensive checklist of Rubus species in India with their centers of origin

Species name	Indian phytogeographic distribution	Subgenera	Centre of origin
R. calycinus Wall. ex D. Don	Central and Eastern Temperate Himalaya	*Chamaebatus*	**Pacific North-west America (Boreal Kingdom)**
R. acuminatus Sm.	Central and Eastern Temperate Himalaya	*Malachobatus*	
R. griffithii Hook.f. (Synonyms of *R. moluccanus*)	Eastern Himalaya	*Malachobatus*	
R. hexagynus Roxb. ex Wall. (Synonyms of *R. pyrifolius*)	Assam (Khasi Mountain)	*Malachobatus*	
R. hamiltoni Hook. f. (Synonyms of *R. pyrifolius*)	Central and Eastern Himalaya	*Malachobatus*	**South East Asia (Palaeo-tropical Kingdom)**
R. assamensis Focke (Synonyms of *R. moluccanus*)	Mishmi and Khasi Hills	*Malachobatus*	
R. glomeratus Blume	Eastern Himalaya	*Malachobatus*	
R. paniculatus Sm.	Temperate Himalaya	*Malachobatus*	
R. insignis Hook. f. (Synonyms of *R. moluccanus*)	Eastern Tropical Himalaya	*Malachobatus*	
R. ferox Craib (Synonyms of *R. efferatus*)	Central Himalaya, Khasi Mountain	*Rubus*	**South America (Neo-tropical Kingdom)**
R. moluccanus L.	Central and Eastern tropical area, Eastern Peninsula, Western Peninsula, Khasi Mountain	*Malachobatus*	**South East Asia (Palaeo-tropical Kingdom)**
R. reticulatus Wall. Ex Hook. f. (Synonyms of *R. kumaonensis* N.P.Balakr.)	Temperate Himalaya	*Malachobatus*	
R. lanatus Wall. Ex Hook. f. (Synonyms of *R. glandulifer* N.P.Balakr.)	Central and Western Temperate Himalaya	*Rubus*	**South America (Neo-tropical Kingdom)**
R. birmanicus Hook. f.	East of Assam	*Rubus*	
R. treutleri Hook. f. (Synonyms of *R. moluccanus* var. *treutleri Kuntze*)	Eastern Temperate Himalaya	*Malachobatus*	**South East Asia (Palaeo-tropical Kingdom)**
R. alpestris Blume	Temperate Himalaya	*Idaeobatus*	**East Asia (Boreal Kingdom)**
R. thomsonii Focke	Sikkim Himalaya	*Idaeobatus*	
R. lineatus Reinw. ex Blume	Sikkim Himalaya	*Malachobatus*	**South East Asia (Palaeo-tropical Kingdom)**
R. andersoni (Synonyms of *R. splendidissimus* H. Hara)	Sikkim Himalaya	*Rubus*	**South America (Neo-tropical Kingdom)**
R. saxatilis L.	Western Temperate Himalaya	*Cylactis*	**Alpine and Artic region of Northern Hemisphere (Boreal Kingdom)**
R. nutans (Synonyms of *R. nepalensis* (Hook. f.) Kuntze)	Temperate Himalaya	*Dalibardastrum*	**East Asia (Boreal Kingdom)**
R. fockeanus Kurz (Synonyms of *R. nutans* var. *fockeanus Kuntze*)	Eastern Temperate Himalaya	*Malachobatus*	**South East Asia (Palaeo-tropical Kingdom)**
R. hookeri Focke (Synonyms of *R. wardii* Merr.)	Eastern Temperate Himalaya	*Malachobatus*	
R. niveus Thunb.	Temperate Himalaya	*Idaeobatus*	
R. macilentus Cambess.	Temperate Himalaya	*Idaeobatus*	
R. sikkimensis Kuntze ex Hook.f. (Synonyms of *R. rosifolius* var. *rosifolius*)	Sikkim Himalaya	*Idaeobatus*	**East Asia (Boreal Kingdom)**
R. ellipticus Sm.	Temperate and Sub-tropical Himalaya, Khasi Mountain, Western ghat	*Idaeobatus*	
R. fruticosus L.	Western Temperate Himalaya	*Rubus*	**South America (Neo-tropical Kingdom)**
R. clarkei Hook. f. (Synonyms of *R. saxatilis* L.)	Kashmir (Sonamung)	*Cylactis*	**Alpine and Artic region of Northern Hemisphere (Boreal Kingdom)**
R. antennifer Hook. f. (Synonyms of *R. caesius* L.)	Kashmir (Sonamung)	*Rubus*	**South America (Neo-tropical Kingdom)**
R. purpureus Bunge (Synonyms of *R. parvifolius* var. *parvifolius* and *R. irritance*)	Western Temperate Himalaya	*Idaeobatus*	
R. biflorus Buch. -Ham ex Sm.	Temperate Himalaya (Sirmour to Sikkim)	*Idaeobatus*	**East Asia (Boreal Kingdom)**
R. lasiocarpus Sm. (Synonyms of *R. niveus* var. *niveus*)	Temperate Himalaya, Peninsular Western ghat	*Idaeobatus*	
R. racemosus Roxb.	Nilgiri Mountain	*Idaeobatus*	
R. foliolosus D. Don *R. horridus*	Western Himalayan temperate (Chamba to Kumaon)	*Rubus*	**South America (Neo-tropical Kingdom)**
R. opulifolius Bertol.	Khasi Mountain, Upper kali pani	*Rubus*	
R. horridus Hartm. (Synonyms of *R. hartmanii* Gand.)	Eastern Himalaya	*Rubus*	
R. pungens Cambess.	Kashmir	*Idaeobatus*	**East Asia (Boreal Kingdom)**
R. rosaefolius Sm. (Synonyms of *R. rosifolius* var. *rosifolius*)	Temperate Himalaya (Kumaon to Sikkim)	*Idaeobatus*	

Regarding the distribution of the species of the genus in different phytogeographic region, maximum diversity can be observed in four regions such as Western Himalaya, Eastern Himalaya, Assam and Deccan region (Fig. 3).

Thirty-five species and 1 variety of Genus *Rubus* was reported from Sikkim while dealing with Flora of Bhutan (73). The taxonomic revision of the genus *Rubus* in India was conducted and estimated that more than 75 species occur in India and are distributed principally in dense primary/ secondary forests of tropical to temperate regions with an altitudinal range between 300–3500 m and reported *Rubus sengorensis* Grierson & DG Long, a new record to India from Arunachal Pradesh, which is a narrow endemic species to Bhutan (74). A comprehensive investigation and evolutionary data showed that the yellow Himalayan Raspberry (*Rubus ellipticus*) is native to tropical and subtropical India (75). The native regions for *R. ellipticus* include Asia-temperate specifically China (Guangxi, Guizhous, Sichuan, Xizang and Yunnan) as well as Asia-Tropical, such as Bhutan, India, Myanmar, Nepal, the Philippines, Sri Lanka and Thailand (76). A detailed field survey has reported nine species of *Rubus* in the southern regions of the country (77). As for *Rubus racemosus,* it is an endemic species with its distribution confined strictly to southern parts of the Western Ghats (80).

The data regarding the specimens of *Rubus* were collected from the western Himalaya of India are from secondary sources like herbarium specimens and identified as *R. chambicus* Rolfe distributed in Himachal Pradesh, Punjab, probably endemic to the Dhauladhar and Zanskar ranges, south of the inner Himalayas and *R. almorensis* Dunn distributed in Uttarakhand, probably endemic to the Kumaon hills or central Himalaya, of India (79). Regarding the distribution of genus *Rubus* in the north-western Himalayan state of Himachal Pradesh, their book 'Flora of Himachal Pradesh' described 9 different species, distributed in almost every district of the state. The nine different species can be enlisted as *Rubus biflorus*, *R. ellipticus*, *R. irritance*, *R. macilentus*, *R. niveus*, *R. paniculatus*, *R. saxatilis*, *R. chambicus* and *R. ulmifolius* (80). The ample distribution of wild raspberry (*Rubus macilentus* C.) in the Garhwal Himalaya between altitudes of 600 to 2200 meters above mean sea level was studied (81). The subgenus *Idaeobatus*. *R. fruticosus* (European blackberry, European bramble, known as vilaayati anchhu) was reported in the valley of Kashmir, Assam and Tamilnadu (India) up to 2000 meters (82). The distribution of *Rubus ellipticus* (which comes under subgenus *Idaeobatus*) was studied and it was concluded that this species is found native to the states of Assam, Sikkim, Tamil Nadu, Kerala and Maharashtra (83). A new species, *Rubus ramachandrae*, from upper Subansiri district of Arunachal Pradesh, India, was described and reported (84). Hence, the Himalayan hills of the northern regions of India and southern areas of China were found to be the central region for *Rubus ellipticus*.

India has a great diversity of *Rubus* species under the *Malachobatus* subgenus with abundant distribution in both Pan-India and IHR, making the Western & Eastern Himalaya a major phytogeographic origin center for this genus. Along with that, maximum species that are identified in the region either originated in the Boreal kingdom and migrated to the Indian subcontinent or developed by the sexual dimorphism between species. Due to the ample adaptation and acclimatization, the species of the genus can be recorded in a diverse climatic condition, starting from the harsh cold winter of the western Himalaya to the hot and humid condition of the Deccan region.

Ecological and pharmaceutical significance of genus *Rubus* L.

Rubus species, encompassing a diverse group of brambles such as raspberries and blackberries, play a pivotal role in various ecosystems. Their ecological significance is multifaceted, contributing to biodiversity, providing resources for wildlife and demonstrating resilience to environmental changes. These species exhibit remarkable climate resilience through their adaptability to diverse environmental conditions, rapid vegetative propagation and genetic plasticity. Additionally, *Rubus* species contribute significantly to pollinator support, promoting biodiversity through their nectar and pollen resources.

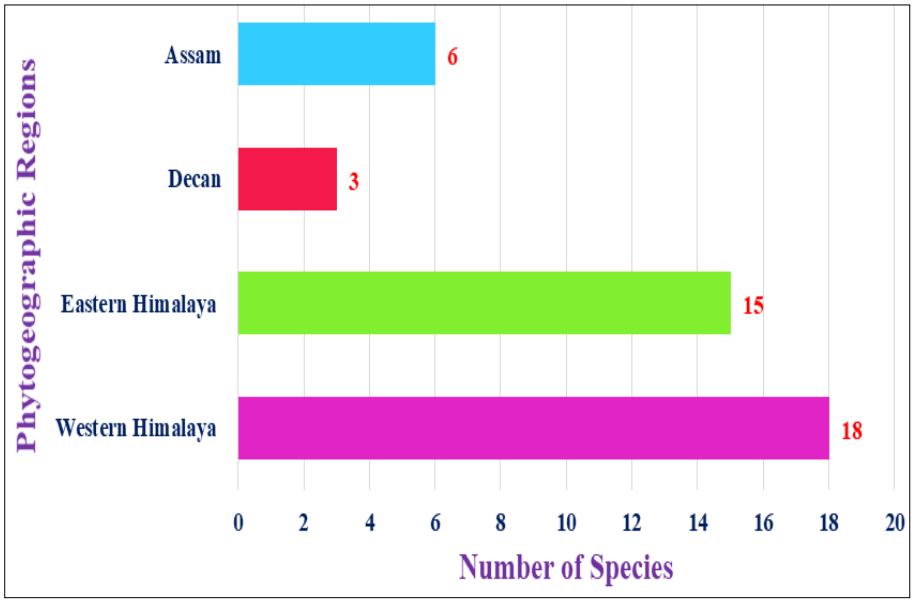

Fig. 3. Dominant subgenera of genus *Rubus* in Indian subcontinent.

Rubus species exhibit high ecological plasticity, enabling them to colonize diverse habitats, including forests, meadows and human-disturbed environments. Their ability to thrive under varying temperature, moisture and soil conditions makes them significant in the context of climate change (85). Some *Rubus* species, such as *Rubus idaeus* L. (red raspberry), have developed deep root systems that enhance water uptake and drought survival. Species like *Rubus arcticus* L. can withstand extreme cold due to physiological adaptations such as dormancy, antifreeze proteins and increased carbohydrate storage in roots (86). Adaptations like increased trichome density and waxy leaf coatings in *Rubus fruticosus* L. (common blackberry) reduce water loss and protect against excessive solar radiation. One of the key resilience traits of *Rubus* species is their ability to regenerate vegetatively via rhizomes, suckers and layering. This allows them to recover quickly from disturbances such as wildfires, deforestation and habitat fragmentation. Such traits make *Rubus* species important for ecological succession and land rehabilitation (87). Due to their dense growth, extensive root systems and perennial nature, *Rubus* species contribute to carbon sequestration. Their presence in forest understories and degraded lands enhances soil organic matter, reduces erosion and improves soil fertility, making them valuable in climate mitigation strategies (88).

Rubus species produce nectar- and pollen-rich flowers, attracting a wide range of pollinators. Their ecological interactions with insects make them critical components of pollination networks as they are predominantly insect-pollinated, with flowers that produce substantial quantities of nectar, attracting a diverse array of pollinators (89). Studies have identified specific pollinators for various species; for example, cloudberry is pollinated by insects, including bees and flies (90). The bramble (*Rubus fruticosus* L.) has been recognized for its valuable role in supporting a wide range of flower-visiting insects, including bees, butterflies and hoverflies. The pollination ecology of cultivated and wild raspberry (*Rubus idaeus* L.) has been extensively studied, revealing that factors such as time of sampling, insect visitor activity, flower age and weather conditions significantly influence nectar availability and, consequently, pollination success. Additionally, the functional diversity of pollinators, encompassing various species and groups, has been shown to enhance fruit and seed set in raspberry cultivars, highlighting the importance of maintaining diverse pollinator communities for optimal reproduction (91, 92).

Horticulturally, *Rubus* plants are valued for their aesthetic appeal and ecological benefits. Their flowers provide nectar for pollinators like bees, while the fruits attract birds and mammals, enhancing biodiversity within cultivated landscapes (93). Moreover, the dense growth habit of many *Rubus* species offers shelter for small mammals, further supporting local wildlife populations. However, it is important to note that certain *Rubus* species, such as the blackberry (*Rubus fruticosus* L.), have exhibited invasive tendencies in regions like Australia and New Zealand, where they have been recognized as significant weeds impacting native vegetation and agricultural lands. (94).

The genus *Rubus*, encompassing species such as raspberries and blackberries, has been integral to traditional medicine across various cultures for centuries. Ancient pharmacopoeias from Europe and China document the medicinal use of *Rubus* species, highlighting their longstanding therapeutic applications (95). Phytochemical analyses reveal that *Rubus* species are rich in bioactive compounds, including polyphenols, flavonoids, tannins and terpenoids. These constituents contribute to their diverse pharmacological properties. Preliminary studies suggest that *Rubus* species may possess neuroprotective properties. Extracts have shown potential in modulating neurotransmitter activity, indicating possible applications in managing neurological disorders (96).

The antioxidant potential of *Rubus* species is primarily attributed to their high polyphenol content. These compounds scavenge free radicals, thereby reducing oxidative stress and potentially lowering the risk of chronic diseases. Extracts from *Rubus* leaves have demonstrated significant anti-inflammatory properties (97). These effects are largely due to the presence of ellagitannins and flavonoids, which inhibit pro-inflammatory mediators. The antimicrobial activity of *Rubus* species has been documented against various bacterial pathogens. Studies indicate that leaf extracts exhibit inhibitory effects on bacterial growth, supporting their traditional use in treating infections (98).

Certain *Rubus* species have been investigated for their antidiabetic effects. Compounds such as flavonoids and tannins may enhance insulin sensitivity and modulate glucose metabolism, offering potential benefits for diabetes management along with that these compounds have been observed to suppress tumour cell proliferation through various mechanisms, including the induction of apoptosis and inhibition of cell signalling pathways, which ultimately reduces the danger of cancer (96).

Major research gaps

The concerned genus *Rubus* play a significant ecological role in the Forest ecosystem like regeneration, pollination network and food sources for wildlife (99). However, despite such ecological contribution, several research gaps are prevalent.

a. **Taxonomic and phylogenetic uncertainty:** *Rubus* is known for its complex taxonomy due to hybridization, polyploidy and apomixes. Limited molecular studies have been conducted to resolve species boundaries (100). Along with that, there lack of global phylogenetic frameworks which can integrate morphological and genetic data.

b. **Ecological interaction and functional role:** There is an insufficient study regarding the role of the genus in forest succession and soil stabilization. Poor understanding of its interaction with pollinators, herbivores and microbial communities again creates an insufficient research platform for this important genus. Research data for another major research area such as carbon sequestration and nutrient cycling for this genus is in its minimum, which again diminish its importance in forest ecosystem.

c. **Invasive potential and impact on biodiversity:** Several *Rubus* species are invasive in nature such as *Rubus armeniacus* Focke, *Rubus idaeus* L., *Rubus alceifolius* Poir, they are found heavily outside their native range (101). So, there is a minimum study regarding the impact of this invasive nature of this flora on the native flora & fauna is available. This genus has been considered as an invasive species in some localities but there is absolutely no research output regarding the management strategies and control its invasive nature.

d. **Climate change & Environmental adaptation:** Limited knowledge about the resilience of *Rubus* species to climate change is available. The specific interaction of this particular genus with the climatic adaptability and changing environment is of utmost importance and can provide a path for other floral components growing in the same climatic condition. There is a huge uncertainty regarding their response to extreme climatic conditions like higher temperature, drought and altered precipitation patterns. So much study on this adaptive mechanism is required.

e. **Ethno-botanical and Agro-ecological potential:** Due to the palatable nature of fruit, it has a huge potential in sustainable agriculture and food security. But unfortunately, there is a large unexplored potential in it. Along with the food security, the fruits have high medicinal properties due to the presence of a higher number of antioxidants. So, many studies on these medicinal properties, such as photochemical and antimicrobial activities, are needed to prove its true potential. Regarding the sustainability of agro-ecological condition, the potential of this genus in the form of ecological restoration and agro-forestry systems, is totally unexplored.

Future prospective

The genus *Rubus* holds ecological, agricultural and economic significance. However, taxonomic confusion, limited ecological data and the lack of comprehensive climatic adaptation studies hinder its full understanding. Future research integrating molecular tools, ecological modeling and conservation strategies is crucial for maximizing the ecological and economic potential of *Rubus*. There are some suggestive future prospects regarding the research of the genus mentioned below:

a. **Integrative taxonomic approaches:** By using genomics, transcriptomics, proteomics and metabolomics to clarifying species relationships and their interaction with surrounding vegetation can be performed. Standardized DNA bar-coding can be done for identification of economically better species.

b. **Ecological modelling and conservation strategies:** Through proper ecological modeling, the habitat suitability under different change scenarios can be predicted for the species. This ecological niche modeling is also very much helpful for conservation planning for rare and endangered *Rubus* species. This can be helpful regarding the ecological restoration and land reclamation.

c. **Sustainable utilization and agro-ecological application:** Domestication and breeding programs for climate resilient *Rubus* varieties and their role in organic farming and perma-culture will enhance the sustainable utilization. Evaluating their potential as bio-resources for natural dyes, antioxidant and pharmaceuticals can be done.

d. **Invasive species management:** As some species in the genus *Rubus* have allelopathic effects and competition mechanisms, it is of utmost importance to have clear knowledge regarding the invasive dynamics so that a bio-control method for controlling the invasion can be developed.

e. **Climate resilience and ecosystem services:** The contribution of the genus *Rubus* in various ecosystem functions, including pollination, erosion control and soil stabilization is also a matter for higher research. Along with that, the capacity for genetic resilience and climatic adaptability of the genus in different climatic conditions can also be a matter of investigation.

Conclusion

The genus *Rubus* is a very diversely distributed on almost every geographical landmass of the globe except Antarctica, with the maximum number of hybrids and varieties. Southeast Asia (Palaeo-tropical Kingdom), South America (Neo-tropical Kingdom) and East Asia (Boreal Kingdom) can be identified as the center of origin for this genus and all species of this genus originated either from this region and were distributed to other parts of the world or originated from the sexual dimorphism between species. Regarding the subgenera, *Idaeobatus*, *Eubatus* (later known as *Rubus*) and *Malachobatus* are found to be the major source of almost all *Rubus* species in the world. The species of this genus are native to six continents and their occurrence stretches at an elevation from mean sea level to 4500 m. As East Asia is a phytogeographic center for this genus, India has a great diversity of *Rubus* species under the *Malachobatus* subgenus. *Rubus* is distributed abundantly in both Pan-India and the Himalayan region (both in the eastern and western parts) and is reported principally in dense tropical forests as well as temperate regions with an altitudinal range of 300 m to 3500 m.

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Authors' contributions

All co-authors contributed to the draft version of the work and approved the manuscript for submission. JD, US done the conceptualization, supervision, project administration, investigation, resources and data curation. Writing original draft, review and editing were done by JD, US, SS.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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