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REVIEW ARTICLE

Conservation and pharmacological significance of endangered *Cinnamomum* spp. in India- A review

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Abstract

India, a hotspot of biodiversity, supports a rich diversity of *Cinnamomum* spp., most of which are endemic and rapidly declining because of habitat destruction, overharvesting and climate change. The rich bioactive diversity of the species rendered them the backbone of traditional medicine and contemporary pharmacology and demonstrated impressive anti-inflammatory, antimicrobial, anticancer, anti-diabetic and hepatoprotective potentials. They have also been utilized in folk medicine for the treatment of asthma, rheumatism, respiratory conditions, gastrointestinal issues and liver ailments. Although they hold promising medicinal potential, most of the species are threatened by extinction from indiscriminate harvesting, forest destruction and global environmental change that sends an alarm of issues regarding the loss of useful genetic resources, not just for their medicinal traits but also for their increasingly valued position in the international market for natural health products. The presence of various bioactive compounds identified from these species, such as cinnamaldehyde, eugenol, geraniol, linalool, α-phellandrene and benzyl benzoate, led to the anti-inflammatory, anti-microbial, anticancer, anti-diabetic and hepatoprotective activities. This review presents phytochemical profiling and therapeutic prospects of various red-listed *Cinnamomum* spp. distributed in India. The review emphasizes the need to preserve the wild species, which are effective providers of the world market demand of linalool, eugenol, safrole and eucalyptol and play a crucial role in the ecological and economic well-being of the nation.

Keywords: *Cinnamomum*; conservation; endangered species; medicinal plants; phytochemicals; therapeutic potential

Introduction

The *Cinnamomum* (Cinnamon) genus is part of the Lauraceae family (1), which has a broad distribution in tropical and subtropical parts of Asia and sections of South and Central America, Africa and Australia (2). The Lauraceae family comprises around 56 genera and 2700 species, of which *Cinnamomum* Schaeffer is a commercially cultivated species and one of the leading contributors to the cinnamon industry. The genus consists of approximately 300 species and is found all over the world and in numerous parts of India as in Western Ghats, Eastern Himalayas, Northeastern India and the Andaman and Nicobar Islands. Among 43 species of *Cinnamomum* along with two varieties that are found in India; 24 species are endemic in India and 13 species are endemic in the Western Ghats (3). Cinnamon Research Institute (CRI) was created in 1980 in Sri Lanka and today comprises around 602 accessions of better genotypes of cinnamon, based on resistance to insect pests and diseases, quality and quantity of produce (4).

It was also reported that 408 accessions, 166 cultivated forms and 14 exotic accessions of cinnamon were conserved at the IISR, Kozhikode (5). Several Indian *Cinnamomum* species that are threatened, such as *C. malabatrum*, *C. travancoricum*, *C. parthenoxylon* and *C. champokianum*, contain bioactive compounds that are rich in cinnamaldehyde, camphor, eucalyptol, eugenol, linalool and safrole. The compounds are anti-inflammatory, antimicrobial, antioxidant, anti-cancer and anti-diabetic and therefore find applications in the pharmaceutical and cosmetics industries. These species are traditionally used in local medicine to treat conditions such as asthma, fever, rheumatism, cold and digestive problems and hence their therapeutic value has been appreciated over generations. The wild species of *Cinnamomum* can be preserved not only to ensure biodiversity but also to maintain their special and precious phytochemical characteristics.

Genetic diversity in the wild population is significant because it can possess some favourable traits that can be

applied to the development of cultivated varieties and drugs. International Union for Conservation of Nature (IUCN) has categorized most wild *Cinnamomum* spp. under threatened categories because of habitat degradation, increased population decline, widespread deforestation for Agriculture, unsustainable bark and leaf harvesting for traditional medicine and climate change. Many of the wild species are listed as endangered, least concerned and vulnerable by the IUCN. Despite their pharmacological potential, many wild *Cinnamomum* spp. are underutilized and poorly documented. This review examines and documents the phytochemical diversity, medicinal significance and conservation status of twenty-three endangered *Cinnamomum* species, native to and distributed in India. The review covers phytochemical compounds revealed by GC-MS and HPLC methods, indigenous medicinal applications and conservation rankings according to IUCN Red List criteria. The review is intended to advance the wild and threatened *Cinnamomum* species to sustainable utilization and biodiversity conservation, guaranteeing the realization of their full potential in medical and conservation practice.

Overview of Cinnamomum Schaeffer species in India

The genus *Cinnamomum* consists of several groups of trees with numerous beneficial components. It is commonly found in the Eastern Himalayas and Western Ghats of India. The twenty-three species from the genus have been compared and assessed for their conservation status, as presented in Table 1. The trees are highly variable in size, from 25 m tall trees to 5-6 m dwarf shrubs. All the species occur naturally in India and are highly distributed in India's regions, such as Kerala, Karnataka and Tamil Nadu and the Eastern Himalayas, such as Assam, Arunachal Pradesh and Sikkim.

The *Cinnamomum* genus exhibits enormous morphological diversity, in the form of evergreen shrubs or trees with leathery, simple, opposite, or sub-opposite leaves 3 -30 cm long. The leaves are elliptic, lanceolate and scented. Flowers are small to medium in size, white or yellow. They are bisexual (occasionally polygamous) and arranged in axillary panicles. 6-lobed perianth, 3 whorled, 9 fertile stamens and 3 staminodes. A delicate form and a capitate, discoid, or trilobed stigma follow the ovary. The fleshy fruit, usually a berry or drupe, possesses a long perianth cup that protrudes from it. It is conical, cupliform, or campanulate and may be truncated, undulated, or denticulate in its margin. They owe their economic significance and ecological versatility to these physical features.

Cinnamomum spp. are found at diverse altitudes from sea level, ranging up to 2600 m. They are found in evergreen forests, wet environments, mountain slopes and along rivers. The reproductive cycle of *Cinnamomum* spp. is typically between January and October, with the peak flowering from March to May. The vast differences among them emphasize their ecological adaptability and their role in evolution.

IUCN categorization of *Cinnamomum* spp.

The International Union for Nature Conservation (IUCN) is a worldwide governing body that classifies species in terms of their extinction risk and notes the species in need of conservation. According to IUCN data, about 40 % of the *Cinnamomum* species are threatened with extinction (Fig. 1). Aspects such as population decline, loss of habitat and threat by human activities, are divided into several levels, including Critically Endangered (CR) Species that are under a very high risk of extinction in the wild (Fig. 2); Endangered (EN) Species under a very high threat of extinction (Fig. 3); Vulnerable (VU) Species under a high threat of extinction due to reduced populations (Fig. 4); Least Concerned (LC) Species that are not presently under significant threat (Fig. 5) and Near Threatened (NT) Species near entering a threatened category. It is a sign of the well-being of the world's biodiversity.

Sri Lanka, a major producer of Cinnamon, consists of eight endemic Species. Among them, some are under the endangered and critically endangered categories, such as *C. sinharajaense*, *C. capparu coronde* and *C. litseafolium,* respectively. They have high concentrations of essential bio-actives like eugenol and cinnamaldehyde in their bark or leaf oils, competing with the commercially cultivated species (6). The linalool and citronellal from *C. capparu coronde* and *C. citriodorum* are the other valuable components of these species and are largely used in traditional medicines. *C. dubium, C. ovalifolium and C. rivulorum* are other species that are endemic to Sri Lanka and are categorized as threatened species (7).

Thus, most of the Indian endemic *Cinnamomum* spp. containing precious bio-actives, which belong to threatened categories (3) are accounted for in the subsequent Table 1. Although the ecological and pharmacological significance of such threatened *Cinnamomum* spp. is much greater, nevertheless, there is little information about several mature

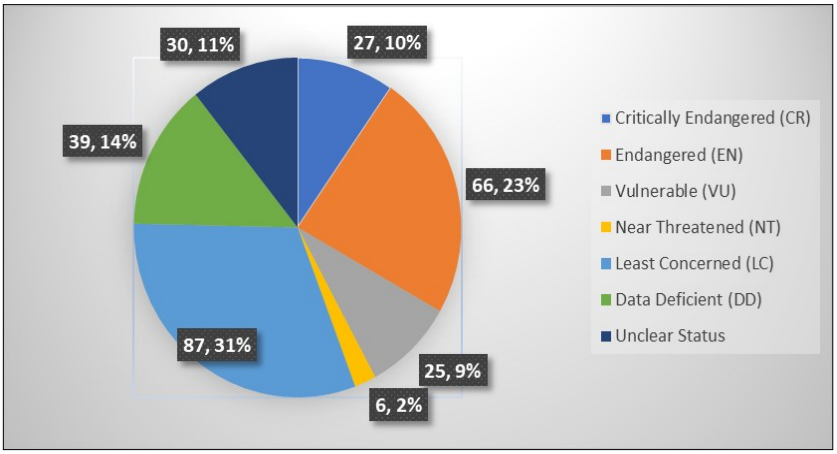

Fig. 1. Conservation status of *Cinnamomum* spp.

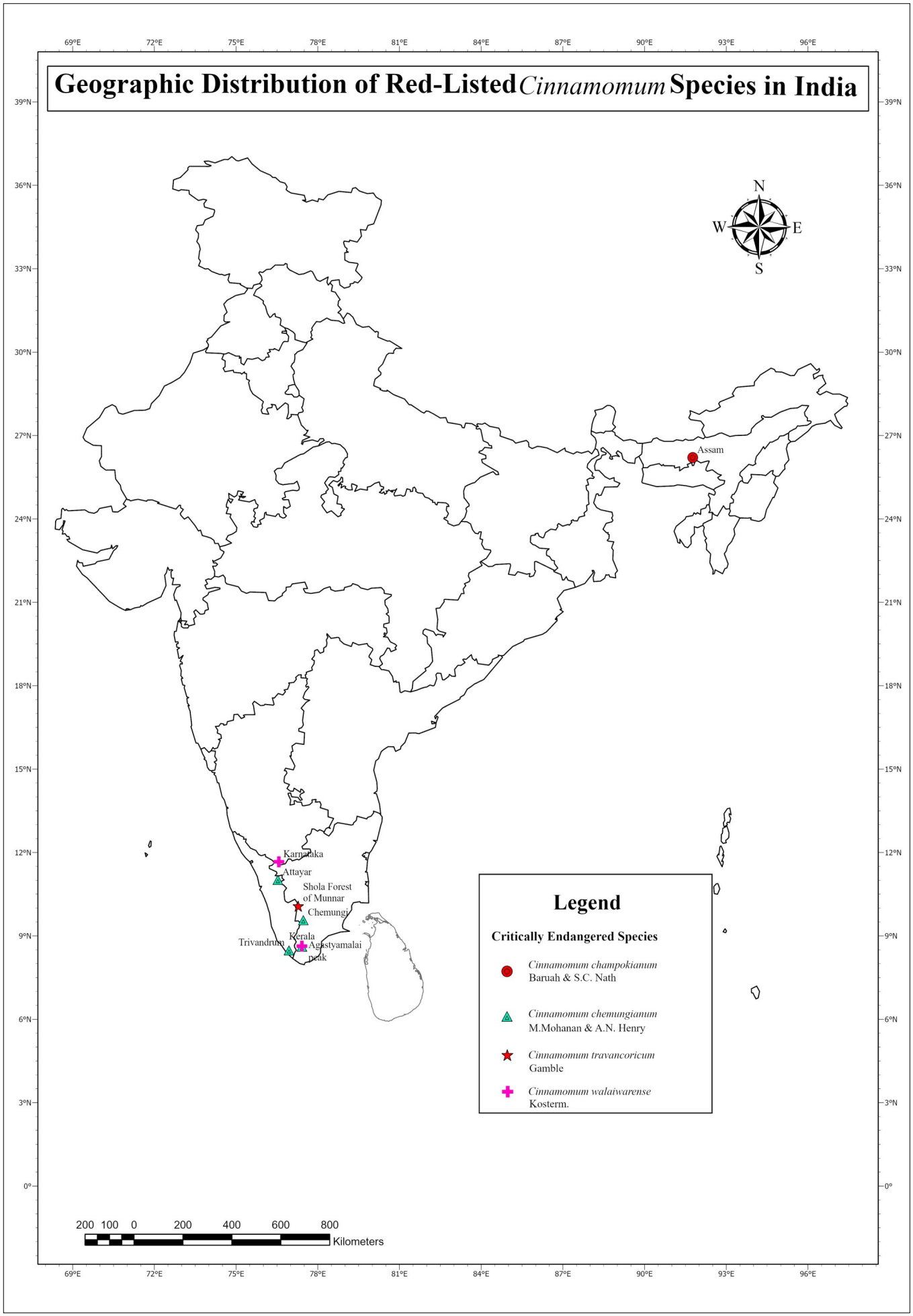

Fig. 2. Critically Endangered *Cinnamomum* spp. in India.

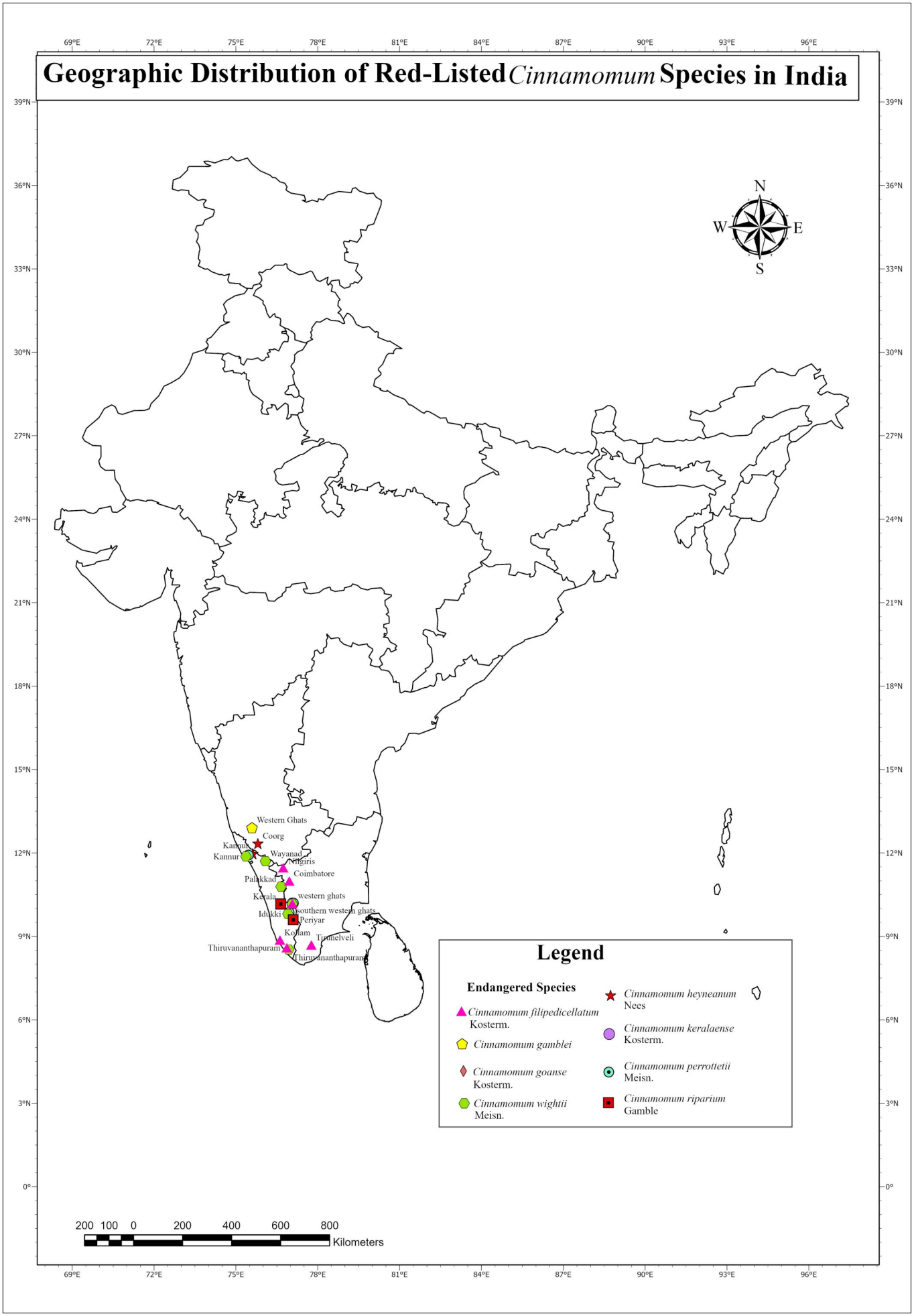

Fig. 3. Endangered *Cinnamomum* spp. in India.

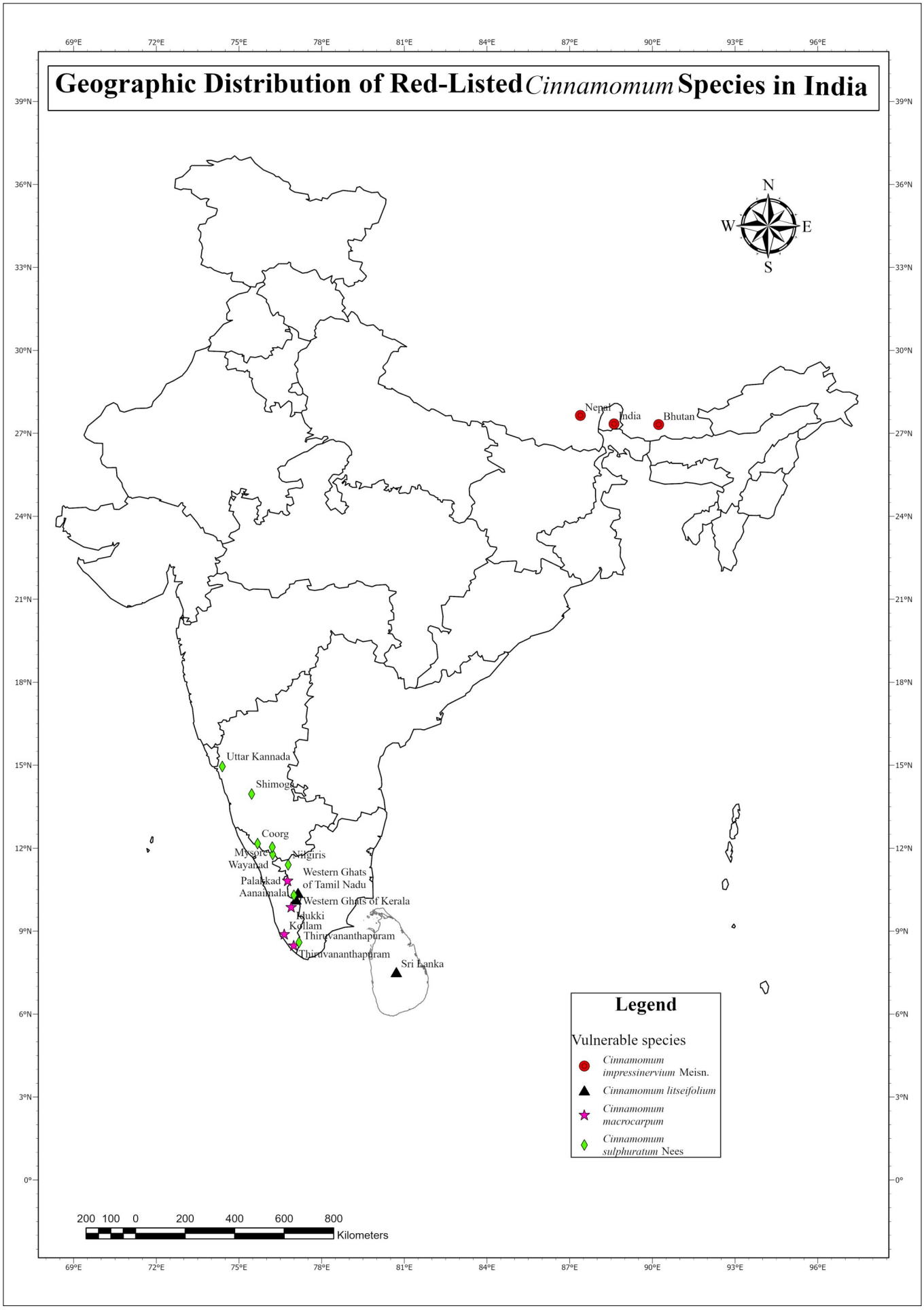

Fig. 4. Vulnerable *Cinnamomum* spp. in India.

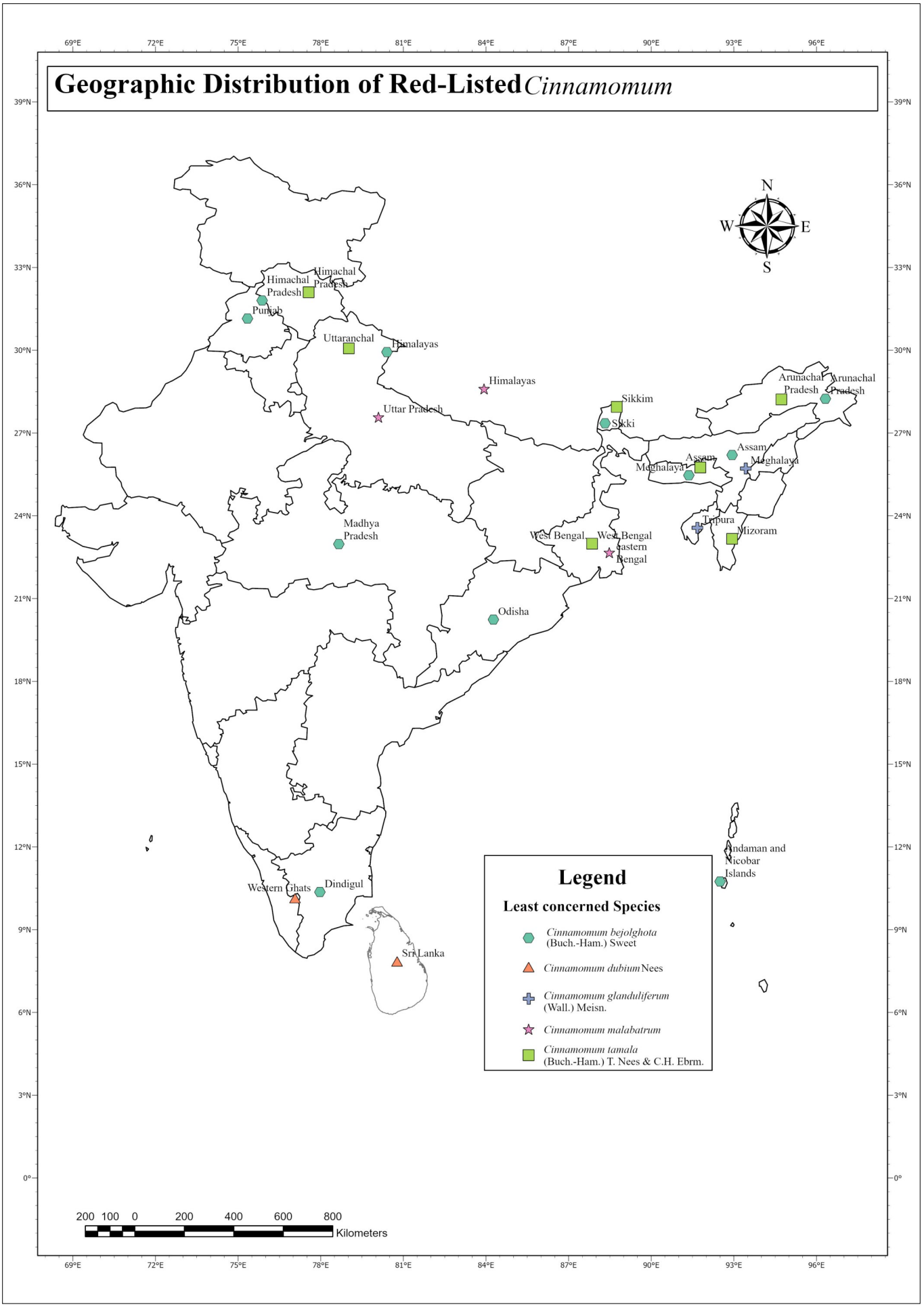

Fig. 5. Least concerned *Cinnamomum* spp. in India.

Table 1. IUCN status, phenology and distribution of threatened *Cinnamomum* spp. in India

Species	IUCN categorization	Phenology	Distribution	References
***Cinnamomum bejolghota* (Buch.Ham.) Sweet**	Least concerned species	Flowering: January - April Fruiting: May-August	Native to the Indo-Chinese region. Distributed in the central and outer parts of Eastern Himalayas, Tamil Nadu (Dindigul) andaman and Nicobar Islands, Arunachal Pradesh, Himachal Pradesh, Madhya Pradesh, Assam, Meghalaya, Orissa, Punjab, Sikkim, West Bengal.	(7, 10-12)
***Cinnamomum champokianum* Barua & S.C. Nath**	Critically endangered species	Flowering: March-May Fruiting: June-September	Endemic to Assam	(13)
***Cinnamomum chemungianum* M.Mohanan & A.N.Henry**	Critically endangered species	Flowering and Fruiting: February to May.	The species are endemic to Western Ghats, found in the evergreen forest and are distributed in the regions of Chemungi, Agasthymala Peak, Attayar and the Thiruvananthapuram district, at an elevation of 700-1500m.	(14, 15)
***Cinnamomum dubium* Nees**	Least concerned species	Flowering and fruiting: October - April.	It is a wild species of Sri Lanka and is distributed in the western Ghats, found at elevations from 750-1500 m.	(16, 17)
***Cinnamomum filipedicellatum* Kosterm**	Endangered species	Flowering and Fruiting: February to March.	The species are endemic to the southern western ghats, they are distributed in Kerala (Kollam and Thiruvananthapuram districts), Tamil Nadu (Coimbatore, Nilgiris, Tirunelveli) and grow at an elevation ranging from 700-1500 m.	(18, 19)
Cinnamomum gamblei	Least concerned species	Flowering and fruiting: March to October	Endemic to Western Ghats and distributed in Kerala and Tamil Nadu at an altitude of 850-1300 m.	(20)
***Cinnamomum glanduliferum* (Wall.) Meisn.**	Endangered species	Flowering: March to May Fruiting: July to September.	The species are distributed in India (Assam, Meghalaya, Tripura), at an altitude of 1500-2500m.	(21)
***Cinnamomum goanse* kosterm**	Vulnerable species	Flowering and Fruiting: March to September	The species are endemic to Western Ghats and are distributed at an altitude of 600 m in Kerala and Karnataka Districts	(9)
***Cinnamomum heyneanum* Nees**	Least concerned species	Flowering and Fruiting: November to March.	The species are rare and endemic to the southern western ghats and are distributed in Karnataka- Coorg district, Kerala-Kannur district. grown well in altitudes ranging from 70-300 m.	(22, 23)
***Cinnamomum impressinervium* Meisn.**	Endangered species	Flowering and Fruiting: July to December.	Endemic to the eastern Himalayas. Distributed in India, Bhutan and Nepal, grown at an altitude of 1500-2500 m.	(10, 24, 25)
Cinnamomum iners	Vulnerable species	Flowering and fruiting: March to June.	Distributed in Southeast Asia from Indo-China, Sumatra, Peninsular Malaysia, Java and the Philippines and grows at an altitude of 1200 m.	(26, 27)
***Cinnamomum keralaense* Kosterm**	Vulnerable species	Flowering and fruiting: December to January.	Endemic to Western Ghats and are grown at an altitude of 600-1500 m.	(19)
Cinnamomum litseifolium	Least concerned species	The flowering and fruiting: March to October.	Distributed in India (Western Ghats of Kerala and Tamil Nadu) and Sri Lanka and are grown at an altitude of 1100 m.	(28)
Cinnamomum macrocarpum	Least concerned species	Flowering and Fruiting: February to March.	Endemic to the southern western ghats and are distributed in the Kollam, Idukki, Palakkad and Thiruvananthapuram, growing in the elevation ranges from 900 and 2000 m.	(3)
Cinnamomum malabatrum	Endangered species	Flowering and fruiting: March to April	Distributed in the tropical and sub-tropical Himalayas, eastern Bengal, UP and Burma, grows at an altitude of 1000 m.	(29)
***Cinnamomum parthenoxylon* (Jack) Meisn**	Endangered species	Flowering: March to May Fruiting: April to October.	Distributed in Vietnam, Asia, the Tropical of Assam, the East Himalayas, Nepal, Myanmar, Jawa, Thailand and Malaya, grows at an altitude of 200 m	(30)
***Cinnamomum perrottetii* Meisn. In**	Vulnerable species	Flowering and fruiting: February to May.	Endemic to the Western Ghats, distributed in the Kannur and Idukki districts of Kerala	(3)
***Cinnamomum riparium* Gamble**	Least concerned species	The flowering and fruiting: February to March.	Distributed in South India (Kerala & Tamil Nadu), rare, on the banks of a river (Periyar) and grows at an altitude between 300 and 1000m.	(31, 32)
***Cinnamomum sulphuratum* Nees**	Critically endangered species	The flowering and fruiting: March to April.	Endemic to southern India and are distributed in the Western Ghats regions of Tamil Nadu (Nilgiris, Aanaimalai), Kerala (Thiruvananthapuram, Wayanad), Karnataka (Coorg, Mysore, Shimoga and Uttar Kannada districts). They grow at an altitude between 1000 and 2400 m.	(33)
***Cinnamomum tamala* (Buch. - Ham.)**	Critically endangered species	Flowering and fruiting: April to May.	The species are found in moist habitats and are distributed in Arunachal Pradesh, Uttaranchal, Himachal Pradesh, Assam, Meghalaya, Mizoram, Sikkim and West Bengal., grow at an altitude of 1100-2000 m.	(34, 35)
***Cinnamomum travancoricum* Gamble**	Critically Endangered species	Flowering: November to March	Endemic to the southern Western Ghats and grows at an altitude of 2000 m. They are distributed in the Shola Forest of Munnar in Idukki District, Kerala.	(8, 36)
***Cinnamomum walaiwarense* Kosterm**	Critically Endangered species	Flowering and fruiting: March to September.	Endemic to the Southern Western Ghats (Kerala and Karnataka) and are found at an altitude of 100 to 1000 m.	(37)
***Cinnamomum wightii* Meisn**	Least concerned species	Flowering and fruiting: April to June.	Endemic to the southern western ghats and are found in elevation ranges from 900-2600 m. They are distributed in the regions of Palakkad, Idukki, Wayanad, Thiruvananthapuram, Kannur)	(38)

plants and the population size. The population census of the species indicated that species such as *Cinnamomum travancoricum*, which is a critically endangered species, occur with fewer than five mature individuals in the wild (8). Likewise, in the Western Ghats, *Cinnamomum macrocarpum* occurs and contains 250 to 2500 mature individuals occurring in the population and decreasing by over 30 % within the past three generations. Re-discovery of *Cinnamomum goaense* from the Thodupuzha district approximated less than 25 mature individuals, a restricted range and a small population (9). Most of the rest of the species lack even a full population study.

Conservation of threatened *Cinnamomum* Schaeffer species

The endemic *Cinnamomum* species of India are under threat and their population is largely reduced due to habitat destruction and over-harvesting. *Cinnamomum travancoricum* in humid evergreen forests of Kerala and Tamil Nadu is severely uneven in habitat and over-harvested for its bark and oils containing eugenol, cinnamaldehyde and linalool (39, 40). *C. wightii*, endemic in southern India's forests, is of very poor population density and poor documentation rate despite its ethnomedicinal potential (41). *C. macrocarpum* and *C. riparium*, both are poorly explored with unique flavonoid and phenolic profiles with neuroprotection potential, but are of poor conservation focus. Similarly, *C. malabatrum,* occurring in the Western Ghats is threatened by habitat destruction and is not covered in formal conservation plans (42).

Conservation of the threatened *Cinnamomum* species requires not only in-situ but also ex-situ methods such as habitat management, reforestation, seed banks and micropropagation of high-yielding elite chemotypes. Conservation of traditional medicinal knowledge and biodiversity requires the participation of indigenous communities (39). All these activities must be regulated by phytochemical studies, ecological modelling and genetic analysis to ensure specific conservation methods (Fig. 6).

Medicinal and pharmaceutical potential

Some endangered *Cinnamomum* species hold high concentrations of major bioactive constituents of great pharmaceutical importance. *Cinnamomum champokianum*, for example, has linalool content extremely high at 65 %, which is a monoterpene alcohol with antimicrobial and anxiolytic activity (13, 43). *C. dubium* shows a remarkable predominance of β-caryophyllene at 41.31 %, which is a sesquiterpene with anti-inflammatory and neuroprotective activity (43, 44). Highly elevated safrole content was observed in *C. heyneanum* at 93.32 % and *C. parthenoxylon* (90.3 %), both of the secondary metabolites of interest due to their potential, but controlled by their toxicological concerns (45, 46). *C. impressinervium* contains eugenol (88.3 %), widely known for its analgesic, antioxidant and antiseptic activities (47), whereas *C. walaiwarense* contains benzyl benzoate (85.9 %), greatly valued for its acaricidal and antiparasitic activities (48) (Table 2; Fig. 7). Indigenous traditional knowledge also indicates that the species are utilized to relieve pain, skin diseases, respiratory diseases and gastrointestinal disorders (Table 3). The medicinal value of these under-explored and underutilized *Cinnamomum* species is not superior to but equal to that of the extensively researched *C. verum* and *C. cassia*.

Economic benefits of conservation

Conservation of endangered Indian *Cinnamomum* species like *C. travancoricum*, *C. malabatrum*, *C. wightii*, *C. macrocarpum* and *C. parthenoxylon* is essential not only to provide a guarantee for biodiversity conservation in the Eastern Himalayas and Western Ghats but also to achieve satisfactory economic returns. The species contains a high percentage of medicinal constituents such as cinnamaldehyde, eugenol, linalool and safrole, which are well-known for their high antioxidant, antimicrobial and anti-inflammatory activities. *C. malabatrum* has been known to treat respiratory and gastrointestinal diseases (98). Some, such as *C. travancoricum* and *C. macrocarpum*, provide aromatic oils that can find possible pharmacological applications (99). They are culturally safe and sustainable, yielding crops whose leaves and bark are utilized to produce essential oil to earn regular income without destroying the crops. Its production stimulation in agroforestry or farm integration systems helps to conserve wild resources, improves rural life and offers industry support, such as for natural remedies, cosmetics and functional foods.

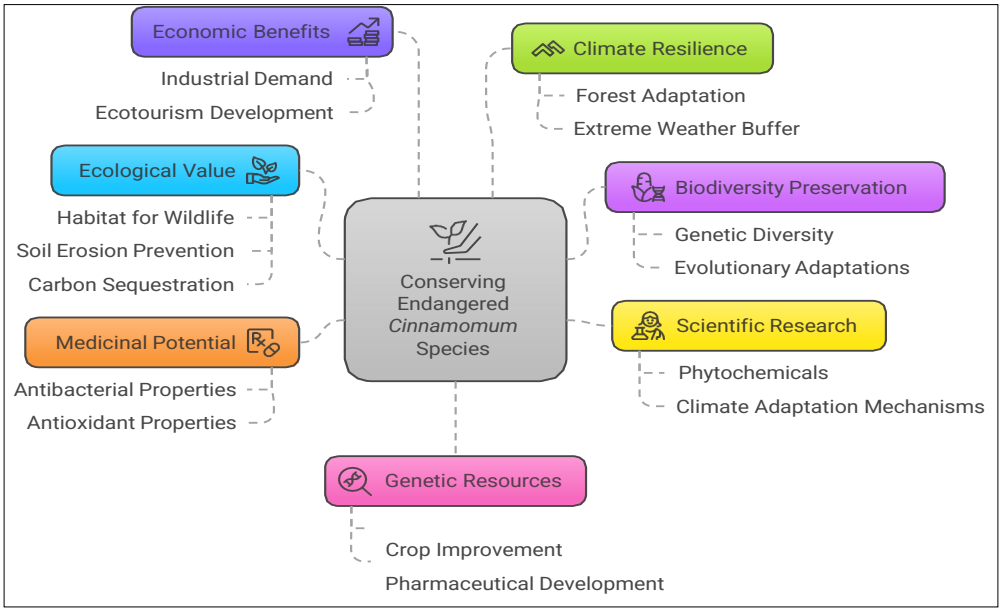

Fig 6. Benefits of conserving endangered *Cinnamomum* spp.

Table 2. Phytochemicals of the threatened *Cinnamomum* spp.

Species	Plant Part	Major Components	Minor Components	References
Cinnamomum bejolghota	Leaves	Linalool, linoleic acid, β-sitosterol, 1,8-Cineole, β-caryophyllene, β-phellandrene	α-terpinol, Nerolidol, Terpinen-4-ol, δ-3-carene, α-farnesene, α-phellandrene, α-pinene	(42, 49, 50)
Cinnamomum bejolghota	Bark	1,8-cineole (40.24 %), γ-Terpineol (15.41 %)	α-Pinene (6.58 %), Borneol (7.86 %), Terpinen-4-ol (7.55 %)	(51)
Cinnamomum champokianum	Leaves	α-phellendrene (32.82 %)	α-pinene (5.30 %), β-pinene (2.06 %), 1,8-cineole (5.55 %), Terpineol (2.38 %), β-caryophyllene (2.00 %), α-farnesence (11.75 %)	(13)
Cinnamomum champokianum	Panicle	Linalool (65 %)	α-phellandrene (8.90 %), 1,8-cineole (3.96 %), α-pinene (3.40 %), β-phellandrene (3.00 %)	(13)
Cinnamomum champokianum	Stem bark	α-terpineol (23.30 %), Linalool (14.40 %), p-cymene (13.90 %)	α-pinene (5.30 %), 1,8-cineole (6.85 %), (E)-methyl cinnamate (3.06 %)	(13)
Cinnamomum chemungianum	Leaves	Benzyl Benzoate (66.36 %), α-Terpineol (9.83 %), β-selinene (21.0 %), Linalool (19.63 %)	Intermedeol (13.5 %), Longiborneol (7.1 %), Caryophyllene oxide (6.4 %),	(52)
Cinnamomum dubium	Leaves	Caryophyllene oxide 64.6 %, β-selinene (21.0 %), Intermedeol (13.5 %), α-Terpineol (13.18 %)	4-terpineol (5.421 %), α-Santalene (4.583 %) Longiborneol (7.1 %)	(16, 42)
Cinnamomum dubium	Bark	β-Caryophyllene (41.31 %)	Geraniol (3.86 %), Hydrocinnamic aldehyde (7.70 %), Cinnamyl alcohol (8.61 %)	(43)
Cinnamomum filipedicellatum	Leaves	Cryptone (36.6 %)	ρ-cymene (10.8 %), Cuminaldehyde (7.7 %) Limonene (6.4 %),	(18)
Cinnamomum glanduliferum	Leaves	Eucalyptol (59.44 %), Sabinene (14.99 %)	α-Terpineol (6.44 %), α-Pinene (5.27 %), β-Pinene (3.75 %)	(53)
Cinnamomum glanduliferum	Branch	Eucalyptol (55.74 %), α-Terpineol (9.81 %)	Sabinene (7.02 %), α-Pinene (4.71 %), Terpinene-4-ol (5.75 %)	(53)
Cinnamomum heyneanum	Leaves	Safrole (93.32 %)	β-Caryophyllene (1.09 %), Caryophyllene oxide (1.22 %)	(45)
Cinnamomum impressinervium	Leaves (Wild)	Eugenol (83.2 %)	δ-3-carene (7.2 %), Limonene (2.3 %), α-pinene (1.2 %)	(47)
Cinnamomum impressinervium	Leaves (Cultivated)	Eugenol (88.3 %)	Limonene (4.1 %), δ-3-carene (1.6 %), Eugenol acetate (1.1 %)	(47)
Cinnamomum iners	Leaves and stems	Geraniol 63.65 %, Linalool (19.4 %).	(E)-caryophyllene 4.80 %, Geranyl propanoate 3.51 %	(54)
Cinnamomum keralaense	Leaves	Benzyl benzoate (58.1 %), (Z)-methyl cinnamate (13.2 %)	(E)-Cinnamyl acetate (10.2 %)	(42)
Cinnamomum litseifolium	Leaves	α-phellandrene (32.1 %)	δ-Cadinene (5.4 %), Bicyclogermacrene (5.5 %), ρ-Cymene (2.6 %), Linalool (1.2 %).	(42)
Cinnamomum macrocarpum	Bark	Benzyl benzoate (49.68 %)	Linalool (6.66 %), cinnamyl acetate (3.09 %), 1-Naphthalenol (2.69 %).	(55)
Cinnamomum macrocarpum	Leaves	γ-Terpinene (21.47 %)	Cinnamyl acetate (4.65 %), α-phellandrene (4.07 %)	(55)
Cinnamomum malabatrum	Leaves	Bicyclogermacrene (18.23 %), Linalool (17.80 %), Trans-caryophyllene (14.38 %), Spathulenol (13.88 %)	Germacrene (9.50 %), Alloaromadendrene (7.42 %), Epiglobulol (4.95 %), δ-Cadinene (4.33 %)	(56)
Cinnamomum parthenoxylon	Root bark	Linalool (81.4 %), Benzyl benzoate (52.0 %)	δ-cadinene (5.4 %), Calamenene (4.5 %), Safrole (3.1 %), - α copaene (2.5 %)	(46)
Cinnamomum parthenoxylon	Wood	Safrole (90.3 %)	Eugenol (4.5 %), elemicin (2.6 %)	(46)
Cinnamomum perrottetii **Meisn**	Leaves	Shyobunol (13.31 %)	α-humulene (10.91 %), α-Cadinol (10.86 %)	(57)
Cinnamomum riparium **Gamble**	Leaves	Methyl eugenol (62.73 %)	Safrole (34.06 %)	(58)
Cinnamomum riparium **Gamble**	Bark	Methyl eugenol (52.71 %), 1,4 Cineole (59.4 %)	Safrole (26.57 %)	(42, 58)
Cinnamomum sulphuratum **Nees**	Leaves	Germacrene D (7.89 %)	Geranial (27.8 %), geraniol (23.2 %), β - Selinene (5.66 %), Isocaryophyllene (5.51 %), β -Elemene (5.44 %)	(57, 59)
Cinnamomum sulphuratum **Nees**	Stem bark	(E)-cinnamaldehyde (65.6 %)	(E)-cinnamyl acetate (5.4 %), tetradecanal (4.6 %)	(59)
Cinnamomum tamala	Leaves	Eugenol (66.1 %)	Caryophyllene oxide (4.8 %), spathulenol (4.8 %)	(35)
Cinnamomum travancoricum **Gamble**	Leaves	Linalool (23.6 %), β-phellandrene (12.6 %)	Safrole (6.8 %), α-phellandrene (5.9 %) and shyobunol (5.1 %)	(40)
Cinnamomum walaiwarense **Kosterm**	Leaves	Benzyl benzoate (85.9 %)	Linalool (3.5 %), limonene (6.1 %)	(48)
Cinnamomum wightii **Meisn**	Leaves	Spathulenol (31.0 %), linalool (24.3 %), β-Phellandrene (26.6 %)	Sylvestrene (6.0 %), α-Phellandrene (10 %), ρ-Cymene (9.1 %)	(48)

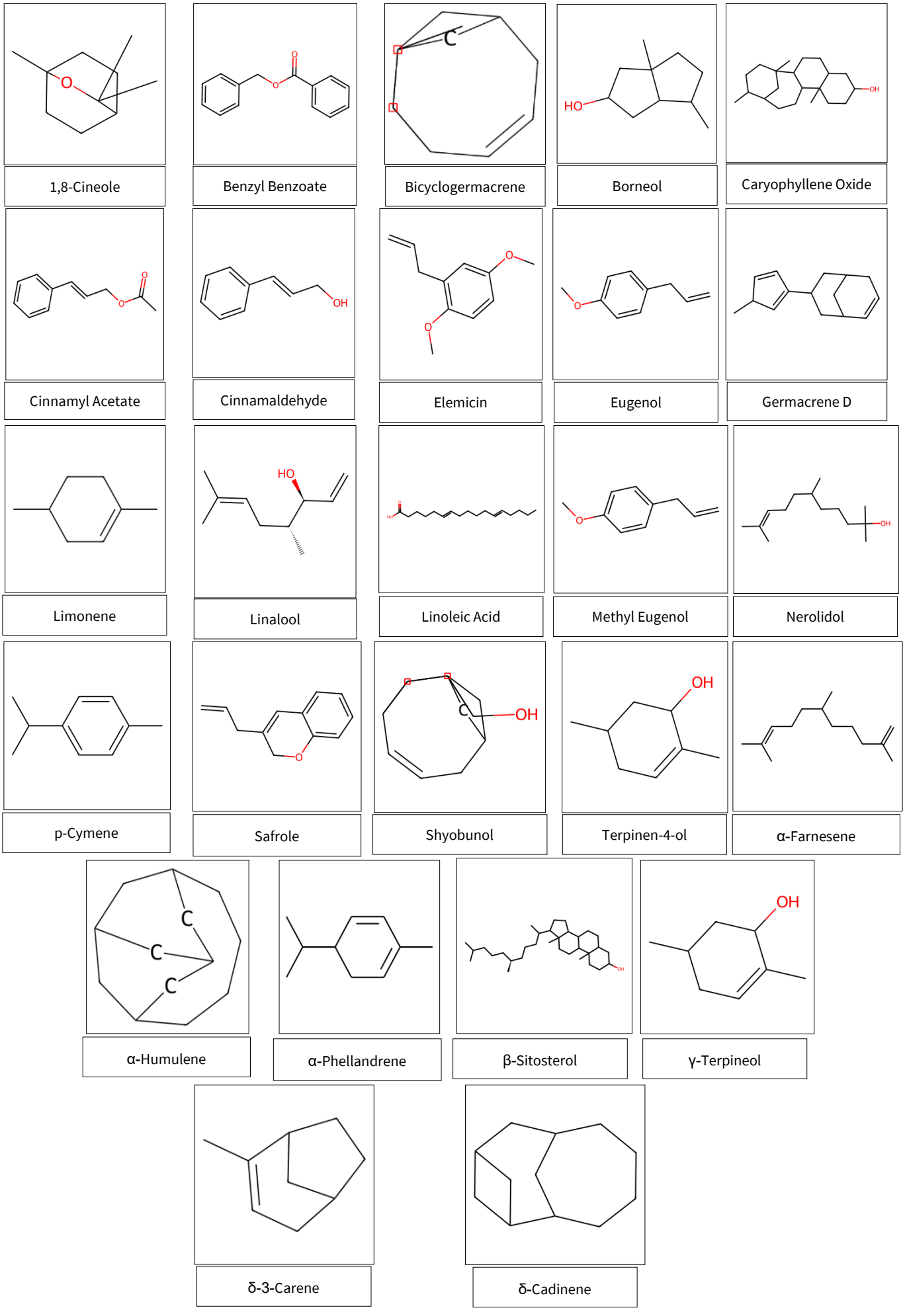

Fig. 7. Bioactive components of threatened *Cinnamomum* spp.

Table 3. Pharmacological properties and medicinal use of threatened *Cinnamomum* spp.

Species	Pharmacological activity	Medicinal uses	References
***Cinnamomum bejolghota* (Buch. -Ham.) Sweet,**	Allergen Reduction Activity, Anthelmintic Activity, Anti-Diabetic Activity, Antimicrobial Activity, Antioxidant Activity, Moderate Cancer Cell Proliferation Inhibitory Activity	Used in the treatment of cough, cold, toothache, liver complaints, gall stones, mouth freshener, wounds, stomach disorder, fever, liver trouble, urinary stones, helminthiasis, blood pressure, rheumatoid arthritis, influenza and malaria.	(7, 11, 49, 50, 60)
***Cinnamomum champokianum* Barua & S.C. Nath**	Anti-microbial activity, anti-inflammatory activity and anti-oxidant activity	Used in the treatment of asthma	(43)
Cinnamomum chemungianum	Anti-bacterial, anti-diabetic, anti-oxidant, lipase inhibitory activity.	Used to alleviate gastrointestinal issues, act as a carminative and digestive aid.	(14, 52, 61)
***Cinnamomum dubium* Nees**	Anti-inflammatory, anti-biotic, anti-oxidant, anti-carcinogenic	Used as a local anesthetic	(44)
***Cinnamomum filipedicellatum* Kosterm.**	Anti-bacterial activity, hepatoprotective activity	Used in the treatment of wounds, fever, intestinal worms, menstrual problems and urinary problems.	(18, 49, 62, 63)
***Cinnamomum glanduliferum* (Wall.) Meisn**	Anti-inflammatory activity, anti-bacterial activity, anti-fungal activity, cytotoxic activity, anti-cancer activity, anti-oxidant activity, anti-diabetic activity, insecticidal activity and fumigant toxicity	Used in the treatment of rheumatism, diarrhoea, respiratory problems, dyspepsia, colic, cough, asthma, snake bite, abdominal disorder, bronchitis, cold, dizziness, dysentery, gonorrhoea, kidney trouble, nausea, oral, pneumonia, shivering, toothache, pyrexia, analgesic, antiseptic, astringent, muscular swelling, joint pain	(21, 49, 53, 61, 64-68)
***Cinnamomum heyneanum* Nees**	Anti-bacterial, insecticidal, anti-inflammatory, cytotoxic, anti-hyperglycaemic activity.	-	(69)
***Cinnamomum impressinervium* Meisn**	Anti-inflammatory activity, anti-oxidant, anti-bacterial, anti-viral, anti-fungal, anti-diabetic and cytotoxicity properties.	-	(70-73)
Cinnamomum iners	Analgesic activity, anti-plasmodial activity, anti-cancer activity, anti-oxidant activity, anti-microbial activity, anti-diabetic activity and anti-hyperlipidaemic activity.	used in the treatment of abdominal pain, appetite problems, asthma, body aches, cardiac disorders, cough and cold, diarrhoea, dysentery, gynaecological disorders, rheumatism, stomach complaints, urinary diseases and wounds.	(27, 74-76)
***Cinnamomum keralaense* Kosterm.**	Anti-inflammatory activity	-	(77)
Cinnamomum litseifolium	Anti-oxidant activity, anti-hyperglycaemic activity, larvicidal activity	Used in reducing blood glucose levels, perfumes and disinfectants.	(42, 78, 79)
Cinnamomum macrocarpum	Anti-oxidant activity, anti-cholinesterase activity, anti-bacterial activity, anti-diabetic, anti-microbial activity, anti-tyrosine activity, anti-allergic, anti-nociceptive agent.	used for the treatment of cold and cough, diarrhoea, dysentery, rheumatism, sciatica pains	(49, 80, 81)
Cinnamomum malabatrum	Anti-oxidant activity, enzyme inhibitory activity, anti-bacterial activity, anti-diabetic activity, anti-carcinogenic activity, insecticidal activity, anti-inflammatory and anti-fungal activity.	used for the treatment of colic, rheumatism, scabies, disease of anus and rectum, tridosha, piles and heart troubles.	(29, 82, 83)
***Cinnamomum parthenoxylon* (Jack) Meisn**	Anti-diabetic activity, anti-oxidant activity, anti-viral activity, anti-bacterial activity, anti-fungal activity, anti-leukemic activity, hepato-protective activity, anti-inflammatory activity, anti-tyrosine activity, cytotoxicity.	Used in the treatment of Anaemia, amenorrhoea, backache, blood circulation, childbirth, dysentery, dyspepsia, impotence, pertussis, pyrexia, rheumatism, rheumatoid arthritis, stomach troubles, traumatic injury and wounds.	(49, 84-88)
***Cinnamomum perrottetii* Meisn**	Anti-bacterial activity, anti-oxidant, larvicidal activity and cytotoxic effects	-	(46, 89)
***Cinnamomum riparium* Gamble**	Anti-microbial activity, anti-oxidant activity, anti-inflammatory activity.	Used as a cytotoxic drug and in the treatment of fever, intestinal worms, headache, wound healing and menstrual problems	(90)
***Cinnamomum sulphuratum* Nees**	Anti-inflammatory activity, larvicidal activity, hepato-protective activity, anti-microbial activity.	used in the treatments of menstrual problems, pyrexia, worm infestation, wounds, urinary problems, backache arthritis, cholera, cough and cold, diabetes, headache, oral problems, dyspepsia and insect bites.	(33, 49, 57, 62, 91)
***Cinnamomum tamala* (Buch. -Ham.)**	Anti-bacterial activity, anti-yeast activity, anticonvulsant activity, anti-mitotic activity, anti-oxidant activity, cell proliferation inhibitor, gastro-protective activity, hypoglycaemic activity, insecticidal activity, anti-diabetic activity, analgesic activity, anti-inflammatory activity, antipyretic activity, anti-cancer activity, anti-HIV activity, anti-parasitic activity and Reno protective properties.	used for the treatment of nasal and chest congestion, coughs, colic, diarrhoea, rheumatism, gonorrhoea, irritations, boils, itching, conjunctivitis, loss of memory, urinary problems, fatigue and stomach ache. Used for Alzheimer's prevention potential	(61, 71, 92-97),
***Cinnamomum travancoricum* Gamble**	Anti-fungal activity, hepato-protective activity and cytotoxicity.	used for the treatment of asthma, backache, cold and cough, dental disease, mouth disease, thirst, vomiting, wounds, urinary problems	(49, 62)
***Cinnamomum walaiwarense* Kosterm**	Anti-oxidant activity, hypo-glycaemic activity, anti-fungal activity, hepato-protective activity and cytotoxicity	used for the treatment of backache, headache, menstrual problems, pyrexia, urinary problems and wounds	(48, 49, 62)
***Cinnamomum wightii* Meisn**	Anti-oxidant activity, hypo-glycaemic activity, pesticidal activity, cytotoxicity and hepato-protective activity.	used for the treatment of abdominal disorders, colic, constipation, cough and cold, diarrhoea, gynaecological disorder, headache, indigestion, insect bite, mumps, nerve disorder, paralytic disorders, pyrexia, rheumatism, stress, worm infestation, wounds	(38, 49, 92)

Economically, it is a chance for indigenous people to earn a living by harvesting judiciously, as per plant patterns and by conducting ecological studies. Small processing and distillation units near raw material value the raw material by manufacturing essential oils and extracts that can be utilized by the drug, cosmetic and spice industries. Through enforced certification, the initiative is aiming to obtain certifications such as organic or sustainably harvested, which can provide these products with a premium price in both local and export markets (100). Legislation like the Biological Diversity Act (2002), which encourages Access and Benefit-Sharing (ABS), also facilitates fair remuneration to indigenous people for the conservation of these plants (101). Conservation of such susceptible *Cinnamomum* species is good for ecological well-being and economically benefits in the long term, especially in rural and multi-ethnic areas.

Global market demand for threatened *Cinnamomum spp*.

The eucalyptol (1,8-cineole) market has grown globally due to its extensive applications in cosmetics, pharma and food and beverages. Eucalyptol is an extremely sought-after natural compound with its well-documented pharmacological effects and decongestant properties, thus possessing potential for commercially sustainable wild harvesting. A few wild and endangered species of *Cinnamomum* can also be used as alternatives, *viz., Cinnamomum bejolghota,* having about 40.24 % eucalyptol of its essential oil content (51), *Cinnamomum dubium* Nees having 51.19 % (16) and *Cinnamomum glanduliferum* having 59.44 % (53). The latter of these is also a potential carrier with a promise of delivering sustainable yields in fulfilling increasing industry demands.

Linalool is another economically valuable bioactive molecule extensively applied in the pharmaceutical and cosmetic industries and as a major intermediate in vitamins A and E manufacturing. Certain wild species of *Cinnamomum* were found to be good sources of linalool and, therefore, great substitutes as commercial processing material. Panicle of *Cinnamomum champokianum* has about 65.00 % linalool (13), while leaves of *Cinnamomum sulphuratum* have up to 92.66 % (57). There are numerous other wild high-linalool-containing species whose commercial potential is highlighted by them.

Eugenol is very much sought after for its wide range of pharmacological activities, ranging from antioxidant, antimicrobial, anti-inflammatory, anticancer, neuroprotective, anti-stress and anti-diabetic activity (102). Eugenol has far-reaching applications in perfumery, flavouring and medicine and thus, a growing demand across the world. Though initially derived from cinnamon, nutmeg and basil, clove is still the greatest commercial source, containing about 55.28 % eugenol (103). Yet, wild and endangered *Cinnamomum* spp., like *Cinnamomum impressinervium,* have been found to have significantly larger content, up to 83.2 % eugenol (47) and thus are future commercial leads.

Safrole is another significant raw material that is widely available in the chemical industry and is used extensively as a perfume and flavour material. Safrole is almost wholly derived from *Cinnamomum* plants (104) and is used as a chemical precursor to iso-safrole, which in turn is used for flavouring food and beverages. The market demand for safrole is still high in the beverage industry, particularly for use in soft drink flavoring and specialty drinks. Wild and endangered *Cinnamomum* spp., such as *Cinnamomum heyneanum* and *Cinnamomum parthenoxylon,* contain very high safrole content of 93.32 % (45) and 93.9 % (105), respectively. Although they are present with valuable bioactive constituents in most wild *Cinnamomum* spp., they are underutilized, which indicates their conservation and sustainable use.

Conservation also ensures economic growth with ecotourism, attracting tourists who are interested in forest ecosystems, plant botany and the traditional uses of plants (106). Conservation work provides permanent employment opportunities for rangers, restoration laborers, nursery staff, field scientists and environmental educators. Conservation work also offers the promise of carbon sequestration with a chance of entering carbon marketplaces, earning long-term conservation funding and addressing climate change mitigation. The average carbon sequestering potential of an 8 -year-old cinnamon plant ranges about 4.04 t/ha/year (107). The carbon credits can be sold at the global carbon market for about USD 132. The necessity to invest in the conservation program to earn these economic rewards for posterity is also backed by ongoing research work in economics, establishing that the long-term economic benefit of conserving *Cinnamomum* Schaffer far outweighs the short-run economic rewards of exploitative use.

Ecological and biodiversity value

Conservation of these red-listed species is important for nutrient cycling via leaf litter decomposition, soil fertility improvement and the preservation of vital microbial communities essential for forest health. The application of cinnamon leaf compost (CLC) promotes the soil water stable aggregates and organic carbon in the soil, which benefits the soil fertility and structure. They also stimulate the arbuscular mycorrhizal fungi colonization, which increases nutrient acquisition and improves soil health (108). Leaf litter decomposition enhances soil microbial carbon and enzyme activities like invertase and urease, thereby improving nutrient cycling (109). The biodiversity value of the threatened *Cinnamomum* Schaffer species is not merely species conservation but also genetic, ecological and ecosystem value. The species have unique genetic material with the characteristics of drought, pest tolerance and aromatic compound synthesis with potential for biotechnological applications. The species are mostly found in tropical and sub-tropical areas and also due to their extensive root system and permanent soil cover aids in stabilizing soil and preventing erosion, particularly in riparian zones and sloped landscapes (110). These species are more resistant to climate-induced perturbations, whose extensive root systems, flexible twigs and dense canopies provide structural reinforcement against excessive meteorological disturbances such as storms, floods and high-velocity winds. The canopy structure of the species promotes microhabitat diversity by controlling light penetration and moisture retention in the soil (111). These conditions enhance soil carbon storage and promote long-term carbon sequestration, reinforcing their ecological importance in forest ecosystems.

Scientific and research value

Phytochemical analyses of these threatened species have a diverse biochemical profile with numerous secondary metabolites, including terpenes, flavonoids, alkaloids and essential oils. Some of these metabolites also differ in structure and characteristics from the commercially available *Cinnamomum* spp. The bioactives from these species have promising activity against pathogenic microorganisms, inflammatory responses and some cancer cell lines (29, 82, 83). These chemicals hold scientific value in pharmaceutical exploration. The thermo-physiological adaptation of the *Cinnamomum* spp. to thermal variation and meteorological fluctuations holds scope for investigation on uptake plant adaptation mechanisms and thermal tolerance in coping with environmental stress. The dense gene pool of *Cinnamomum spp.* can boost productivity and sustainability. Most wild species are rich in bioactives and are not present in generally cultivated species and also have natural resistance to pathogens, fungal diseases and insect pests (46, 89). By using these genetic characteristics, robust cultivars with reduced chemical interventions will be produced. Genetic diversity in wild *Cinnamomum* populations is significant for the restoration of degraded forests.

Conservation strategy and recommendations

Threatened *Cinnamomum* Schaffer species should be conserved with a strategy that includes habitat protection, ecological research and sustainable management. The establishment of nature reserves and key woodland habitats is essential in sustaining biodiversity (112). Population dynamics research, habitat needs and crucial stressors of the species should be researched to allow effective management (113). Promoting the cultivation of the endangered species contributes to the alleviation of the pressure on the wild populations (114).

Restoration of degraded habitats of threatened species ensures long-term persistence. Canopy gap control and enrichment planting are the methods that promote natural regeneration. A study conducted in Sri Lanka reported that selective canopy gap management increased the growth of native trees significantly, particularly *Cinnamomum* (115, 116). India's splintered forests can also gain from the same strategy to recover species. The creation of buffer zones and protected areas within biodiversity hotspots like the Western Ghats and northeast India diminishes human disturbances and thereby ensures population viability and facilitates the recovery of the species (117).

Indian Institute of Biodiversity Conservation preserved the *Cinnamomum* genus for long-term viability under cryogenic storage at -196 °C (118). Cryopreservation is a sustainable solution for conserving genetic diversity, which helps in breeding programmes (119, 120). To offset extinction threats, these conservation efforts need to be increased in scale. Endangered species can be conserved under controlled conditions in botanical gardens. For *Cinnamomum* Schaeffer, institutions like the Indian Botanical Garden in Kolkata and the National Botanical Research Institute (NBRI) can have reserved conservation areas. The survival of the *Cinnamomum* spp. is based on their return to their favorable habitats. For long-term success, the sites must be selected based on the suitability of the habitat and the climatic predictions. Monitoring after planting is most important to assess the impact of ecological integration and plant growth (121, 122).

To prevent the illegal harvesting of threatened species, effective enforcement of trade controls under CITES (Convention on International Trade in Endangered Species) is required (123, 124). Involving local communities in sustainable harvesting practices reduces the degradation process. Community-based agroforestry systems reduced illegal logging and increased awareness in northeast India (125-127). Land use planning and community stewardship are enhanced by incorporating conservation aspects into India's Forest Rights Act (2006) (128). Ecotourism provides livelihood opportunities and community engagement in conservation efforts (129, 130). In Kerala, plant tourism has seen a 20 % increase in funds. This growth is attributed to initiatives like biodiversity conservation, thereby enhancing the conservation of threatened species. The development of eco-trials, tours and information centres will enhance the conservation of threatened species (Fig. 8).

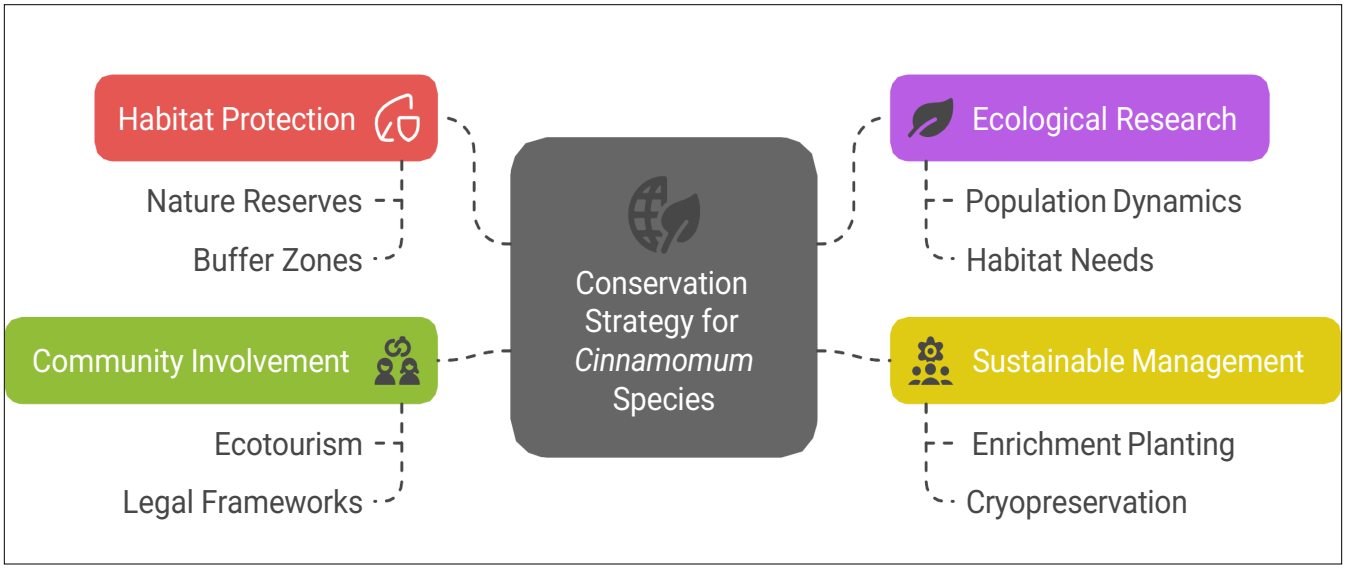

Fig. 8. Conservation strategies of threatened *Cinnamomum* spp.

Conclusion

This peer-reviewed paper discusses the phytochemical richness, therapeutic importance and conservation status of twenty-three threatened Indian native *Cinnamomum* spp. By reporting the bioactive compounds authenticated using Gas Chromatography-Mass Spectrometry (GC-MS) and High-Performance Liquid Chromatography (HPLC) methods, along with their conventional medicinal applications, the study highlights the therapeutic importance of these species. Furthermore, the paper highlights the importance of sustainable management practices and evaluates their conservation status based on the IUCN Red List categories.

Conservation of such species is critical to forest ecology, microbial community well-being and biodiversity conservation and to maintain climate resilience through microclimatological regulation and carbon sequestration traits. Moreover, the medicinal significance of such species makes them crucial for drug development programs. Integrated action involving ecological conservation, economic viability and cultural diversity is essential for such invaluable species conservation. Balancing legislation with legal instruments to enable support for *in-situ* and *ex-situ* conservation programs and enabling public involvement are bare minimum requirements for long-term resilience. Conservation of *Cinnamomum* spp. is justified for investment to preserve a critical element of biodiversity as well as to enable future generations to benefit from its ecological as well as therapeutic potential.

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Authors' contributions

The first draft of the manuscript was written by NM. MG provided guidance for overall correction and improvement. CR, BM and RA assisted with literature collection and formatting. All authors contributed equally to revising the manuscript and approved the final draft.

Compliance with ethical standards

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

Ethical issues: None

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