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Review Paper

Ecology, Phytochemistry and Conservation of Tinospora cordifolia: A Comprehensive Review

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ABSTRACT

Tinospora cordifolia (Willd.) Miers, commonly known as Guduchi or Giloy, is a highly medicinal climber and plays important role in traditional Indian medicine, particularly Ayurveda, due to its immunomodulatory, antipyretic, and antioxidant properties. Disturbances such as deforestation, grazing, and unregulated harvesting have contributed to a decline in wild populations, leading to concerns about its long-term sustainability. Despite its ecological adaptability, the species faces increasing threats from habitat fragmentation, habitat degradation and anthropogenic disturbances in of North Gorakhpur Forest Division and adjoining districts. These pharmacological effects drive its growing demand in herbal, Ayurvedic and nutraceutical industries. Studies also highlight the influence of environmental factors and seasonality on its phytochemical profile, indicating the importance of ecological parameters in conservation planning. The plant exhibits notable immunomodulatory, hepatoprotective, antipyretic, anti-inflammatory, and antioxidant properties. Understanding the current environmental change and regeneration pattern of T. cordifolia is essential for its conservation and for ensuring continued access to its valuable medicinal properties

INTRODUCTION

Tinospora cordifolia (Willd.) Miers, locally known as *Guduchi* or *Giloy*, belongs to the family Menispermaceae and is a perennial, deciduous climber indigenous to tropical and subtropical Asia (Chaudhary et al, 2013; Pandey et al,2024). Widely distributed across tropical and subtropical regions of the Indian subcontinent, it holds significant importance in traditional systems of medicine, particularly Ayurveda, Siddha, and Unani (Kumar et al, 2013; Suresh et al, 2023). Despite its ecological adaptability across habitats such as dry deciduous forests and agroforestry systems, *T. cordifolia* faces increasing threats from overharvesting, habitat fragmentation, and forest degradation (Gupta et al, 2024; Singh et al, 2026).

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Despite this adaptability, the species faces pressures from habitat loss, fragmentation, and unregulated harvesting, which threatens wild populations (Shukla and Pandey 2020). These pressures have led to a decline in wild populations and raised concerns about its long-term conservation status (Pandey and Shukla 2003). Furthermore, natural regeneration through seeds is limited due to low seed viability and germination rates, necessitating reliance on vegetative propagation methods such as stem cuttings and tissue culture for population maintenance and commercial cultivation (Jacob and Kumar 2013; Mangal et al., 2012).

The plant is renowned for its diverse pharmacological properties, including immunomodulatory, anti-inflammatory, antipyretic, hepatoprotective, and antioxidant effects, which have contributed to its rising commercial demand in herbal and nutraceutical industries (Yates et al., 2022; Gupta et al., 2024). Recent studies have advanced understanding of its reproductive biology, ecological requirements, and *ex situ* conservation techniques, including micropropagation and seed storage (Fussi et al., 2025; Chatterjee and Ghosh, 2016). However, knowledge gaps remain regarding the species' response to ecological disturbances and the optimization of regeneration protocols in natural and disturbed habitats. This review synthesizes current research on the ecology, disturbance ecology, conservation challenges, and regeneration strategies of *T. cordifolia* to inform sustainable management practices and highlight future directions for research in plant ecology and ethnobotany. By understanding these aspects, sustainable utilization and effective conservation of this important medicinal plant can be better achieved.

2. Ecology of Tinospora cordifolia

2.1 Habitat and Distribution

T. cordifolia is widely distributed throughout India, Pakistan, Sri Lanka, Nepal, Bangladesh, and parts of Southeast Asia (Chaudhary et al, 2014). It primarily occurs in tropical dry deciduous forests and mixed woodlands but is also found in scrublands and open areas (Shukla and Pandey 2020). The plant grows as a climbing shrub on host trees, frequently observed on neem (*Azadirachta indica*), mango (*Mangifera indica*), and other broad-leaved species (Shukla and Pandey 2020). The species exhibits broad ecological amplitude and is also reported from anthropogenically disturbed habitats such as roadsides, fallow fields, and agroforestry landscapes, indicating some tolerance to habitat disturbance (Pandey and Shukla 2003). However, its presence is often linked to availability of suitable host plants and canopy structure, which provide physical support and microclimatic stability.

2.2 Growth and Phenology

T. cordifolia is a woody, deciduous climber that can reach lengths exceeding 10 meters and climbs by twining around host stems. The plant bears heart-shaped leaves that are large, simple, and glabrous on the upper surface. Stems are cylindrical, greenish, with a warty texture, often producing aerial roots that aid attachment (Rai et al., 2026). The plant exhibits vigorous growth as a scandent climber, often using other trees as physical support by twining its cylindrical, greenish-brown, and warty stems around the host and the stem is succulent and fleshy, facilitating water storage and drought tolerance in dry environments. Flowering occurs during the monsoon season (June-August), producing small, yellowish-green flowers arranged in panicles. Fruits ripen in post-monsoon months (September-November), appearing as red or orange drupes, each containing a single seed (Rai et al., 2026).

Leaves of *T. cordifolia* are simple, alternate, and heart-shaped with a glossy, smooth upper surface and paler underside, measuring 7-10 cm in length. The plant is dioecious, producing male and female flowers on separate individuals. Flowers are small, yellow-green, and arranged in axillary clusters blooming primarily during the monsoon season (June to August). The fruit is a small drupe, turning red when ripe, each containing a single seed dispersed mainly by birds. The species shows adaptability to various habitats, including dry deciduous forests and disturbed areas, aided by its efficient vegetative propagation through stem cuttings and aerial roots that enhance attachment and nutrient These morphological and physiological traits enable *T. cordifolia* to survive under variable environmental conditions and contribute to its widespread occurrence (Mishra et al., 2012).

2.3 Reproductive Biology and Dioecy of *Tinospora* cordifolia

T. cordifolia exhibits dioecy *i.e.* male and female flowers are borne on separate plants. This sexual dimorphism requires the presence of both male and female individuals within a population for successful pollination and fruit set. Male flowers are more numerous and typically found in clusters, while female flowers occur singly or in small groups. The species flowers during the monsoon season (June–August), followed by fruiting in the post-monsoon months (September–November) (Gupta et al., 2024; Mishra et al., 2012). Pollination in *T. cordifolia* is primarily entomophilous (insect-mediated), with bees and small flies acting as key pollinators. The small, yellowish-green flowers produce nectar, attracting these insects (Rai et al., 2026). However, reproductive success is often limited due to skewed sex ratios in wild populations and spatial separation between male and female plants, which can hinder effective pollination (Chatterjee and Ghosh, 2016).

3. Disturbance Ecology

3.1 Impact of Anthropogenic Disturbances

T. cordifolia thrives in tropical dry deciduous forests and semi-urban landscapes, often relying on host trees for structural support. However, widespread anthropogenic disturbances such as deforestation, agricultural encroachment, infrastructure development, logging, and unregulated harvesting have led to significant degradation and fragmentation of its natural habitats (Pandey and Shukla 2003). These human-induced disturbances alter microhabitat conditions, reduce the density and diversity of host trees, and lead to soil compaction and erosion—all of which adversely affect the establishment and persistence of *T. cordifolia* (Gowthami et al., 2021). The extraction of stems and leaves for use in Ayurvedic and herbal medicine has intensified in recent years, putting additional pressure on wild populations (Mishra et al., 2012). Forest fragmentation also restricts movement of pollinators and seed dispersers, which in turn can impair gene flow and genetic diversity. Fragmented landscapes with low habitat connectivity make it more difficult for male and female plants to grow in proximity, further reducing the probability of successful sexual reproduction (Gowthami et al., 2021).

Table 1. Ecological Aspects of *Tinospora cordifolia*

Ecological Aspect	Description	Reference
Habitat preference	Deciduous forests, moist mixed forests; climbs on host trees like *Neem*, *Mango*	Pandey and Shukla 2003
Growth habit	Perennial, dioecious climbing shrub with vigorous vegetative growth	Gupta et al., 2024
Soil and moisture requirements	Prefers well-drained loamy soil; tolerates moderate drought	Khan et al., 2016
Light requirements	Grows in partial shade to full sunlight conditions	Chitra et al., 2006
Host dependency	Relies on large trees for support; host removal negatively impacts establishment	Shukla and Pandey 2020
Impact of habitat fragmentation	Fragmentation reduces gene flow and increases inbreeding risks	Shukla and Pandey 2020
Ecological interactions	Interacts with endophytes enhancing stress tolerance and secondary metabolism	Mishra et al, 2012

3.2 Response to Environmental Stressors

Despite the ecological pressures, *T. cordifolia* demonstrates a moderate level of resilience owing to its rapid vegetative growth, ability to regenerate from stem cuttings, and adaptation to secondary habitats, including fallow lands and disturbed forest margins (Abhijeen and Mokat 2018). This regenerative ability has made it a preferred species in traditional home gardens and agroforestry systems. However, resilience has its limits. In landscapes where disturbance is severe—such as areas of complete canopy removal, elimination of host trees, or intensive grazing by livestock—the survival and spread of *T. cordifolia* is drastically reduced (Gowthami et al., 2021). Research indicates that landscapes maintaining a mosaic of undisturbed and moderately disturbed habitats support higher population densities of *T. cordifolia*. These transitional zones often have sufficient host trees and open niches for vegetative spread, promoting both survival and secondary colonization (Chatterjee and Ghosh 2016). Sustainable land-use practices and assisted natural regeneration could enhance its resilience under changing environmental conditions. The removal of potential host trees is particularly detrimental, as this species depends on vertical support to reach sunlight in competitive forest environments. Heavy grazing by domestic animals not only damages young shoots but also compacts the soil, reducing seedling establishment.

3.3 Role of Endophytes and Symbionts

Recent investigations into *T. cordifolia*'s microbial associations have revealed that it hosts a rich community of endophytic fungi and bacteria. These endophytes play a crucial role in enhancing plant tolerance to abiotic stressors, improving nutrient acquisition, and promoting the biosynthesis of important secondary metabolites, such as alkaloids and glycosides (Mishra et al., 2012). These microbial relationships may be critical in determining the plant's ecological success in fragmented and resource-poor habitats. Endophyte diversity tends to vary seasonally and across habitats. Plants growing in disturbed areas often show changes in endophyte community composition, which could help them adapt to environmental stress through increased resistance to pathogens or drought (Chatterjee and Ghosh, 2016). The ecological implications of these symbiotic relationships warrant further research, particularly in the context of biocontrol, restoration ecology, and climate resilience. Harnessing beneficial endophytes could become a key strategy in conserving and sustainably managing *T. cordifolia* populations (Table 1).

4. Conservation Status and Challenges

4.1 Conservation Status

T. cordifolia, though widely distributed across India, is increasingly facing conservation concerns due to its rising medicinal demand and habitat degradation. While the species has not yet been evaluated on a global scale by the IUCN, national and regional studies have flagged it as vulnerable or at risk in several parts of India (Gowthami et al., 2021). The National Medicinal Plants Board (NMPB) of India has included *T. cordifolia* on its list of priority species for conservation and sustainable utilization, recognizing its pharmacological importance and overharvest risk (Rai & Tripathi, 2019). Its listing reflects growing concern about the long-term sustainability of wild populations, especially as demand increases in both domestic and international herbal product markets.

4.2 Threats to Wild Populations

Wild populations of *T. cordifolia* face multiple threats. Unregulated harvesting, often targeting aerial stems and leaves for medicinal use, is among the most critical pressures. This is compounded by selective harvesting of female plants, which are prized for their fruits. Since the species is dioecious, preferential removal of female individuals significantly disrupts natural sex ratios, limiting seed production and reducing reproductive success (Chatterjee and Ghosh 2016). Fragmentation of habitats leads to isolation of populations, further increasing the risk of inbreeding and reduced genetic variability. The degradation of forest ecosystems also alters microclimates, making them less suitable for the species' growth and establishment (Gowthami et al., 2021). Another significant threat is habitat loss due to deforestation, urban expansion, and agricultural encroachment, which results in the removal of host trees essential for the climber's growth. Additionally, the lack of coordinated monitoring programs and data on population trends makes it difficult to assess its exact conservation status, hindering timely interventions.

4.3 *In* Situ and *Ex Situ* Conservation Strategies

To address these challenges, both *in situ* and ex situ conservation strategies are being employed. In situ conservation includes the protection of natural habitats, particularly within sacred groves, community-managed forests, and protected forest reserves, where *T. cordifolia* naturally occurs. These areas serve as refuges for maintaining ecological interactions, including pollinator and seed disperser presence (Rai and Tripathi, 2019). *Ex situ* conservation involves germplasm preservation through seed banks, botanical gardens, and plant nurseries, as well as advanced methods like micropropagation and tissue culture. These efforts aim to conserve genetic diversity and provide planting material for reintroduction and large-scale cultivation (Gururaj et al., 2007). Propagation through stem cuttings has proven effective for maintaining viable populations outside natural habitats, especially in community herbal gardens and farm-based conservation programs. Encouraging local stakeholders to grow *T. cordifolia* on agroforestry systems reduces pressure on wild stocks and enhances conservation outcomes. Despite these efforts, challenges remain—including policy gaps, limited funding, and the need for long-term ecological studies to guide adaptive management. Strengthening both conservation research and grassroots implementation will be key to safeguarding *T. cordifolia* for future generations.

5. Regeneration and Propagation

Effective propagation strategies are crucial for the conservation, sustainable utilization, and commercial cultivation of *Tinospora cordifolia*. The species exhibits both sexual and asexual regeneration pathways, each with distinct benefits and limitations. However, in the wild, regeneration is often compromised due to environmental stressors, biotic interference, and physiological constraints. Thus, integrating natural and assisted propagation methods is vital for long-term species management.

5.1 Natural Regeneration

Tinospora cordifolia exhibits limited natural regeneration through seeds. Several studies have reported low seed germination rates primarily due to seed dormancy, short viability periods, and low moisture retention capacity (Khan et al., 2016). In natural settings, seedlings are often exposed to fungal pathogens, insect predation, and competition from other flora, leading to high mortality (Shukla and Pandey, 2020). Additionally, dioecy complicates seed production, as male and female plants must occur in proximity for pollination to succeed. Seed production and germination rates also show strong seasonal variability, with peak seed set during post-monsoon months (October–November). However, environmental fluctuations can disrupt flowering synchronization and pollinator activity, further reducing seedling establishment.

5.2 Vegetative Propagation

Due to the challenges of sexual reproduction, vegetative propagation via stem cuttings is widely used. This method offers high success rates, especially when cuttings are taken from healthy, mature vines during the dormant season and planted under controlled nursery conditions. Under optimal humidity and temperature, root initiation occurs within 15–20 days, enabling rapid multiplication (Shukla and Pandey, 2020). This technique is particularly suitable for commercial plantations and community-based conservation programs, as it provides a quick and cost-effective way to produce large numbers of plants. However, reliance solely on vegetative propagation can lead to reduced genetic variability, which may compromise the long-term adaptability and disease resistance of cultivated populations.

5.3 Micropropagation and Tissue Culture

Advances in biotechnology have enabled the development of in vitro micropropagation protocols for *T. cordifolia*. Techniques using nodal segments, axillary buds, and callus culture have demonstrated high success in producing disease-free, genetically uniform plantlets (Handique 2014). Micropropagation offers a sustainable solution for mass multiplication, especially in conservation programs where maintaining genetic purity and health is critical. Moreover, tissue culture allows for the long-term storage and propagation of rare or elite genotypes, supporting ex situ conservation and germplasm exchange. Genetic fidelity assessments using molecular markers have confirmed the stability of micropropagated plants (Fussi et al., 2025).

5.4 Seed Storage and Germination Techniques

Tinospora cordifolia seeds are classified as recalcitrant, meaning they do not tolerate desiccation or long-term storage well. Research shows that maintaining moisture content at 8–9% and storing seeds at 10–15°C can preserve viability for up to six months (Khan et al., 2016). Beyond this period, viability rapidly declines. Several pre-sowing treatments have been shown to improve germination. Mechanical scarification of the seed coat and gibberellic acid (GA_3) treatment significantly enhance germination percentage and speed. Soaking seeds in warm water for 24 hours before sowing also helps in softening the seed coat and stimulating embryo growth (Jacob and Kumar, 2013). These combined strategies—natural regeneration enhancement, vegetative propagation, micropropagation, and improved seed handling—form the foundation for *T. cordifolia*'s conservation and commercial deployment.

6. Phytochemical Variability and Ethnobotany

T. cordifolia is a highly valued medicinal climber in traditional Indian medicine. It possesses a rich phytochemical profile that includes a wide variety of bioactive constituents such as alkaloids (berberine, palmatine), diterpenoid lactones (tinosporide, cordifolide), glycosides (tinosporaside), steroids (β-sitosterol), flavonoids (quercetin, apigenin), and polysaccharides (arabinogalactan-type) (Chaudhary et al., 2013; Yamini and Rana 2026). These compounds contribute to the plant's pharmacological activities, including immunomodulatory, antidiabetic, and antioxidant effects. Secondary metabolites such as alkaloids (berberine, palmatine), phenolics, and glycosides vary seasonally and between sexes, affecting medicinal value and ecological interactions (Yamini and Rana, 2026). These compounds deter herbivory and pathogens, influencing survival and reproduction, especially in disturbed habitats.

Ethnobotanically, *T. cordifolia* holds significant traditional value across various tribal and rural communities in India. It is used in Ayurveda as a Rasayana (rejuvenator), primarily for enhancing longevity, treating chronic fevers, and managing conditions such as diabetes, asthma, jaundice, and digestive disorders (Gupta et al., 2024). In tribal medicine, decoctions and stem extracts are used for malaria, snakebite, and urinary infections, often as part of polyherbal preparations.

Modern pharmacological studies validate many of its traditional uses. *T. cordifolia* exhibits strong immunomodulatory activity by enhancing macrophage function and cytokine release, aiding in immune regulation (Yates et al., 2022). Its antidiabetic potential is attributed to improved insulin sensitivity and reduced gluconeogenesis. The plant also demonstrates hepatoprotective, anti-inflammatory, neuroprotective, and antimicrobial effects. Additionally, several diterpenoid compounds are being investigated for anticancer activity. During the COVID-19 pandemic, *T. cordifolia* was recommended by India's Ministry of AYUSH as a natural immune booster (Ministry of AYUSH, 2020) (Table 2).

Table 2. Phytochemistry, Chemical Constituents, and Medicinal Uses of *Tinospora cordifolia*

Aspect	Details	Reference
Major Chemical Constituents	Alkaloids (berberine, palmatine), diterpenoid lactones (tinosporide, cordifolide), glycosides (tinosporaside), steroids (β-sitosterol), flavonoids (quercetin, apigenin), polysaccharides (arabinogalactan)	Yamini and Rana, 2026; Gururaj et al., 2007
Alkaloids	Berberine and palmatine responsible for antimicrobial and antidiabetic properties	Yamini and Rana, 2026
Diterpenoid lactones	Tinosporide and cordifolide exhibit anti-inflammatory and immunomodulatory effects	Chaudhary et al., 2013
Polysaccharides	Arabinogalactan-type polysaccharides with immunomodulatory and antioxidant activities	Jacob and Kumar 2013
Medicinal Uses - Immunomodulation	Enhances macrophage activity, cytokine release; used in Ayurveda as an immune booster	Ministry of AYUSH, 2020

Medicinal Uses - Antidiabetic	Improves insulin sensitivity; reduces blood glucose levels in diabetic patients	Gupta et al., 2024
Medicinal Uses - Hepatoprotection	Protects liver cells from toxins and oxidative stress	Chaudhary et al., 2013
Medicinal Uses - Anti-inflammatory & Neuroprotective	Reduces inflammation and oxidative stress; potential use in neurodegenerative disorders	Yamini and Rana, 2026
Traditional Ethnobotanical Uses	Treatment of fever, jaundice, asthma, urinary infections, snakebite, and malaria in tribal medicine	Gupta et al., 2024
Modern Research and COVID-19	Recommended as an immune-supportive supplement during COVID-19 pandemic by Indian health authorities	Ministry of AYUSH, 2020

7. Future Perspectives and Recommendations

Future conservation and utilization of *Tinospora cordifolia* require an integrated and multidisciplinary approach. First, there is a pressing need for detailed ecological and genetic studies focusing on population dynamics, gene flow, and species responses to environmental disturbances. Such research will inform habitat-specific management plans and help identify conservation priorities. Propagation efforts should be refined by adopting standardized, science-based protocols that combine seed-based and vegetative methods to ensure both scalability and genetic diversity. Current reliance on clonal propagation through cuttings and tissue culture, while efficient, may reduce adaptive potential, necessitating research into optimizing conditions for seed germination and vegetative rooting. Sustainable use of *T. cordifolia* must be promoted through community-based management systems that involve local stakeholders in conservation and cultivation. Establishing clear guidelines for sustainable harvesting—including rotation cycles, protection of female plants, and seasonal collection practices—will help balance ecological health with livelihood needs. Policymakers should integrate *T. cordifolia* conservation into national medicinal plant strategies and forest biodiversity plans. Incentives for agroforestry and cultivation on marginal lands can further reduce pressure on wild populations while supporting rural economies. Simultaneously, documenting and preserving the ethnobotanical knowledge of indigenous and local communities is vital. Their insights on cultivation techniques, optimal harvesting times, and medicinal preparation methods can complement scientific approaches and enrich conservation strategies. A coordinated policy, research, and community engagement framework will be essential to ensure the long-term survival and sustainable utilization of *T. cordifolia*, securing its role as a valuable medicinal resource and ecological component of India's biodiversity.

CONCLUSION

T. cordifolia is a valuable medicinal climber facing threats from habitat degradation and overharvesting. Its ecological resilience and vegetative propagation potential provide opportunities for conservation and sustainable use. Integrated efforts involving habitat protection, propagation technologies, and community participation are vital to safeguard this species for future generations. *T. cordifolia* stands as a highly valued medicinal plant with deep roots in traditional Indian medicine and growing significance in modern pharmacology. Its extensive therapeutic potential—ranging from immunomodulatory and antidiabetic to hepatoprotective and neuroprotective effects—is attributed to a rich phytochemical profile. Despite its widespread use, natural populations of *T. cordifolia* are increasingly threatened by overharvesting, habitat fragmentation, and unsustainable practices. Limited natural regeneration, dioecious reproductive biology, and dependence on host trees further constrain its resilience in disturbed ecosystems.

While vegetative and tissue culture propagation offer scalable solutions, they must be implemented alongside strategies that preserve genetic diversity. Conservation efforts must focus on in situ protection, ex situ propagation, and community-based management. Policy integration and promotion of sustainable agroforestry models are also crucial for reducing pressure on wild populations. Moreover, documenting ethnobotanical knowledge can complement scientific approaches and enrich conservation strategies. Moving forward, a multidisciplinary approach that combines ecological research, biotechnological innovation, traditional knowledge, and supportive policy frameworks is essential for ensuring the long-term survival and sustainable utilization of *T. cordifolia*. Such efforts will not only conserve a keystone medicinal species but also support biodiversity, livelihoods, and traditional healthcare systems.

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