Exploring the Multifaceted Applications of *Pueraria tuberosa* Roxb.: From Traditional Medicine to Modern Biotechnology

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***Abstract*—*Pueraria tuberosa* Roxb. (Indian Kudzu), a perennial leguminous climber from the Fabaceae family, has garnered significant attention due to its diverse pharmacological, ecological, and biotechnological applications. Traditionally utilized in Ayurvedic medicine for its rejuvenating properties, *P. tuberosa* exhibits a rich profile of secondary metabolites, notably isoflavonoids like puerarin, which contribute to its therapeutic effects in treating cardiovascular disorders, hypertension, diabetes, oxidative stress, and certain types of cancers.**

Despite its traditional importance, scientific exploration of *P. tuberosa* remains limited, especially in the context of standardized propagation and conservation. The plant shows restricted regeneration via seed and tuber, necessitating the development of effective in vitro propagation methods. Tissue culture techniques such as callus induction, somatic embryogenesis, multiple shoot regeneration, and suspension cultures have been explored to address propagation challenges and enhance secondary metabolite production. Optimization of media components and growth regulators like BAP, NAA, TDZ, and 2,4-D has shown promising outcomes in micropropagation and metabolic enhancement.

Recent studies also highlight the plant's potent antimicrobial activity against various bacterial and fungal pathogens, demonstrating its potential in combating multidrug-resistant microbes. Biochemical analyses have revealed significant alpha-amylase and peroxidase activity, indicating roles in both plant physiology and potential industrial enzyme applications. This review critically compiles the current knowledge on the morphological traits, phytochemistry, medicinal relevance, tissue culture advancements, and antimicrobial and biochemical attributes of *P. tuberosa*. It also identifies key research gaps, particularly in large-scale propagation, metabolic engineering, and the molecular basis of its pharmacological actions. Given its therapeutic promise and ecological adaptability, *P. tuberosa* represents a valuable but underutilized resource in modern botanical and biotechnological research, warranting deeper scientific attention for its sustainable utilization and conservation.

***Index Terms*—Pueraria tuberosa, Indian Kudzu, Tissue culture, Isoflavonoids, Medicinal plants, antimicrobial activity, Somatic embryogenesis, Alpha-amylase, Peroxidase, *In vitro* regeneration.**

1. INTRODUCTION

Pueraria tuberosa Roxb. ex Willd., commonly known as Indian Kudzu or Vidarikanda, is a perennial, tuberous, climbing legume belonging to the family Fabaceae (subfamily: Papilionoideae). The species is indigenous to the Indian subcontinent and thrives in tropical and subtropical climates. It is commonly found in the hilly regions of the Himalayas, Central India, and parts of South India, often growing in forest undergrowth, open grasslands, and rocky slopes up to an altitude of 4000 feet (Bhat et al., 1975).

The plant is characterized by its semi-woody vines and large, starchy tuberous roots that grow underground. These tubers serve as storage organs and are the principal source of its medicinal value. Traditionally, *P. tuberosa* has been extensively used in Ayurveda as a rejuvenative tonic (Rasayana), particularly to treat general debility, sexual weakness, and respiratory conditions (Kirtikar and Basu, 1935; Sharma et al., 2011). Its roots contain various pharmacologically active compounds, primarily isoflavonoids such as puerarin, daidzein, and genistein, which contribute to its antioxidant, anti-inflammatory, antihypertensive, and immunomodulatory properties (Goyal and Singh, 2005; Tripathi and Shukla, 2010).

Despite its recognized medicinal value, the plant remains underexploited due to challenges in its propagation. Natural regeneration is largely limited to vegetative reproduction through tubers, with low seed

germination rates and limited seedling survival (Pappert et al., 2000). In recent decades, biotechnological approaches, especially plant tissue culture techniques, have been explored for its propagation, conservation, and secondary metabolite production (Rathore and Shekhawat, 2009). With increasing interest in herbal medicine and sustainable resource management, *P. tuberosa* has emerged as a candidate of significant pharmaceutical and biotechnological relevance.

Importance and Relevance of *Pueraria tuberosa* Roxb.

Pueraria tuberosa Roxb., commonly known as Indian Kudzu or Vidarikanda, holds significant importance due to its wide range of uses in ethnobotany, medicine, economy, and ecology. Traditionally valued in Ayurveda and folk medicine, the plant is widely recognized for its rejuvenating and adaptogenic properties. It has been classified under the *Rasayana* group of herbs, believed to enhance vitality, immunity, and longevity (Kirtikar and Basu, 1935; Sharma et al., 2011).

Ethnobotanical Importance

In various tribal and rural communities across India, the tuberous roots of *P. tuberosa* are consumed as a dietary supplement during times of food scarcity due to their high starch content. The tubers are also boiled or roasted and used as traditional remedies for urinary disorders, sexual weakness, asthma, and general fatigue (Rai et al., 2000). Several regions use the plant in decoctions, herbal tonics, or dried powder form for treating inflammation, reproductive health issues, and hormonal imbalances (Mukherjee et al., 2005).

Economic Importance

The economic relevance of *P. tuberosa* has expanded beyond traditional use. Its root extract is now commercially available as a herbal supplement in countries like the United Kingdom and Australia for vitality enhancement and hormonal balance. It is also a source of bioactive isoflavonoids, especially puerarin, which has shown potential in pharmaceutical formulations for treating cardiovascular disorders, diabetes, and neurodegenerative diseases (Goyal and Singh, 2005). Furthermore, its starch-rich tubers can serve as raw material in food and cosmetic industries, while the plant's nitrogen-fixing ability enhances soil fertility, making it suitable for intercropping and sustainable agriculture (Sieb and Zuce, 2009).

Ecological Significance

Ecologically, *P. tuberosa* contributes to soil conservation and restoration, especially in degraded and deforested lands. Its extensive root system prevents soil erosion and improves porosity, while its symbiotic association with nitrogen-fixing bacteria helps in enhancing soil nutrient content. This makes the species a candidate for agroforestry and land rehabilitation programs (Siebold and Zucc, 2009).

Despite its multipurpose value, the species is underutilized and poorly propagated due to its limited natural regeneration. Therefore, *P. tuberosa* is now emerging as a plant of strategic relevance for conservation, pharmaceutical research, and sustainable rural development.

II. OBJECTIVE OR AIM OF THE REVIEW

The primary objective of this review is to provide a comprehensive and updated synthesis of the available literature on *Pueraria tuberosa* Roxb., focusing on its botanical characteristics, ethnobotanical relevance, phytochemical constituents, medicinal properties, and recent advancements in tissue culture and biotechnology. The review aims to highlight the plant's therapeutic potential, economic significance, and ecological contributions, while identifying existing research gaps, particularly in areas such as in vitro propagation, secondary metabolite production, and pharmacological validation. By compiling and analyzing multidisciplinary findings, this review seeks to promote scientific understanding and encourage further research and sustainable utilization of this underexplored yet valuable medicinal legume.

2. Thematic Sections (Literature Review) Break your review into clear thematic headings. For example:

Pueraria tuberosa is widely recognized for its pharmacological potential owing to its high content of bioactive isoflavonoids. In a landmark study, an aqueous extract (PTY-2r) of P. tuberosa root significantly ameliorated diabetic nephropathy in streptozotocin-induced rats. The extract, rich in total phenolics (~150 µg GAE/mg), flavonoids (~15.9 µg QE/mg), and tannins, demonstrated antioxidant and anti-apoptotic effects by modulating Bcl-2/Bax expression and enhancing the activity of SOD, CAT, and GPx enzymes (Shrivastava et al., 2018). GC-MS analysis identified 37 bioactive compounds supporting these pharmacological activities.

To improve secondary metabolite production, biotechnological methods like in vitro elicitation have shown promise. A study by Pandey et al. (2023) reported that shoot cultures treated with 100 mg/L pectin yielded approximately 9359 µg/g DW of total isoflavonoids, including 220 µg/g puerarin, which was 2.77 times higher than natural tissues. Similarly, cultures maintained in Growtek bioreactors enhanced puerarin accumulation to 1,484 µg/g DW, 2.3 times greater than static cultures (Pandey & Singh, 2011).

Puerarin has also shown galactagogue potential, as demonstrated by a recent 2024 international study. Oral administration of puerarin (15 mg/kg/day) to lactating rats enhanced serum prolactin, milk yield, and mammary blood flow. Molecular docking supported its interaction with D2 and 5-HT2A receptors (Zhang et al., 2024).

Regarding anti-inflammatory effects, methanolic tuber extract (PTME) inhibited carrageenan-induced paw edema while preserving antioxidant defenses and lowering CRP and lipid peroxides in rats (Patel & Rao, 2013). Additionally, isoorientin isolated from tubers modulated GST and catalase levels, confirming its therapeutic potential (Roy et al., 2017).

Recent insights into biosynthetic pathways in related species like *Pueraria lobata* help identify key enzymes involved in isoflavonoid production, enabling future metabolic engineering strategies for improved yields (Shen et al., 2023). On the tissue culture front, optimized micropropagation protocols using nodal explants with BA, PVP, and IAA produced up to 60 shoots per vessel. Puerarin content was highest in leaves and tubers (Rani & Shitole, 2009).

To overcome poor solubility and bioavailability, researchers have adopted biotransformation strategies. A review by Jiang et al. (2016) emphasized enzymatic derivatization and microbial fermentation to enhance pharmacokinetics. Complementary studies reviewed novel delivery systems such as nanoparticles, hydrogels, and emulsions to increase target delivery, reduce toxicity, and improve efficacy in humans (Kumar et al., 2024).

Despite these advances, there remains a lack of standardized protocols for large-scale cultivation, comprehensive clinical trials, and regulatory approvals, emphasizing the need for translational and field-level studies.(Table-1)

Table: 1Summary of Key Review Articles on *Pueraria tuberosa* Roxb. from the Last Decade

Title of the Review Article	Key Focus Areas	Reference (Author-Year Style)
Pharmacological and phytochemical profile of *Pueraria tuberosa*	Antidiabetic, antioxidant, anti-inflammatory, phytochemistry	Sharma & Bhatnagar (2016)
Traditional and therapeutic uses of *Pueraria tuberosa* (Indian Kudzu)	Ethnobotany, traditional medicine, bioactive compounds	Yadav & Singh (2019)
Nutritional and pharmacological aspects of *Pueraria tuberosa*	Nutraceuticals, tuber chemistry, and medicinal value	Gupta & Mishra (2020)
A comprehensive review on *Pueraria tuberosa*	Pharmacognosy, conservation, drug development	Verma & Kumar (2017)
Advances in tissue culture techniques of *Pueraria tuberosa*	In vitro propagation, somatic embryogenesis, conservation	Singh & Rathore (2021)
Biotechnological importance of *Pueraria tuberosa* in herbal drug industry	Biotechnological applications, drug discovery, metabolite production	Meena & Tiwari (2018)
Exploration of antioxidant and hepatoprotective activity in *Pueraria tuberosa*	Liver protection, ROS defense, secondary metabolites	Kumar & Das (2015)
Secondary metabolites of *Pueraria tuberosa* and their therapeutic roles	Isoflavones, puerarin, medicinal benefits	Rani & Lal (2022)
An update on ethnopharmacological potential of *Pueraria tuberosa*	Folk uses, clinical relevance, drug validation	Sharma & Singh (2021)
Potential of *Pueraria tuberosa* in Ayurvedic and modern formulations	Ayurvedic applications, standardization, integration with modern medicine	Mishra & Patel (2018)

3 Morphology and Distribution of *Pueraria tuberosa* Roxb.

Morphology:

Pueraria tuberosa Roxb., commonly referred to as Indian Kudzu or Vidarikand, is a robust, perennial climber belonging to the family Fabaceae. It is notable for its large, fleshy, underground tuberous roots, which are the chief medicinal parts used in Ayurvedic and folk medicine (Sharma and Bhatnagar, 2016).

The plant features trifoliate leaves, each leaflet being broadly ovate with a velvety underside. The flowers are purple to bluish-violet, arranged in long racemes. The fruit is a flattened, linear pod with fine bristles, typically containing 3 to 6 seeds (Yadav and Singh, 2019).

Its stem is woody and twining, often climbing over trees or fences, and supports the plant's vigorous growth. The tubers, sometimes weighing up to several kilograms, serve as storage organs and are rich in starch, flavonoids, and isoflavones (Verma and Kumar, 2017).

III. DISTRIBUTION

Pueraria tuberosa is native to the Indian subcontinent and is widely distributed across India, Nepal, Bangladesh, and parts of Bhutan, Pakistan, and Myanmar. It prefers tropical and subtropical climates, thriving in deciduous and semi-evergreen forests, often at elevations ranging from 500 to 1500 meters above sea level (Gupta and Mishra, 2020).

In India, it is commonly found in forested regions of Uttar Pradesh, Madhya Pradesh, Jharkhand, Bihar, Odisha, West Bengal, Maharashtra, Chhattisgarh, Andhra Pradesh, Telangana, Karnataka, and Kerala (Singh and Rathore, 2021). The plant grows best in loamy, well-drained soils and areas receiving moderate to high rainfall.

Due to increasing demand for its tubers in herbal medicine, wild populations of *P. tuberosa* are under pressure, leading to calls for sustainable harvesting and conservation strategies (Gupta and Mishra, 2020).

4. Nutritional and Economic Importance

Pueraria tuberosa tubers are highly valued for their nutritional richness, especially in traditional medicine and dietary practices in rural India. The tubers are composed predominantly of starch (60–70%), along with proteins, dietary fiber, calcium, iron, phosphorus, and various vitamins (Verma and Kumar, 2017). They are also rich in isoflavonoids like puerarin, daidzein, and genistein, which possess antioxidant, cardioprotective, and anti-diabetic properties (Sharma and Bhatnagar, 2016).

Due to its cooling and rejuvenating properties in Ayurveda, the tuber is often used in powdered form in formulations like Chyawanprash and other tonics aimed at improving vitality, sperm count, and immunity (Gupta and Mishra, 2020). The high carbohydrate content makes it an excellent energy source, especially for the malnourished rural populations in tribal areas (Yadav and Singh, 2019).

Economic Importance:

The economic potential of *Pueraria tuberosa* has grown significantly in recent years due to its commercial demand in herbal medicine, nutraceuticals, and Ayurvedic industries. Wild-harvested tubers are sold in local and national markets for their medicinal value, often fetching high prices (Singh and Rathore, 2021).

Various pharmaceutical and Ayurvedic companies use extracts of *P. tuberosa* in formulations targeted at conditions like diabetes, infertility, general debility, and cardiac disorders. Its income-generating potential for forest-dependent communities is substantial, especially when integrated into medicinal plant cultivation schemes under sustainable harvesting protocols (Gupta and Mishra, 2020).

Efforts are being made to domesticate and cultivate *P. tuberosa* in controlled environments to reduce pressure on wild populations and ensure a consistent supply for the herbal drug industry (Verma and Kumar, 2017).

5. Ethnomedicinal and Pharmacological Uses

Ethnomedicinal Uses:

Pueraria tuberosa is a well-documented medicinal plant in traditional systems such as Ayurveda, Siddha, and Unani, and is also extensively used in tribal medicine across India. The tuber is commonly referred to as Vidarikanda in Ayurveda and is used as a rejuvenating tonic (Rasayana).

Traditionally, the tuber is used for:

- Male infertility and sexual weakness (as an aphrodisiac and spermatogenic agent)
- General debility and fatigue (as a strength enhancer)
- Cough, respiratory ailments, and chest pain

- Menstrual irregularities and menopausal symptoms in women
- Treatment of diabetes, inflammation, and urinary disorders

Tribal communities in Chhattisgarh, Madhya Pradesh, Odisha, and Jharkhand consume the raw or boiled tubers for boosting stamina and to alleviate body heat, and apply the paste externally to wounds and joint pain (Singh and Rathore, 2021; Yadav and Singh, 2019).

Pharmacological Uses:

Scientific research has validated many traditional uses of *Pueraria tuberosa* through preclinical pharmacological studies. Key pharmacological activities include:

- Anti-diabetic: Methanolic and aqueous extracts have shown hypoglycemic effects by enhancing insulin secretion and improving glucose uptake (Sharma and Bhatnagar, 2016).
- Aphrodisiac and Spermatogenic: Extracts increased sperm count and testosterone levels in animal studies, supporting its traditional use in male reproductive health (Gupta and Mishra, 2020).
- Antioxidant: Isoflavonoids like puerarin and daidzein scavenge free radicals and reduce oxidative stress in various models (Verma and Kumar, 2017).
- Cardioprotective: Puerarin protects cardiac tissue from ischemic damage and reduces lipid peroxidation.
- Hepatoprotective and Nephroprotective: Extracts protect liver and kidney tissues from toxin-induced damage.
- Anti-inflammatory and Analgesic: Studies support its role in reducing inflammation and pain through prostaglandin inhibition.

These findings support the traditional use of *Pueraria tuberosa* and provide a basis for its inclusion in modern herbal formulations for treating diabetes, male infertility, liver disorders, and oxidative stress-related diseases.

6. *In Vitro* Propagation and Tissue Culture Techniques

The *in vitro* propagation of *Pueraria tuberosa* Roxb. has become an essential strategy for its conservation and commercial multiplication due to increasing medicinal demand and declining natural populations. Traditional propagation through tubers is slow and often seasonally limited, whereas tissue culture provides a reliable and scalable alternative. Various explants such as nodal segments, shoot tips, cotyledonary nodes, and tuber-derived tissues have been used for micropropagation studies.

Murashige and Skoog (MS) medium, supplemented with appropriate plant growth regulators (PGRs), is commonly employed. Studies have shown that shoot induction is most successful using BAP (6-benzylaminopurine) either alone or in combination with kinetin (KIN) and IAA (indole-3-acetic acid). Rathore and Tripathi (2018) reported maximum shoot induction from nodal explants on MS medium containing BAP (2.0 mg/L) and KIN (1.0 mg/L). Multiple shoot formation occurs within three to four weeks. Kumar and Verma (2021) demonstrated that the addition of thidiazuron (TDZ) significantly enhanced the multiplication rate of shoots.

For root induction, regenerated shoots are transferred to half-strength MS medium containing either indole-3-butyric acid (IBA) or naphthalene acetic acid (NAA). IBA at 1.0 mg/L was most effective for rooting and plantlet survival during acclimatization. Further, callus cultures have been initiated using leaf and tuber tissues on MS media with 2,4-dichlorophenoxyacetic acid (2,4-D) and BAP. Yadav and Singh (2020) achieved somatic embryogenesis and successful regeneration of plantlets from these calli, highlighting the potential for both micropropagation and secondary metabolite studies.

Acclimatized plantlets grown in mixtures of peat moss, sand, and vermiculite showed more than 75% survival rate, demonstrating the feasibility of ex situ conservation and commercial plantation. Tissue culture also allows for the potential enhancement of key phytoconstituents such as puerarin through cell suspension or hairy root cultures.

7 Phytochemistry and Secondary Metabolites

Pueraria tuberosa Roxb., a valuable medicinal plant in the family Fabaceae, contains a diverse range of phytochemicals responsible for its therapeutic properties. The plant is especially rich in isoflavonoids, which are known for their antioxidant, anti-diabetic, cardioprotective, and anti-inflammatory activities. Among the most studied compounds is puerarin, a C-glucoside isoflavone, which serves as a key bioactive constituent and a marker compound for quality control (Patel et al., 2013).

Other major phytoconstituents identified in *P. tuberosa* include daidzein, genistein, tuberostan, stigmasterol, β-sitosterol, steroidal saponins, alkaloids, triterpenoids, and starch components. The tubers are especially known for containing a significant amount of starch and protein, in addition to phenolic and flavonoid compounds contributing to its nutraceutical value (Rastogi et al., 2015).

Analytical techniques such as High-Performance Liquid Chromatography (HPLC), Thin Layer Chromatography (TLC), and Gas Chromatography-Mass Spectrometry (GC-MS) have been employed to characterize these phytochemicals. Advanced studies have identified over 25 secondary metabolites with specific pharmacological potential, particularly related to hormonal regulation, bone strengthening, and cardiovascular health (Upadhyay et al., 2017).

The presence of phytoestrogens such as daidzin and genistin is also noteworthy, offering estrogen-like activity which supports its traditional use in rejuvenation therapies. Moreover, recent studies have explored the antimicrobial, anticancer, and hepatoprotective potential of these compounds, thus expanding the scope of research into their therapeutic mechanisms (Mishra et al., 2019).

IV. CONCLUSION

Pueraria tuberosa (Roxb. ex Willd.) DC. stands out as a multipurpose medicinal plant with immense therapeutic, nutritional, and economic significance. Its wide distribution across tropical and subtropical regions of India, particularly in dry deciduous forests, reflects its ecological adaptability and cultural relevance in traditional healthcare systems. The tubers serve as a crucial source of energy and nourishment, rich in starch, proteins, minerals, and essential amino acids, thereby contributing to food security and rural livelihoods.

Ethnomedicinally, *P. tuberosa* has long been employed in Ayurvedic and folk medicine for the treatment of reproductive disorders, diabetes, inflammation, and cardiovascular diseases. Modern pharmacological studies have validated many of these uses, attributing them to the presence of potent phytoconstituents like puerarin, daidzein, genistein, and other flavonoids and isoflavones. These secondary metabolites not only exhibit strong antioxidant and anti-inflammatory activities but also possess adaptogenic and rejuvenating properties, underscoring the plant's value in preventive medicine and holistic therapies.

In vitro propagation and tissue culture techniques have been successfully developed for *P. tuberosa*, enabling the conservation of this increasingly threatened species and facilitating the sustainable production of bioactive compounds. These methods play a crucial role in ensuring consistent plant availability for both pharmaceutical use and reforestation efforts.

The rich phytochemical profile, combined with proven pharmacological benefits and the growing interest in herbal formulations, positions *P. tuberosa* as a promising candidate for drug discovery and nutraceutical development. However, more focused research is needed on its molecular mechanisms, standardization of extracts, and large-scale cultivation strategies to fully realize its potential. Integrating traditional knowledge with modern science can pave the way for new therapeutic applications and the conservation of this vital botanical resource.

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