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REVIEW ARTICLE

PHYTOTHERAPEUTIC APPLICATIONS OF *PIPER LONGUM* FOR THYROID DYSFUNCTION: A REVIEW OF MECHANISMS AND POTENTIAL

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Abstract: Hypothyroidism is a significant global endocrine disorder resulting from insufficient thyroid hormone production, leading to widespread metabolic dysregulation with symptoms like fatigue, weight gain, and cold intolerance. While synthetic levothyroxine constitutes the primary treatment, there is increasing interest in adjunctive therapies from traditional medicine. This review investigates the potential of Piper longum (Pippali), a revered herb in Ayurveda, as a complementary agent for managing hypothyroidism. The therapeutic efficacy of Piper longum is primarily attributed to its bioactive alkaloid, piperine, which functions as a bio-enhancer to improve the absorption of selenium a critical cofactor for the deiodinase enzymes that convert thyroxine (T4) to the active triiodothyronine (T3). Furthermore, its documented anti-inflammatory, antioxidant, and metabolic-regulating properties may help alleviate the systemic symptoms and secondary complications associated with the condition. While its long-standing use in traditional systems provides a strong ethnobotanical basis, there is a distinct lack of robust clinical trials to validate these effects in hypothyroid patients. This review highlights the promising, multifactorial role of Piper longum in supporting thyroid function while underscoring the urgent need for rigorous scientific investigation to confirm its efficacy and establish its place in modern integrative care.

Keywords: Hypothyroidism, *Piper longum*, Ayurveda, Piperine, Selenium, Bioavailability

INTRODUCTION

Hypothyroidism is a clinical syndrome resulting from the insufficient production of thyroid hormones by the thyroid gland, an endocrine organ situated in the anterior neck. This deficiency impairs the body's capacity to regulate metabolism, cellular function, energy expenditure, and thermogenesis [Chaker L. *et al.*, 2017]. The etiology of hypothyroidism is most commonly attributed to autoimmune processes, such as Hashimoto's thyroiditis, which leads to the progressive destruction of thyroid tissue [Vanderpump M.P.J. 2011]. Other significant causes include iatrogenic factors like surgical thyroidectomy and radiation therapy, pharmacological side effects, and nutritional deficiencies, notably insufficient iodine intake [Taylor P. N. *et al.*, 2018]. Epidemiological data indicate a higher prevalence in females, particularly those over the age of 60 **[**Hollowell J.G. *et al*., 2002]. Failure to address hypothyroidism can result in significant morbidity, including cardiovascular complications, reproductive dysfunction, and neurocognitive decline. However, with appropriate therapeutic intervention, the prognosis is generally excellent.

The diagnosis of hypothyroidism is primarily established through biochemical assays of serum thyroid-stimulating hormone (TSH) and free thyroxine (T4). The standard of care for treatment involves hormone replacement therapy with synthetic levothyroxine, which restores euthyroid status and alleviates clinical manifestations [Graber J.R. *et al*., 2012, Tomar, 2012].

Function of the Thyroid Gland

The thyroid gland's primary role is the synthesis, storage, and secretion of thyroid hormones: thyroxine (T4) and triiodothyronine (T3). This intricate process is regulated by the hypothalamic-pituitary-thyroid (HPT) axis. The hypothalamus secretes thyrotropin-releasing hormone (TRH), which stimulates the anterior pituitary to release TSH. TSH, in turn, acts on the thyroid gland to promote the uptake of iodine and the production of T4 and T3. These hormones are then released into the bloodstream, where they are transported to target tissues throughout the body. A negative feedback loop exists wherein circulating T4 and T3 levels inhibit the secretion of TRH and TSH, thus maintaining hormonal homeostasis [Chaker L. *et al.*, 2017]. Within the cells, T4 is largely converted to the more biologically active T3, which then binds to nuclear receptors to modulate gene expression and, consequently, a wide array of physiological processes.

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Prevalence of Hypothyroidism

The global prevalence of hypothyroidism demonstrates significant geographic and demographic variability, primarily determined by etiological factors such as regional iodine nutrition and the incidence of autoimmune thyroid disease.

Epidemiological data indicate that overt hypothyroidism affects up to 5% of the general population. An additional 5% to 10% of the population is estimated to have subclinical hypothyroidism. When accounting for undiagnosed cases, the aggregate prevalence of thyroid hormone deficiency may approach 10% [Chiovato L. *et al*., 2019]. This heterogeneity underscores the necessity for localized epidemiological studies, especially in iodine-deficient regions, to accurately assess disease burden and inform public health strategies.

In India, a large-scale, cross-sectional, multi-center epidemiological study involving a cohort of 5,360 individuals from eight major urban centers revealed a hypothyroidism prevalence of 10.95% (n=587; 95% CI: 10.11%−11.78%). This prevalence comprises 7.48% self-reported cases and a notable 3.47% of previously undiagnosed cases, highlighting a significant disease burden. The investigation identified statistically significant regional and demographic disparities:

- Geographical Variation: Prevalence was significantly higher in inland cities (11.73%) compared to coastal regions (9.45%; P=0.01).
- Gender Disparity: A marked sex-based difference was observed, with a prevalence of 15.86% in females compared to 5.02% in males.

Furthermore, a substantial autoimmune etiology is implicated, as evidenced by a 21.85% seropositivity for anti-thyroid peroxidase (anti-TPO) antibodies within the cohort, indicating that the high prevalence of hypothyroidism constitutes a major public health concern in the region [Unnikrishnan A.G. *et al*., 2013].

While specific epidemiological data on hypothyroidism prevalence for the state of Uttar Pradesh are not extensively available, the National Family Health Survey (NFHS-5, 2019–2021) provides some insight. According to the survey, the self-reported prevalence of goiter or other thyroid disorders among women in Uttar Pradesh is 1,281 per 100,000, which corresponds to 1.28% [Ministry of Health and Family Welfare 2022].

It is critical to note that this figure is derived from self-reported diagnoses and, therefore, likely represents a significant underestimation of the true disease burden. This is substantiated by findings from a multi-center study in India, which identified that 3.47% of its cohort consisted of previously undiagnosed cases. Given Uttar Pradesh's geographical classification as an inland state, it is plausible that its prevalence rates could be comparable to those observed in other inland urban centers, such as Delhi, which reported a hypothyroidism prevalence of 11.07%.

However, in the absence of dedicated seroprevalence studies within Uttar Pradesh, such comparisons remain speculative. A definitive assessment of hypothyroidism prevalence in this region necessitates targeted epidemiological research.

Piper Longum

Piper longum Linn., commonly known as long pepper and referred to as "pippali" in Ayurvedic medicine, is a perennial, flowering vine belonging to the Piperaceae family [Chauhan K. *et al*., 2011]. This slender, aromatic climber is indigenous to the Indo-Malayan region and is widely distributed throughout India, Nepal, Indonesia, Malaysia, and Sri Lanka. For millennia, *P. longum* has been a cornerstone of traditional medical systems, particularly Ayurveda, where it is revered as a potent medicinal herb [Kumar A. *et al*., 2009].

Botanical Description and Cultivation

P. longum is a dioecious climber, typically reaching a height of 1-2 meters. Morphologically, the plant is characterized by alternate, petiolate, cordate-shaped leaves with entire margins. Its flowers are small, unisexual, and arranged in dense, solitary spikes. The female spikes mature into the medicinally significant fruiting bodies, which are spike-like structures (1-2 cm long) composed of numerous minute, embedded fruits. These fruits are harvested while unripe and subsequently dried for therapeutic use [Kumar S. *et al.*, 2011; Zaveri M. *et al.*, 2010].

The plant flourishes in warm, humid climates with partial shade and requires well-drained, fertile soil for optimal growth. Commercial cultivation is prominent in several Indian states, including the northeastern regions, Kerala, and Tamil Nadu. Propagation is typically achieved vegetatively through stem cuttings or suckers, with the first harvest possible within 6-8 months of planting [Zaveri M. *et al*., 2010].

Historical Context and Modern Applications

The historical importance of *P. longum* is well-documented in ancient Sanskrit texts, including the *Charaka Samhita* and *Sushruta Samhita*, which date back to approximately 1000 BCE [Zaveri M. et.al., 2010]. Traditionally, both the dried unripe fruits and the roots have been utilized for a wide range of therapeutic applications, notably for managing respiratory and digestive disorders [Kumar S. *et al.,* 2011].

In recent decades, extensive scientific investigation has begun to validate these ethnobotanical uses. Research has elucidated the complex phytochemical composition of *P. longum*, identifying compounds responsible for its diverse pharmacological properties [Sunila E.S. *et al*., 2004]. Furthermore, in classical Ayurvedic practice, it is often a key ingredient in polyherbal formulations. For instance, it is combined with black pepper (*Piper nigrum*) and ginger (*Zingiber officinale*) to create the "Trikatu" preparation, a synergistic blend designed to enhance the bioavailability and therapeutic efficacy of other active compounds [Chauhan K. *et al.*, 2011].

BOTANICAL DESCRIPTION [Ministry of Health and Family Welfare, Department of AYUSH, 2001]

Table 1: Shows the taxonomical classification of the herb pippali (*Piper longum* Linn.)

Taxonomical Rank	Taxon
Kingdom	Plantae
Division	Magnoliophyta
Class	Magnoliopsida
Order	Piperales
Family	Piperaceae
Genus	Piper
Species	longum
Common name	Pippalimool, long pepper

Phytochemical Properties
Piper longum, commonly known as long pepper, possesses a rich and diverse phytochemical profile that contributes to its therapeutic efficacy [Choudhary N. *et al.*, 2017].

Table 2: Shows the most bioactive compound in the herb pippali (*Piper longum* Linn.).

Alkaloids	**Volatile Oils**	**Lignans**	**Other Compounds**
Piperine (5-9%): The primary alkaloid, responsible for its pungent taste and many health benefits	Contains components like caryophyllene and eugenol	Compounds like sesamin and sesamol provide antioxidant properties	Also contains steroids, flavonoids, and terpenoids
Others include piperlongumine and piplartine			

Effects of Pippali in Managing Hypothyroidism
Piper longum (Pippali), a phytotherapeutic agent utilized in traditional medicine, is postulated to exert beneficial effects in the management of hypothyroidism, a condition characterized by deficient thyroid hormone production and consequent metabolic dysregulation [Jameson J.L. *et al.*, 2018]. Its potential mechanisms of action are multifaceted and target several pathophysiological aspects of the disorder.

Modulation of Nutrient Bioavailability
The primary bioactive constituent of *P. longum*, piperine, functions as a potent bio-enhancer. It has been shown to improve the gastrointestinal absorption and systemic bioavailability of essential micronutrients, including selenium. Selenium is an indispensable cofactor for the deiodinase enzymes responsible for converting the prohormone thyroxine (T4) into its more biologically active form, triiodothyronine (T3). By optimizing selenium status, piperine may facilitate more efficient T4-to-T3 conversion, a process often impaired in hypothyroid states, thereby supporting overall thyroid hormone economy [Rayman M.P. 2012].

Metabolic Regulation
Hypothyroidism is frequently associated with metabolic sequelae, such as dyslipidemia and impaired glycemic control. Preclinical and clinical evidence suggests that *P. longum* exhibits hypoglycemic and lipid-lowering properties, which can help mitigate these secondary complications [Kumar S. *et al.*, 2011]. By improving insulin sensitivity and lipid profiles, it may alleviate common symptoms like weight gain and fatigue by optimizing cellular energy utilization [Graber J.R. *et al.*, 2012].

Anti-Inflammatory and Antioxidant Mechanisms
Chronic inflammation and oxidative stress are often implicated in the pathogenesis and symptomatology of hypothyroidism, particularly in cases of autoimmune etiology (e.g., Hashimoto's thyroiditis). The documented anti-inflammatory and antioxidant properties of *P. longum* may help attenuate the inflammatory cascade and reduce oxidative damage. This can lead to the amelioration of systemic symptoms such as arthralgia (joint pain) and fatigue.

Clinical Symptom Amelioration
Clinical observations and trials have indicated that administration of *P. longum* can lead to a reduction in the clinical symptoms of hypothyroidism, such as xeroderma (dry skin) and cold intolerance, sometimes even in the absence of significant alterations in serum thyroid hormone levels [Puri H.S. 2003]. This suggests that its therapeutic effects may not be limited to direct modulation of the thyroid gland but could also involve enhancing peripheral tissue sensitivity to existing thyroid hormones or through other non-thyroidal metabolic pathways [Bianco A.C., *et al.*, 2019].

Mechanism of Action

Pippali's involvement with body metabolism to improve hypothyroidism can be understood through the points as under:

Enhancement of Selenium Absorption:

Pippali contains piperine, an alkaloid known to enhance the bioavailability of various nutrients. Research indicates piperine facilitates the absorption of selenium, a critical mineral for thyroid health. Selenium is essential for the activity of deiodinase enzymes, which convert thyroxine (T4) to triiodothyronine (T3), the more biologically active form. In hypothyroidism, this conversion can be impaired, and improved selenium absorption could support better thyroid hormone utilization. For example, studies have shown piperine increases selenium absorption, potentially aiding in maintaining adequate selenium levels, which are vital for thyroid function [Haritha H. *et al*., 2021].

Regulation of Glucose and Lipid Metabolism:

Pippali exhibits anti-hyperglycemic and anti-hyperlipidemic properties, which are significant for managing metabolic disturbances in hypothyroidism. Hypothyroid patients often experience insulin resistance and dyslipidemia, contributing to weight gain and cardiovascular risks. A review article highlights pippali's ability to lower blood glucose and lipid levels, suggesting it could mitigate these metabolic issues [Biswas P. *et al.*, 2022]. This could improve energy expenditure and reduce symptoms like fatigue and weight gain.

Anti-inflammatory and Antioxidant Effects:

Hypothyroidism is associated with increased inflammation and oxidative stress, which can exacerbate symptoms. Pippali's anti-inflammatory and antioxidant activities, attributed to compounds like piperine and piperlongumine, may reduce these effects, potentially alleviating symptoms such as joint pain and tiredness. These properties are supported by pharmacological reviews, which note pippali's role in modulating signaling pathways and reducing oxidative damage [Biswas P. *et al.*, 2022].

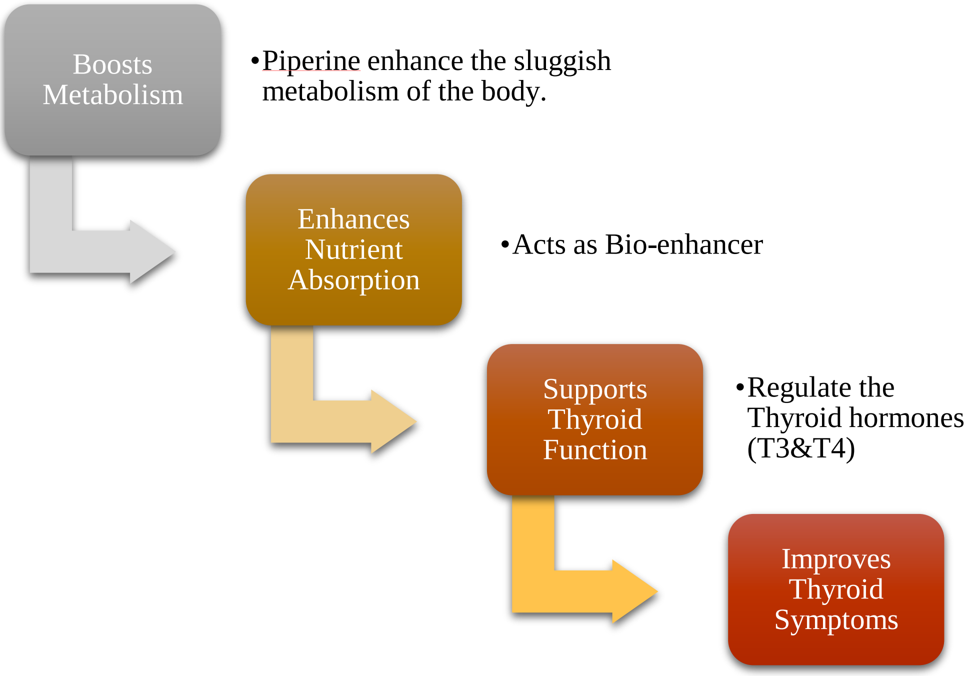

Fig 1. Shows the mechanism of action of pippali.

Dosage

Traditional Ayurvedic Dosage Patterns

Table 3: Description of the dosage pattern of pippali in Ayurveda.

Powder Form [Kumar A. *et al.*, 2009, Chauhan K. *et al.*, 2011]	**Extract Form** [Meghwal M. *et al.*, 2013, Sunila E.S. *et al.*, 2004]	**Trikatu Formulation** [Panda S. *et al.*, 2009, Keshari P.K. *et al.*, 2014]	**Combination Therapies** [Sharma A.K. *et al.*, 2021, Chandrasekhar K. *et al.*, 2012, Panda S. *et al.*, 2009, Keshari P.K. *et al.*, 2014, Mahapatra A. *et al.*, 2018]

Morning Dose: 500 mg once daily on an empty stomach	**Evening Dose:** 500 mg before dinner	**Standardized Extract:** 250-500 mg twice daily	Combination of Pippali, Ginger, and Black Pepper	**With Ashwagandha**	**With Guggul**
Can be mixed with honey or warm water	Suggested to be taken with ghee or warm milk	Morning: After breakfast	1-2 grams daily	Helps improve thyroid hormone levels	Supports thyroid function
Recommended time: Before breakfast		Evening: Before dinner	Helps enhance metabolism and thyroid function	Dosage: 500 mg Pippali + 300 mg Ashwagandha daily	Dosage: 250 mg Pippali + 500 mg Guggul daily

Precautions [Meghwal M. et.al., 2013, Kumar A. *et al.,* 2009, Sunila E.S. *et al.,* 2004]
- Consult an endocrinologist before starting
- Regular thyroid function tests
- Monitor for any side effects
- Not a replacement for conventional thyroid medication

Recommended Duration [Chandersekhar K. *et al.,* 2012, Sharma A.K. *et al.,* 2021, Panda S. *et al.,* 2009]
- Initial Phase: 3-6 months
- Maintenance Phase: 1-2 grams weekly
- Continuous monitoring required

Health Benefits

Piper longum (Long Pepper) is a traditional medicinal herb rich in piperine, primarily used for respiratory and digestive health. Modern science confirms it has potent anti-inflammatory, antimicrobial, and antioxidant effects. Its most significant function is as a natural "bio-enhancer," which helps the body better absorb other drugs and nutrients. It is prescribed for various conditions:

Bioavailability Enhancement: A paramount modern application of *P. longum* is its capacity to enhance the bioavailability of other phytochemicals and drugs. Its key compound, piperine, achieves this by inhibiting hepatic and intestinal glucuronidation and interfering with P-glycoprotein-mediated drug efflux. This mechanism effectively boosts the absorption and slows the metabolism of various substances, a property that has spurred the creation of commercial bioavailability enhancers [Meghwal M. *et al*., 2013].

Anti-inflammatory and Analgesic Activity: *P. longum* demonstrates potent anti-inflammatory and analgesic activity. Piperine and other constituent alkaloids exert these effects by suppressing pro-inflammatory cytokines and enzymes such as cyclooxygenase-2 (COX-2) and lipoxygenase. In animal models, extracts from the plant have successfully reduced edema and pain at levels comparable to standard medications like indomethacin and diclofenac, but with a more favorable side effect profile [Stohr J.R. *et al.,* 2001; Zaveri M. *et al.,* 2010].

Immunomodulatory Effects: The plant exhibits significant immunomodulatory effects, strengthening both humoral and cellular immune responses. Research shows that its compounds, piperine and piperlongumine, boost the production of interleukins and interferon-gamma while also modulating T-helper cell activity [Sunila E.S. *et al.,* 2004]. These actions make it a valuable agent for autoimmune conditions and as a supportive therapy during infections.

Antimicrobial Properties: A broad-spectrum antimicrobial activity against diverse pathogens is another key property of *P. longum*. *In vitro* investigations have confirmed its efficacy against bacteria, including multidrug-resistant strains like *Staphylococcus aureus* and *Escherichia coli*, as well as fungi (notably *Candida* species) and select viruses [Chauhan K. *et al.,* 2011]. Essential oil components such as eugenol and caryophyllene are major contributors to this antimicrobial action.

Antioxidant Activity: *P. longum* possesses powerful antioxidant activity, primarily due to its lignan and flavonoid content. These compounds demonstrate robust free-radical scavenging capabilities. Scientific studies have verified that its extracts can safeguard lipids, proteins, and DNA from oxidative damage, suggesting potential roles in neuroprotection and anti-aging [Chauhan K. *et al*., 2011].

Traditional Applications: These scientifically validated properties underpin its extensive traditional applications. It has long been prescribed for:
- **Respiratory Disorders:** Treating conditions such as asthma, bronchitis, and cough, featuring prominently in formulations like "Trikatu" and "Sitopaladi Churna."
- **Digestive Ailments:** Managing dyspepsia, anorexia, flatulence, and various intestinal issues.
- **Metabolic Disorders:** Aiding in the management of obesity and diabetes.
- **Women's Health**: Addressing amenorrhea, dysmenorrhea, and providing post-partum support.

- **General Health Promotion:** Serving as a key component in rejuvenative therapies (Rasayanas) to enhance vitality and promote longevity.

Using Pippali for Everyday Health (Long Pepper) [Sharma L. *et al*., 2018]

- **For Cough and Congestion:** Create a soothing herbal powder by finely grinding and mixing 10 grams each of holy basil leaves (tulsi), dried ginger (sonth), and long pepper (pippali). Enhance this blend with the powder of 4-6 small cardamoms. To use, mix a small amount of this powder with an equal part of honey to help loosen mucus and relieve coughs.
- **To Help Manage Fever:** Prepare a therapeutic decoction by simmering long pepper root in water. Drinking this twice a day is traditionally believed to help reduce fever, aid in detoxification, and support overall liver function.
- **For Headache Relief:** For a simple, aromatic remedy, gently warm a few long peppers and inhale the vapor. The volatile oils released are thought to help alleviate the symptoms of a tension headache.
- **To Promote Restful Sleep:** For those struggling with sleeplessness, stir approximately 1 gram of long pepper powder into a warm glass of milk. Consuming this before bedtime is considered highly beneficial for promoting sleep.
- **To Ease Breathing Difficulties:** To find relief from respiratory discomfort or shortness of breath (dyspnoea), mix about 2 grams of long pepper powder with a teaspoon of honey. This mixture is traditionally used to help open the airways.
- **For Liver and Spleen Support:** A traditional remedy involves boiling 1-5 grams of long pepper in 200 ml of water until the liquid is reduced. This preparation is often recommended in traditional practices to support the health of the liver and spleen, especially in conditions involving enlargement.

CONCLUSION

Hypothyroidism represents a significant and often underdiagnosed public health concern, particularly in inland regions of India like Uttar Pradesh. The condition's impact on metabolism, energy, and overall well-being necessitates effective management strategies. While conventional hormone replacement therapy remains the standard of care, traditional phytotherapeutic agents like *Piper longum* (Pippali) offer a promising adjunctive approach to support patient health.

The therapeutic potential of Pippali in hypothyroidism is not rooted in direct hormone production but in its multifaceted, supportive mechanisms. Its primary bioactive compound, piperine, acts as a powerful bio-enhancer, notably improving the absorption of selenium a critical micronutrient for the conversion of T4 to the active T3 hormone. Furthermore, its ability to regulate lipid and glucose metabolism directly addresses the secondary complications often associated with hypothyroidism, such as weight gain and dyslipidemia. By exerting potent anti-inflammatory and antioxidant effects, Pippali also helps mitigate the systemic inflammation and oxidative stress that contribute to symptoms like fatigue and joint pain, especially in autoimmune cases.

In essence, *Piper longum* provides a holistic approach that complements conventional treatment by enhancing nutrient utilization, managing metabolic dysregulation, and alleviating clinical symptoms. However, it's crucial to emphasize that Pippali should be viewed as a supportive therapy rather than a replacement for prescribed medication. A safe and effective approach requires a collaborative strategy, integrating the wisdom of Ayurveda with modern medicine under the guidance of qualified healthcare professionals to optimize patient outcomes and improve their quality of life.

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RESEARCH ARTICLE

DUAL-METHOD QUANTIFICATION OF COPPER OXYCHLORIDE RESIDUES IN AGRICULTURAL SOILS: A COMPARATIVE STUDY OF TITRATION AND ATOMIC ABSORPTION SPECTROSCOPY ANALYSIS

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Abstract: Copper oxychloride (COC) is extensively utilized in agriculture, but its accumulation in soil can threaten soil health and productivity. This research evaluated two analytical techniques—titration and atomic absorption spectroscopy (AAS)—to measure copper levels in soils from COC-treated and control areas in four districts of Kerala, India. A total of 64 samples were examined on the 15th and 30th days following COC application. Both methods consistently found low copper concentrations in control soils (<0.4 ppm), whereas treated soils exhibited significantly higher levels, ranging from 70.08±0.03 ppm to 132.00±1.10 ppm on day 15th and decreasing to 61.85±1.60 ppm to 104.90±0.85 ppm by day 30th in titration tests. AAS reported slightly higher values, demonstrating its superior sensitivity and precision. Both methods showed a 15–30% reduction in copper levels over time, indicating environmental dissipation. While titration is economical for routine assessments, AAS offers more dependable results for accurately monitoring copper contamination in agricultural soils.

Keywords: Copper oxychloride, Atomic absorption spectroscopy, Fungicide

INTRODUCTION

Copper based fungicides are in use in agriculture since a long time, Bordeaux mixture (a combination of lime and copper sulphate) being the first among them which was initially used to control downy mildew in vineyards. Presently, a variety of copper-based fungicides are used for crop protection, and these include copper oxychloride (COC), copper hydroxide, copper sulphate, bordeaux mixture and copper acetate (Chrisfield *et al*., 2021; Burandt*et al*., 2023; Gao *et al*., 2023). COC, a commonly used fungicide in agriculture was initially employed to control diseases particularly in orchards and vineyards. Its chemical composition, represented as $Cu_2(OH)_3Cl$, allows it to perform as a broad-spectrum plant protectant that helps to combat fungal pathogens like *Phytophthora infestans* responsible for late blight in potato, *Phytophthora palmivora* causing abnormal leaf fall and *Cornyespora cassicola* causing *Cornyespora* leaf fall in rubber and *Guignardia citricarpa* infesting citrus plants (Jayasuriya, 2006; Schutte *et al*., 2012; Ferreira *et al*., 2014; Keiblinger *et al*., 2018; Manju *et al*., 2019; Oghama *et al*., 2023).

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Application of COC in rubber plants retains the copper particles appropriately distributed on the leaf surface and stalks, even during high humidity and heavy rainfall ensuring proper protection from *Phytophthora palmivora*, thus improving the yield of rubber and rubber latex production. Research have demonstrated that COC accumulation in soil adversely affect soil microbial community including beneficial fungi and bacteria. Copper accumulation in soil disrupts soil fungal activity. Research indicates that COC residues in soil significantly reduce microbial biomass which alters the functional diversity of soil fungal community (Masaka and Muunganirwa, 2007; Keiblinger *et al*., 2018; Wang *et al*., 2018). Soil pH, chemical forms of copper and soil organic matter influence the bioavailability of COC in soil. Bioavailability of COC is higher compared to other copper-based fungicides like bordeaux mixture which leads to more environmental impacts (Schutte *et al*., 2012; Keiblinger*et al*., 2018). COC also has detrimental impacts on soil fauna, especially earthworms. Exposure to COC decreases earthworm growth and impacts their reproduction, which are vital for maintaining soil structure and fertility. A decrease in earthworm population leads to reduced soil aeration and nutrient availability (Eijsackers *et al*., 2005; Wang *et al*., 2018). In addition to these environmental implications, COC is also known to induce oxidative stress in plants. Even though copper is an essential plant micronutrient, higher concentration leads to the production of reactive oxygen species (ROS) that damages cellular structure thus impairing plant growth (Ferreira *et al*., 2014). Hence this study was performed to compare efficacy of two different methods for determining the copper concentration the active ingredient of COC in soil samples.

MATERIALS AND METHODS

Study Area and Sample Collection

Details of the study area are outlined in table 1. According to data from the COC application collected by the Regional Rubber Board (RRB) in Kerala, India, a total of 64 soil samples (192 in triplicate) were gathered from both COC-treated and untreated control sites (where no pesticides were applied) across four locations in the Kasaragod, Kannur, Kozhikode, and Wayanad districts of Kerala, India, as specified in figure 1. These samples were collected on the 15th and 30th days following COC application. Ongoing analysis indicated that pesticide contamination peaked on the 15th day after COC application, followed by a gradual decline, with the most notable reduction observed by the 30th day. Consequently, samples for further research were collected on the 15th and 30th day post-COC application. The samples were transported to the laboratory in ice boxes, air-dried, sieved through a 2mm mesh, and stored at room temperature for later analysis.

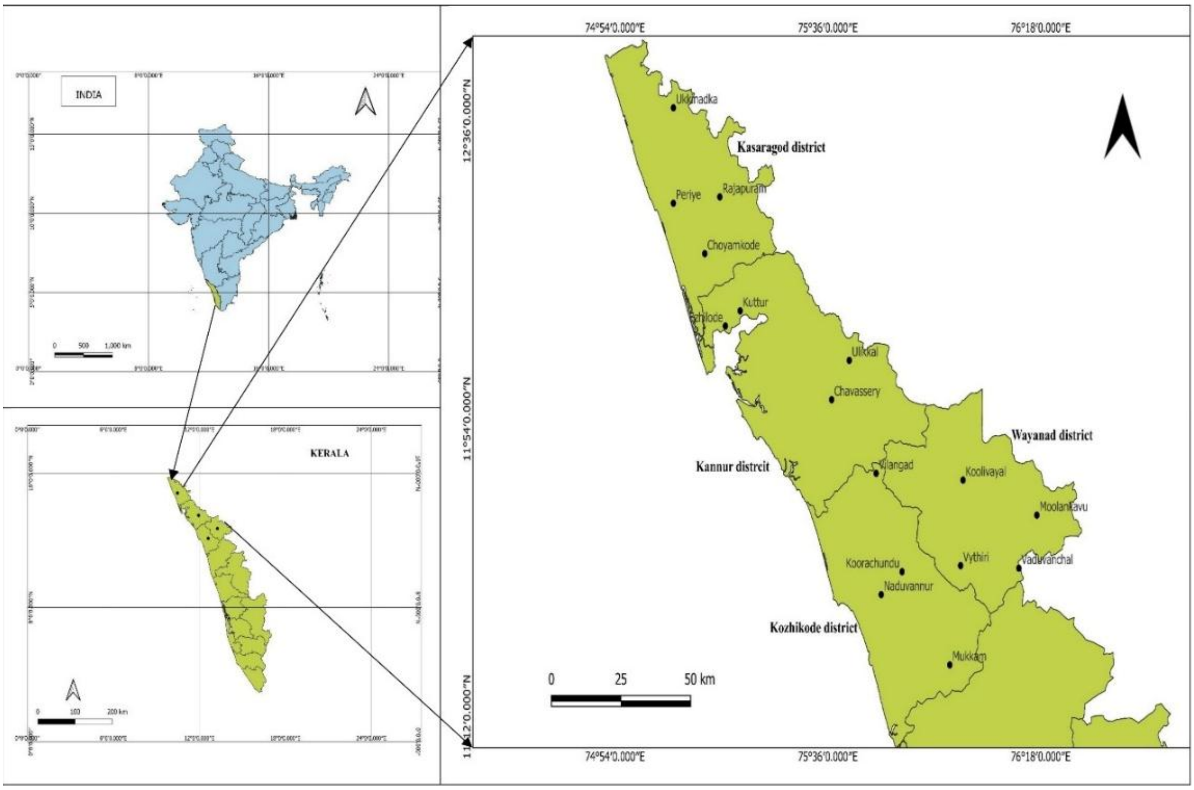

Figure 1: Soil Sampling Sites

COC Analysis

COC concentration in soil samples was determined using titration method and atomic absorption spectroscopy (AAS).

Determination of COC concentration in soil samples using titration method

Approximately 0.20 g of soil sample was placed in a 250 ml conical flask, to which 3 ml of concentrated nitric acid and 20 ml of distilled water were added, and the mixture was shaken for 5 minutes. After cooling, 1 g of urea was added and the solution was boiled for 5 minutes. Once cooled, 1 g of sodium carbonate was added. Subsequently, 5 ml of a 10% acetic acid solution was introduced to dissolve the precipitate. Then, 5 ml of a 30% potassium iodide solution was added, and the solution was titrated with 0.1N standard sodium thiosulphate until a pale straw yellow colour appeared. Following this, 2 g of potassium thiocyanate and 1 ml of a 1% starch solution were added, and the titration continued until the blue colour disappeared (Sridevi *et al*., 2011). The copper concentration was calculated and expressed in ppm.

Determination of COC concentration in soil samples using AAS method

The protocol by Shah *et al*. (2013) was employed to determine the active copper ingredient in COC. A standard solution of COC fungicide was obtained from Sigma-Aldrich Chemicals Private Limited, Bangalore, India. About 1 g of powdered soil sample was placed in a conical flask, and 10 ml of HNO_3 was added. The solution was left to stand for 24 hours. Then, 5 ml of $HClO_4$ was added and the solution was heated until its volume reduced to 3 ml. After complete cooling, the solution was filtered using Whatman No 42 filter paper. The filtrate was then diluted to 25 ml in a volumetric flask using double-distilled water. The copper concentration in the filtrate was measured at a wavelength of 324.80 nm using atomic absorption.

RESULTS AND DISCUSSION

Copper oxychloride (COC) application led to markedly elevated copper concentrations in test soil samples across all four districts (Kasaragod, Kannur, Kozhikode, and Wayanad), as determined by both titration and atomic absorption spectroscopy (AAS). Control samples consistently showed low baseline levels (<0.4 ppm), while test samples exhibited concentrations far exceeding this. Titration results revealed sharp increases post-COC application. Copper values on day 15th found in the range between in 0.11±0.01 ppm and 0.39±0.02 ppm control and in the test samples from 70.08±0.03ppm to 132.00±1.10 ppm. On 30th day in the control samples values ranged between 0.08±0.01ppm and 0.32±0.03 ppm and, in test samples it was found in the range between 59.10±0.40 ppm and 99.01±0.23 ppm. AAS results confirmed these findings, often showing slightly higher peaks. On day15th of COC application copper values were observed in the range between 0.07±0.03 ppm and 0.40±0.03 ppm in control and, from 75.10±0.24 ppm to 135.08±1.08 ppm in the test samples. By day 30th, test concentrations declined but remained elevated. On 30th day in the control samples, values ranged between 0.04±0.01 ppm to 0.38±0.06 ppm and in test samples it was found to be in the range between 61.85±1.60 ppm to 104.90±0.85 ppm. Both methods confirmed a consistent 15–30% decline from day 15th to 30th across districts. Both techniques exhibited strong spatial consistency across 16 sites, validating COC persistence, but AAS demonstrated superior sensitivity, particularly for subtle district variations (e.g., Kozhikode's lower peaks). Titrimetry proved simpler and cost-effective for field screening, though its indirect iodide-based endpoint may underestimate tightly bound copper fractions released more completely by AAS digestion. Standard errors overlapped minimally, indicating high reproducibility; AAS is recommended for precise regulatory monitoring in copper-contaminated soils. These trends align with prior reports of copper accumulation from COC and similar copper based-fungicides (Aarya and Mathew, 2020; Kakutey *et al*., 2023; Matse *et al*., 2024). The reductions over time likely stem from leaching, soil/plant uptake, or environmental factors like moisture and temperature influencing bioavailability (Droz *et al*., 2021; Cheng *et al*., 2024). Excess copper, while an essential micronutrient, proved toxic at these concentrations. It disrupts plant membrane integrity, enzyme/photosynthetic activity, root growth, biomass, and causes chlorosis/necrosis (Kumar *et al*., 2021; Mir *et al*., 2021; Al-Jayashi *et al*., 2023; Feil *et al*., 2023). Soil nutrient availability (P, K, Mn, Fe) diminishes via reactions with oxides and organic matter, curbing crop yields (Schutte *et al*., 2012; Ambrosini *et al*., 2018). Copper also harms soil biota, particularly fungi. COC inhibits saprobic and rhizosphere fungal diversity (e.g., lowest alpha diversity in fungicide-treated tea plantation rhizospheres) (Mallano *et al*., 2023) and impairing nutrient cycling, fertility, and ecosystem resilience (Eijsackers *et al*., 2005; Ferreira *et al*., 2014; Keiblinger *et al*., 2018; Wang *et al*., 2018; Lasota *et al*., 2019; Golubeva *et al*., 2020; Marini *et al*., 2024). Regular monitoring is essential to sustain optimal soil copper levels and mitigate these risks in COC-treated farmlands.

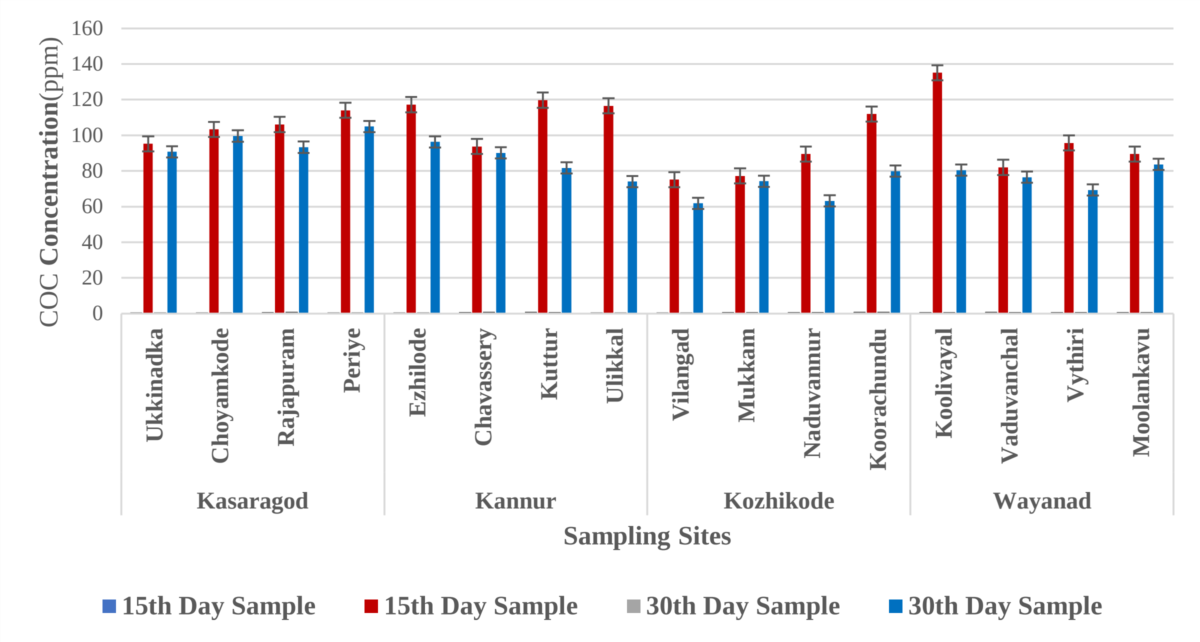

Figure 2: Concentration of COC in Northern Kerala analysed using AAS

Table 1. Concentration of COC in soil samples using titrimetry

District	Sampling site	Day 15 Control*	Day 15 COC applied*	Day 30 Control*	Day 30 COC applied*
Kasaragod	Ukkinadka	0.11±0.01	92.00±1.02	0.14±0.02	81.00±0.86
	Choyamkode	0.23±0.09	91.00±0.03	0.18±0.05	89.01±0.73
	Rajapuram	0.32±0.02	103.00±0.91	0.29±0.06	83.00±0.66
	Periye	0.08±0.01	101.00±1.05	0.09±0.05	99.01±0.23
Kannur	Ezhilode	0.16±0.01	86.00±1.20	0.13±0.01	79.00±1.02
	Chavassery	0.18±0.01	90.00±1.03	0.15±0.02	88.00±0.98
	Kuttur	0.32±0.03	99.00±0.92	0.28±0.02	78.00±0.83
	Ulikkal	0.20±0.01	105.00±0.83	0.12±0.02	94.00±0.69
Kozhikode	Vilangad	0.17±0.03	71.00±0.01	0.12±0.01	60.18±0.55
	Mukkam	0.09±0.01	70.08±0.03	0.06±0.03	59.10±0.40
	Naduvannur	0.39±0.02	72.00±0.05	0.32±0.01	61.00±0.36
	Koorachundu	0.10±0.01	98.00±1.05	0.08±0.01	86.00±1.03
Wayanad	Koolivayal	0.28±0.09	132.00±1.10	0.27±0.01	71.00±0.92
	Vaduvanchal	0.12±0.03	109.00±0.03	0.11±0.02	73.00±0.80
	Vythiri	0.37±0.12	80.00±0.23	0.32±0.03	67.00±1.03
	Moolankavu	0.26±0.10	79.50±0.18	0.24±0.02	75.00±0.03

***mean±SE of concentration of COC in ppm**

CONCLUSION

This research reveals that applying copper oxychloride (COC) significantly raises copper levels in agricultural soils, with concentrations greatly surpassing those in untreated areas across all four districts studied. Both titration and atomic absorption spectroscopy (AAS) successfully identified these increases, but AAS consistently offered higher sensitivity, better precision, and more dependable quantification of copper residues. Although copper levels decreased by 15–30% between the 15^{th} and 30^{th} days post-application, the concentrations in treated soils remained notably high, indicating the persistence of COC in the environment. These results highlight the importance of regularly monitoring copper contamination in plantation soils, especially in regions with frequent fungicide use. Titration is a practical, cost-effective method for initial assessments, while AAS is recommended for regulatory, research, and long-term environmental studies. Overall, responsible management of COC application is crucial to protect soil quality, microbial diversity, crop productivity, and the broader ecosystem's health.

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RESEARCH ARTICLE

ASSESSING THE IMPACT OF IMPROVED FARM TOOLS ON DRUDGERY REDUCTION AND OPERATIONAL EFFICIENCY OF FARM WOMEN IN GROUNDNUT PRODUCTION

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Abstract: The present study aimed to assess the impact of improved farm tools on drudgery reduction and operational efficiency of farm women engaged in groundnut cultivation. Demonstrations of a groundnut decorticator for pod dehulling and a hand wheel hoe one-lane weeder for weeding were conducted by Krishi Vigyan Kendra, Banasthali Vidyapith, in selected villages of Tonk district. The performance of these tools was compared with traditional practices involving manual dehulling by hand and mouth and weeding using *kudali*. The results revealed a significant reduction in time and energy expenditure while performing dehulling and weeding operations with improved tools. Farm women reported enhanced ease of operation, reduced physical strain, and improved work comfort compared to conventional methods. The total drudgery index of farm women was notably lower with the use of improved implements, indicating their effectiveness in reducing workload and enhancing operational efficiency. The study highlights the potential of gender-friendly farm tools in improving the occupational well-being of farm women in groundnut production.

Keywords: Groundnut, Drudgery, Farm women, Groundnut decorticator, Cono weeder

INTRODUCTION

Women constitute the backbone of Indian agriculture and play a pivotal role in sustaining farm productivity. Their participation spans almost all agricultural operations, including seed selection, sowing, intercultural operations, weeding, harvesting, processing, and storage. Several studies have reported that women contribute nearly 60–70 per cent of the total labour input in Indian agriculture, particularly in small and marginal farming systems (Kumar *et al.*, 2011; Nag and Nag, 2004). Despite their significant contribution, most farm operations performed by women continue to rely on traditional tools and manual methods, exposing them to excessive physical workload and occupational health hazards.

Farm women generally work for prolonged hours under unfavourable environmental conditions, adopting awkward and static postures that lead to fatigue, musculoskeletal disorders, and reduced work efficiency (Corlett and Bishop, 1976; Varghese *et al.*, 1994). Repetitive movements, continuous bending, squatting, and load carrying significantly increase physiological stress and perceived exertion among women workers (Nag and Nag, 2004). The lack of access to gender-friendly and ergonomically designed farm implements further aggravates drudgery and negatively affects women's health and productivity (Gite and Singh, 1997; Khadatkar *et al.*, 2015).

Groundnut production in India during 2024 was estimated at around 100–105 lakh tones**.** Major groundnut-producing states in India include Gujarat, Rajasthan, Madhya Pradesh, Tamil Nadu, and Andhra Pradesh**.** Groundnut crop provides livelihood security to millions of small and marginal farmers. Women play a dominant role in groundnut cultivation, particularly in pre-sowing and intercultural operations. One of the most tedious pre-sowing activities is manual dehulling of groundnut pods, which is predominantly carried out by farm women using hands or teeth. This traditional practice exposes women to mouth lesions, dental problems, hand injuries, and severe back and shoulder pain. Continuous engagement in such repetitive and forceful activities leads to cumulative trauma disorders and reduced operational efficiency (Gite and Agarwal, 2000; Sam and Kathirvel, 2008).

After sowing, weeding is considered one of the most labour-intensive and drudgery-prone operations in groundnut cultivation. Manual weeding requires continuous bending for long durations and is mostly performed using conventional tools such as *kudali*.

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This posture-intensive task results in excessive physical load, leading to lower back pain, muscular fatigue, and discomfort in the neck and shoulders among farm women (Varghese *et al.*, 1994; Nag and Nag, 2004). Studies have shown that prolonged bending during weeding significantly increases heart rate, energy expenditure, and perceived exertion, thereby reducing work efficiency and increasing time consumption (Sam and Kathirvel, 2008).

The problem of drudgery becomes more severe during peak agricultural seasons when labour scarcity compels women to work for longer hours, often without adequate rest. This adversely affects not only their health but also the overall productivity of farm operations (Kumar *et al.*, 2011; Yadav *et al.*, 2016). Researchers have emphasized that introduction of women-friendly, labour-saving implements can significantly reduce physical strain, improve posture, save time, and enhance work output (Gite and Agarwal, 2000; Mehta *et al.*, 2012).

In this context, ergonomic interventions in the form of improved agricultural tools assume great importance. Groundnut decorticators and hand wheel hoe weeders have been identified as potential drudgery-reducing technologies for farm women. These implements help in minimizing repetitive hand movements, reducing bending posture, lowering physiological workload, and improving operational efficiency (Rama Lakshmi *et al.*, 2009; Khadatkar *et al.*, 2015). Impact assessment of such technologies is essential to scientifically quantify their benefits in terms of time saving, reduction in physical load, postural comfort, and enhancement of work efficiency (Corlett and Bishop, 1976; Varghese *et al.*, 1994).

Therefore, the present study was undertaken based on demonstrations conducted by Krishi Vigyan Kendra, Banasthali Vidyapith, to assess the impact of a Groundnut Decorticator and Hand Wheel Hoe One-Lane Weeder on drudgery reduction and work efficiency of farm women engaged in groundnut cultivation. The study aims to generate empirical evidence on the ergonomic and productivity benefits of these tools, thereby supporting their wider adoption for improving the occupational well-being of farm women.

The research was designed with following objectives:

- To demonstrate Groundnut decorticator over traditional dehulling method
- To demonstrate Hand Wheel Hoe One Lane Weeder over traditional weeding method
- To assess output, manpower requirement and energy requirement in farm women
- To estimate drudgery index in farm women

MATERIALS AND METHODS

Selection criteria of farm women:

Thirty farm women were selected from three villages Sangrampura, Damodarpura and Motipura of Tonk district, Rajasthan. In the inclusion criteria, Farm women had good experience of groundnut dehulling by hands and manual weeding of groundnut crop with *Kudali.* They were all healthy and with no disease. Anthropometric parameters of farm women were assessed. BMI (Body Mass Index) of farm women was calculated from the formula weight (kg)/Height (meter^2) and classified it based on WHO standards.

Description of groundnut decorticator and Hand Wheel Hoe one lane Weeder:

For groundnut dehulling, Groundnut Decorticator was used which was developed by Tamil Nadu Agricultural University, Coimbatore with characteristics of Manually operated, Groundnut Decortication Efficiency- 25-30 kg/hour, Length-2 feet, width-1 feet, weight- 30 Kg. Groundnut decorticator is most suitable of medium sized groundnut pod. For weeding in groundnut crops, Hand Wheel Hoe one lane Weeder was used which was developed by Central Institute for Women in Agriculture, Bhubaneshwar. It works in the soil up to a depth of 5 cm in crop in groundnut, wheat and seasonal vegetables. Its length can be adjusted according to the height of the worker.

Demonstration ofgroundnut decorticator and Hand Wheel Hoe one lane Weeder:

Groundnut decorticator was demonstrated before sowing of Groundnut crop as the basis requirement is its dehulling. The demonstration was conducted at different time intervals of the day from nine AM to five PM. Dehulling by hands was also performed by farm women to find the difference with above demonstrated technology. When the crop was sown in the field, its weeding was the tedius task to be performed. Hand Wheel Hoe one lane Weeder was demonstrated for weeding in groundnut crop. First Weeding in groundnut as performed at 20-25 days of sowing and second Weeding was done at 35-40 days of sowing at different time intervals of the day from nine AM to five PM. To check the difference, weeding with *Kudali* was also performed by the farm women.

Output, Man power and physiological workload:

Output, Manpower required and physiological workload in farm women are the important parameters to assess efficiency of the equipments. Output of groundnut decorticator was assessed as dehulling in kg per hour while in weeding it was assessed as weeding in square meters per hour. Total manpower, time and drudgery index were assessed in both demonstrations in comparison to their traditional methods. Average heart rate of farm women during work and rest were assessed. On the basis of average heart rate at work and rest, physiological load was assessed and classified on the basis of classification given by Varghese, 1994 (Table 1).

Table 1. Classification of Workload

Physical work load	Physiological variables	
	Energy expenditure (KJ/Min)	Heart beats (Beats/min)
Very light	< 5.0	< 90
Light	5.0-7.5	91-105
Moderate	7.6-10.0	106-120
Heavy	10.0-12.5	121-135
Very heavy	12.6-15.0	136-150
Extremely heavy	>15.0	> 151

Varghese (1994)

Estimating drudgery index

Drudgery index is used to estimate drudgery level in farm women. There were certain rating scales that has been used to estimate drudgery index. These rating scales were based on physical/Manual load, Pastural discomfort and pain in body parts, repetitive work, physiologically stressful work, work demanding more time at task and work causing musculo skeletal disorder and pain. Each parameter of rating for drudgery estimation is given below:

Ratings on the basis of manual loads: Manual handling of loads includes the load exerted on body muscles to push, lift and carry the material. It also leads to a perception among women that work is heavy and demands muscular potential. Rating on manual loads operative: No loads-(1), Light loads-(2), Moderately heavy loads-(3), Heavy loads-(4), Very heavy loads-(5)

Rating on the basis of postural discomfort: Improper body postures c), Veryomfort and stress on skeletal and joints. Sitting on feet, bending and stooping are the common postures adopted by farm women performing agriculture tasks. Such working postures result in pains, body disorders, hazards, and low output efficiency. Ratings on postural discomfort related pain**:**No pain-(1), Mild pain-(2), Moderately painful-(3), Painful-(4), Very painful-(5)

Ratings on the basis of repetitive work: Repetitive work refers to the work that are performed with the same operation again. Such type of work needs same amount of strength or physical action and operations with similar length. Ratings on repetitive work: Repetitive less than 10 per cent of time-(1), Repetitive work 10-29%-(2), Repetitive work 30-49%-(3), Repetitive work 50-79%- (4), Repetitive work greater than 80%-(5)

Ratings on the basis of physical stress: when work needs forceful and rapid muscular movements, it exerts physical stress. Headache, muscle tension and fatigue are the main symptoms under this stress. Rating on physical stress: Very Light/ no exhaustion-(1), Light/mild exhaustion-(2), Moderately heavy/exhausting-(3), Heavy/exhausting-(4), Very heavy/very exhausting-(5)

Ratings on the basis of work demands more Time: Based on the time spent on task, time loads are perceived asVery less duration-(1) less duration-(2), moderate duration-(3), high duration-(4), Very high duration tasks-(5). In this eight hour/day is taken as high duration to consider the time load.

Ratings on the basis of Work causing Musculo skeletal disorders and pain: Prevalence of musculo skeletal disorders due to work situations, exposure to risk factors, incompatible postures, constrain workers and effect their output efficiency. Body disorder symptoms, pain ratings and pain frequency were considered suitable factors to assess musculo skeletal disorder.

Drudgery Index calculations:

It was calculated total Drudgery/150*100. Drudgery level categorization on the basis of drudgery index (Table 2).

Where

- Total drudgery = PL+P+RS+T+MSD+Phy.L
- ML=Manual load (25 points)
- P = Postural load (25 points)
- RS= Repetitive strain load (25 points)
- T= Time load (25 points)
- MSD= Musculo skeletal disorders (25 points)
- PhsL= Physiological load (25 points)

Table 2. Drudgery level categorization on the basis of drudgery index

Drudgery Index %	Drudgery level	Expected heart rate
< 10	Very low	Upto 90
10-20	Low	91-105
20-30	Moderate	106-120
40-50	Very high	121-135
>50	Extremely high	136-150

RESULTS AND DISCUSSION:

Physical characteristics of farm women: The anthropometric data of farm women have been presented in Table 3. The average age and height of the selected thirty farm women was 26 years and 160 cm respectively and the gross body weight was 52.4 kg. The average body mass index was 20.6 indicating that they were having normal body weight (Table 4).

Table 3. Selection criteria of farm women (N=30)

Physical characteristics	Range	Mean
Age (years)	18-45	26.0
Weight (kg)	145-175	160
Height (cm)	43-70	52.4
Body Mass Index	18-25	20.6

Table 4. Body Mass Index score of farm women (N=30)

BMI Score	Interpretation	BMI score of farm women (%)
< 18.5	Underweight	0
18.5-24.9	Normal	0
25-29.9	Overweight	100
> 30.0	Obese	0

(According to WHO Cutt off)

Man power, output and physiological workload:

Man power: After using groundnut decorticator for groundnut dehulling, 91.66% man power was saved over traditional dehulling. On the other hand, 35.71% manpower was saved in groundnut crop weeding by hand wheel hoe one lane weeder in comparison to its traditional weeding with *Kudali*. Saving man power in both demonstrations also saved money which would be spent on man power.

Output: by groundnut decorticator, 25 kg of groundnut per hour were decorticated while 2 kg/har were decorticated by hands. With this demonstrated technology, 1150 % output was increased. On the other hand, the output was increased 45.75% by hand wheel hoe one lane weeder.

Physiological workload: On the basis of heart rate and energy expenditure, the activity of dehulling was moderate while using groundnut decorticator and light with traditional dehulling but the farm women worked with comfort and they did not have to do both tasks for longer period of time which in turn saved farm women's energy as well (Table 5).

Groundnut dehulling by groundnut decorticator by farm women

Groundnut weeding by hand wheel hoe one lane weeder by farm women

Table 5. Man power, Output and Physiological workload

Parameter	Traditional dehulling	Dehulling by Groundnut decorticator	% change	Traditional weeding	Weeding by hand wheel hoe one lane weeder	% change
Man power required (No/ha)	6	0.5	↓ 91.66	14	9.0	↓ 35.71
Output (kg/hr)	2.0	25	↑ 1150	95.23 (m2/hr)	138.8 (m2/hr)	↑ 45.75
Av. Resting heart rate (beats/min)	72	72.1	↑ 0.13	73	73.5	↑ 0.68
Av. working heart rate (beats/min)	105	116	↑ 10.47	134	119	↓ 12.6
Av. Energy expenditure resting (kj/min)	5.14	5.15	↑ 0.19	5.21	5.25	↑ 0.7
Av. Energy expenditure working (kj/min)	7.5	9.66	↑ 28.8	12.40	9.91	↓ 25.12

Total Drudgery Index:

In traditional dehulling of groundnut the percentage of drudgery index was found to be 50 which indicated very high level of drudgery in farm women in manual dehulling of groundnut while on the other hand, using groundnut decorticator for groundnut dehulling the percentage of drudgery index was 26 showing moderate level of drudgery in farm women.

When drudgery level was estimated between wedding *Kudali* and weeding by hand wheel hoe one lane weeder in farm women, weeding of groundnut crop by *Kudali* had 86 percentage of drudgery index which indicated extremely high level of drudgery in farm women. While percentage of drudgery index was found to be 30 indicating moderate level of drudgery in farm women in Weeding by hand wheel hoe one weeder (Table 6).

Table 6. Total Drudgery Index

Parameter	Traditional dehulling	Dehulling by Droundnut decorticator	Traditional weeding	Weeding by hand wheel hoe one lane weeder
Manual load	10	10	20	10
Pastural discomfort	10	5	20	5
Repetitive work	20	5	20	5

Physiologically stressful work	5	10	25	10
Time demand	25	5	25	5
Musculo skeletal disorder	5	5	20	10
Total Drudgery	**75**	**40**	**130**	**45**
Total drudgery Index %	**50**	**26**	**86**	**30**

CONCLUSION

Groundnut dehulling and its weeding in crop stage are time consuming and tedious job. To minimize the efforts and reduce drudgery in farm women groundnut decorticator and Hand wheel hoe one lane weeder were demonstrated. In dehulling process of groundnut, 25 kg/hr of groundnut dehulling was found to be recorded by the use of groundnut decorticator in comparison with dehulling by hands that was recorded 2 kg/hr. In weeding of groundnut crop hand wheel hoe one lane weeder was found more effective and time saving as compared to *kudali*. Hand wheel hoe one lane weeder did its job of weeding in one hectare area with 35.71% man power saving in comparison to traditional weeding methods. Groundnut decorticator and Hand wheel hoe one lane weeder were found to be the most appropriate for groundnut crop to reduce drudgery. Hand wheel hoe one lane weeder was found to be most efficient in moist soil while groundnut decorticator was most suitable for medium size pod of groundnut. If they will be Battery operated then they will be more effective.

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RESEARCH ARTICLE

EFFECT OF ENDOPHYTIC BACTERIAL INOCULATION ON GROWTH AND BIOMASS OF SOYBEAN (*GLYCINE MAX* L.)

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Abstract: Endophytic bacteria from medicinal plants represent a valuable resource for novel bioinoculants for enhancing crop productivity. This study evaluated the effect of selected endophytic bacterial isolates (A4 and A6) from *Adhatoda vasica* on the growth and biomass of soybean (*Glycine max* L.) under pot conditions. Healthy soybean seeds were inoculated with individual isolates, and growth parameters including shoot length, root length, and fresh and dry biomass were recorded at 35 and 60 days after sowing. Inoculated plants exhibited significant improvement in all measured parameters compared to uninoculated controls. Inoculation with isolate A4 resulted in more significant enhancement of overall plant growth. This highly potent isolate was identified via 16S rRNA gene sequencing as *Brevibacillus formosus* strain JFI-4. These findings highlight the potential of selected endophytic bacteria as eco-friendly bioinoculants for sustainable soybean cultivation.

Keywords: *Adhatoda vasica*, Biocontrol, Endophytic bacteria, Plant Growth Promotion (PGP), *Fusarium sp.*

INTRODUCTION

The use of chemical fertilizers in modern agriculture has significantly enhanced the agricultural productivity. However, their uncontrolled application adversely affects environmental sustainability, soil health, and human well-being. In response to these issues, there is a growing concern to develop and adopt more sustainable practices, including the application of biofertilizers and biopesticides. Beneficial microbes, particularly bacteria, are preferable due to their rapid growth, genetic tractability, and diverse metabolic capabilities. Recently, a specific group of microbes known as endophytes has attracted more interest from researchers.

Endophytic bacteria are nothing but group of rhizospheric bacteria that colonize the internal plant tissues. These microbes colonize various parts of the plant, such as roots, stems, and leaves, without inducing any damage to the host (Ting *et al.*, 2021). Unlike pathogens, endophytic bacteria coexist with their hosts, forming symbiotic associations (Bhutani *et al.*, 2021). This close association facilitates a more direct and efficient exchange of nutrients and metabolic signals that can significantly enhance host plant fitness, stress tolerance, and defense. Endophytic bacteria offer advantages such as nitrogen fixation, phosphate solubilization, siderophore release, and the production of growth-regulating hormones, all of which significantly contribute to plant growth and productivity. Bacterial endophytes isolated from arid land plants produce substantial levels of Indole-3-Acetic Acid (IAA), leading to enhanced shoot and root growth in crop plants through hormonal regulation (Asaf *et al.*, 2017). Endophytic bacteria also play an important role in enhancing plant tolerance to various biotic and abiotic stress (Ganie *et al.*, 2022; Jan *et al.*, 2019). Endophytic bacteria enhance resistance against abiotic stresses by the modulation of plant antioxidant systems and hormone-mediated stress responses (Narayanan & Glick, 2022).

Hence, the selection of the host plant is a critical factor in the discovery of novel endophytic strains with unique beneficial properties. Medicinal plants, mainly acknowledged for their therapeutic properties, are promising reservoirs of such beneficial microorganisms. In this context, *Adhatoda vasica*, a medicinal plant widely used in traditional medicine, is compelling candidate. Its antimicrobial properties suggest that the associated endophytes may produce bioactive compounds important for plant growth and biocontrol.

In spite of such promising findings, the diversity and functional capabilities of endophytic bacteria in different medicinal plant particularly their application as bioformulations, is still underexplored (Inamdar & Deshpande, 2025). The unique biochemical environment within this medicinal plant could be a reservoir for novel bacterial isolates with dual-function capabilities, promoting plant growth and simultaneously providing biological control against pathogens. As of now, only one significant study has been conducted on the isolation of endophytic bacteria

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from *Adhatoda vasica* and the evaluation of their plant growth-promoting (PGP) traits, highlighting a substantial research gap in this area (Vyas & Kaur, 2019). To address this research gap, the present study was undertaken with the aim to demonstrate the efficiency of most promising isolates in promoting plant growth *in vivo* through a pot experiment.

MATERIALS AND METHODS

Selection of Endophytic Bacterial Isolates

Endophytic bacterial isolates used in the present study were selected based on their superior plant growth–promoting potential identified during preliminary investigations. Selected endophytic bacterial strains obtained from *Adhatoda vasica* were evaluated for their effect on soybean growth under experimental conditions.

Preparation of Bacterial Inoculum

The selected endophytic bacterial isolates were cultured individually in nutrient broth and incubated at 28 ± 2 °C for 24–48 h under shaking conditions until reaching the exponential growth phase. The bacterial cell density was adjusted to approximately 10^8 CFU ml^{-1}. For consortium treatment, equal volumes of individual bacterial suspensions were mixed thoroughly prior to application.

Effect of selected isolates on growth of soybean *(Glycine max)* by pot experiments

Based on the *in vitro* PGP screening results, two promising isolates, A4 and A6, were selected to evaluate their effect on the growth of soybean (*Glycine max*) under greenhouse conditions. The pot experiment was conducted in a randomized complete block design with 3 replications. Bacterial inoculum was prepared by growing isolates in Nutrient Broth at 28°C for 48 hours to a cell density of approximately 10^8 CFU/ml. Soybean seeds were surface-sterilized with 1% NaOCl for 2 minutes, rinsed with sterile water, and then soaked in the respective bacterial suspension for 30 minutes. Control seeds were treated with un-inoculated sterile Nutrient Broth. Five treated seeds were sown per pot. Pots were watered as required. After 35 days of sowing, plants were carefully uprooted, and growth parameters including root length, shoot length, and total dry biomass were recorded.

Molecular identification of potential isolate

The isolate showing significant growth promotion *in vivo* (A4) was identified by 16S rRNA gene sequence analysis. The obtained sequence was then compared with existing sequence in the National Center for Biotechnology Information (NCBI) database using BLASTn. A phylogenetic tree was constructed using MEGA software. The 16S rRNA gene sequence of the isolate A4 was submitted to the GeneBank database to obtain an accession number.

Statistical Analysis

All experiments were performed in triplicate, and the data are presented as the mean ± standard deviation (SD). The experimental data obtained in the study was analyzed by one-way analysis of variance (ANOVA) using Microsoft excel.

RESULT

Effect of selected isolates on growth of soybean *(Glycine max)* by pot experiments

Inoculation of soybean with selected endophytic bacterial isolates significantly improved plant growth compared to the uninoculated control. Both individual isolates enhanced shoot and root development as well as biomass accumulation at 35 and 60 days after sowing (DAS).

The enhanced growth response of soybean plants inoculated with isolates A4 and A6 may be attributed to their ability to express multiple plant growth–promoting traits, including nutrient solubilization and phytohormone production, as evidenced in preliminary studies. These observations were further corroborated by the in vivo evaluation conducted on soybean plants. At 35 days after sowing, inoculation with isolate A4 significantly enhanced both shoot length (13 cm) and root length (17.2 cm) compared to the uninoculated control (12 cm). Furthermore, isolate A4 considerably increased the fresh weight (1.76 g) and dry weight (0.410 g) of shoots, as well as the fresh weight (1.960 g) and dry weight (0.242 g) of roots.

While isolate A6 also displayed multiple PGP traits in vitro, its effect on soybean growth parameters was less pronounced compared to A4. Plants treated with A6 showed a slight decrease in shoot length (10.5 cm) and a notable reduction in root length (10.0 cm) compared to the control. However, A6 did show a marginal improvement in shoot fresh weight (1.280 g) and dry weight (0.233 g) compared to the control, with similar trends observed in root fresh weight (0.623 g) and dry weight (0.129 g).

Table 1. Effect of bacterial isolates on growth parameters of soyabean on 35 DAS (Days After Sowing)

Sr. no.	Treatment	Shoot length (cm)	Root length(cm)	Shoot weight (g)		Root weight (g)	
				Fresh wt.	Dry wt.	Fresh wt.	Dry wt.
1	Control	11	12	1.06	0.245	0.489	0.109
2	A4	13	17.2	1.76	0.410	1.960	0.242
3	A6	11	10.0	1.280	0.233	0.623	0.129

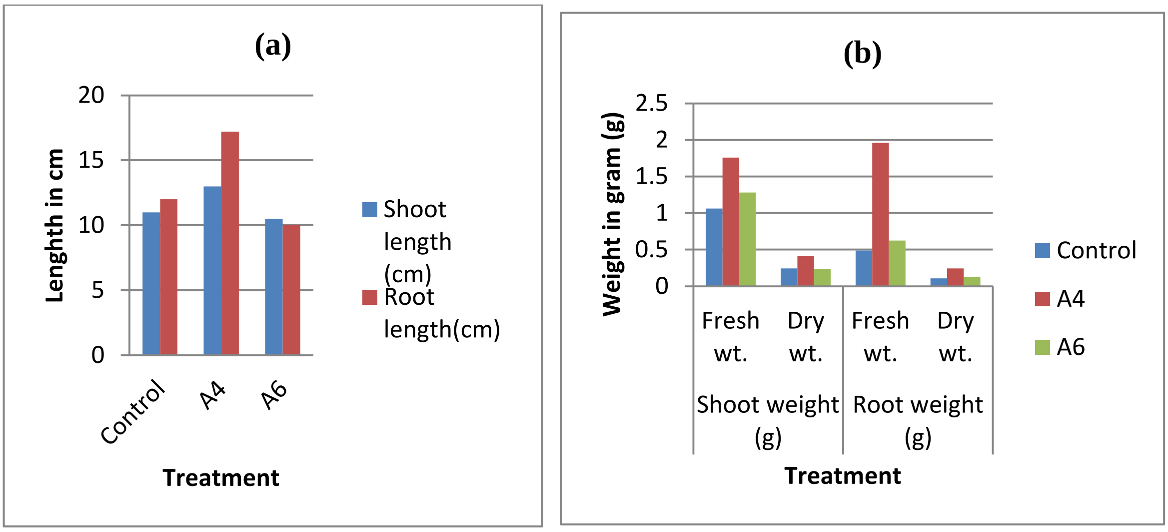

Fig. 1. Effect of endophytic bacterial isolates on (a) shoot length and root length and (b) fresh and dry weight of shoot and root of soybean on 35 DAS

Molecular identification of potential isolate

The most promising plant growth-promoting isolate, A4, was selected for molecular identification through 16S rRNA gene sequence analysis. The partial 16S rRNA gene sequence was deposited in the GenBank database under accession number PQ857179. A subsequent BLAST analysis revealed a high degree of similarity to *Brevibacillus formosus* strain, thereby identifying isolate A4 as *Brevibacillus formosus* strain JFI-4. To further confirm its taxonomic position, a phylogenetic tree was constructed, which showed that isolate A4 clusters closely with *Brevibacillus formosus* and related species (Fig. 2).

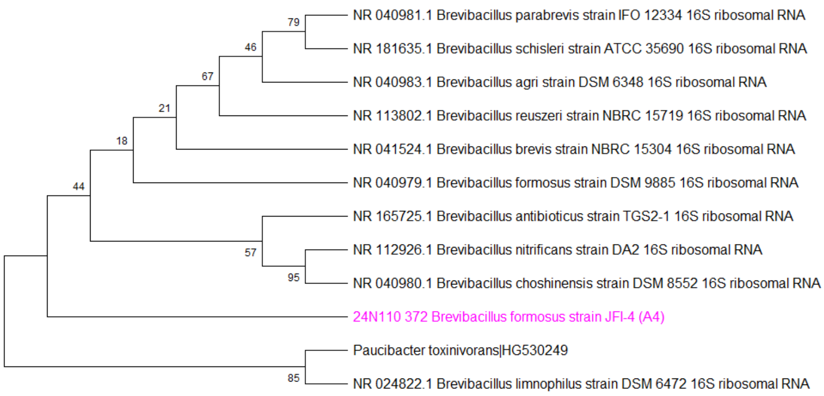

Fig. 2. Phylogenetic analysis of *Brevibacillus formosus* strain JFI-4 (A4) based on 16S rRNA gene sequences

DISCUSSION

The significant improvement in soybean growth due to endophytic bacterial inoculation may be attributed to enhanced nutrient availability, stimulation of root development, and improved physiological efficiency of the plants. Endophytes are known to facilitate plant growth by producing phytohormones, solubilizing nutrients, and promoting root system architecture, which collectively increase biomass accumulation.

The *in vivo* pot experiment provided the ultimate validation of our *in vitro* screening. The results clearly demonstrated that the multifunctional PGP isolate A4 showed significant plant growth promotion in soybean. The substantial increases in shoot and root length, as well as fresh and dry biomass, confirm its efficacy as a bioinoculant. In contrast, isolate A6 exhibiting strong phosphate solubilization and other PGP traits *in vitro*, failed to promote root growth *in vivo*. These findings showed that *in vitro* potential of isolates does not always translate to *in vivo* growth enhancement. The complex and competitive rhizosphere environment, host-microbe specificity, or potential production of inhibitory compounds under specific conditions may explain this inconsistency (Afzal *et al.*, 2019). The superior performance of A4 in the pot experiment strongly suggests its ability to successfully colonize the soybean rhizosphere, and effectively exert its PGP effects.

Molecular identification by 16S rRNA gene sequencing identified the most promising isolate, A4, as *Brevibacillus formosus* strain JFI-4. Its ability to form resilient endospores provides a major advantage for commercial formulation, ensuring a long shelf-life and stability under harsh environmental conditions (Kalboush *et al.*, 2024; Shelke *et al.*, 2023).

In conclusion, this study successfully isolated a potent, multi-trait endophytic bacterium, *Brevibacillus formosus* strain JFI-4, from the medicinal plant *Adhatoda vasica*. This isolate demonstrated significant potential of endophytic bacteria in promoting soybean growth under greenhouse conditions. These findings underscore the value of exploring medicinal plants as reservoirs for potent bio-inoculants and confirm *Brevibacillus formosus* strain JFI-4 as an excellent candidate for the development of a sustainable biofertilizer and biocontrol agent. Future studies should focus on field trials to confirm its effectiveness under diverse agronomic conditions and the specific molecular mechanisms underlying its beneficial effects.

Statements and Declarations

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Author Contributions

Samarin Faruk Inamdar: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing – Original draft.

Seema N. Deshpande: Supervision, Guidance in experimental design, Resources, Final approval of manuscript, Project administration.

Rahul Shelke: Data validation, Laboratory assistance, Writing – Review and editing.

Data Availability

The 16S rRNA gene sequence generated and analysed during the study have been deposited in the NCBI GeneBank database under the accession number PQ857179.

URL:
https://www.ncbi.nlm.nih.gov/nuccore/PQ857179.1/

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RESEARCH ARTICLE

ETHNOMEDICINAL IMPORTANCE, TAXONOMIC CHARACTERIZATION, AND CONSERVATION PERSPECTIVES OF *HYGROPHILA AURICULATA* (SCHUMACH.) HEINE

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Abstract: *Hygrophila auriculata* (Schumach.) Heine, a prominent member of the family Acanthaceae, is a well-known medicinal plant widely used in traditional healthcare systems across India. The species is valued for its therapeutic applications in treating ailments such as rheumatism, jaundice, urinary disorders, and reproductive problems. The present study integrates ethnomedicinal documentation, taxonomic evaluation, and conservation perspectives of *H. auriculata* to provide a comprehensive understanding of its significance. Field surveys and interviews with local healers and traditional practitioners were conducted to record indigenous knowledge related to its usage, preparation methods and cultural importance. Detailed morphological characterization was performed to confirm species identification and to identify its key taxonomic features. The conservation assessment showed that habitat degradation, overexploitation, and poor regeneration are the main threats to the species' natural populations. The study emphasizes the need for community-based conservation strategies, sustainable harvesting practices, and ex situ propagation to safeguard *Hygrophila auriculata* for future generations. This integrative approach highlights the importance of combining traditional wisdom with scientific evaluation to ensure the long-term conservation and sustainable utilization of this valuable ethnomedicinal plant.

Keywords: Ethnomedicinal plant, Taxonomy, Conservation, *Hygrophila auriculata*

INTRODUCTION

Plants have long served as the primary source of medicine for human societies, forming the foundation of traditional healthcare systems across the world. In India, the use of ethnomedicinal plants remains an integral part of rural and tribal health practices, reflecting the deep interconnection between biodiversity, traditional knowledge, and cultural heritage. The documentation and scientific validation of such traditional wisdom not only contribute to ethnobotanical research but also support the conservation of valuable medicinal species that are increasingly threatened by habitat loss and overexploitation.

The family Acanthaceae exhibit considerable variation in its reported taxonomic circumscription across different sources. Scotland and Vollesen (2000) estimated the family to include about 250 genera and 2500 species predominantly distributed in tropical and subtropical regions. Minzitto- Tripp *et al*., (2022), however, recognized 191 accepted genera and with an estimated 2500-3000 species. In contrast, World Flora Online lists 190 genera and roughly 4900 species worldwide. These discrepancies highlights that there is no single universally accepted global estimate for the number of species in Acanthaceae, reflecting ongoing taxonomic revisions, differing classification approaches and continues updates in global floristic databases.

Members of this family are recognized for their wide range of medicinal properties and significant ecological roles in wetland and riparian ecosystems. Among them, *Hygrophila auriculata* (Schumach.) Heine is described in classical Ayurvedic literatures under the names "Ikshagandha", "Ikshura", and "Kokilaksha", the latter referring to a plant whose "eyes" resemble those of the "Kokila" (Indian cuckoo) (Shanmugasundaram and Venkataraman, 2006). The species is widely used in traditional systems of medicine and is commonly known as "Marsh Barbel" in English, "Talmakhana" in Hindi, "Koilikhia" in Odia and "Kuilekha" in the local vernacular usage.

It possesses significance ethnomedicinal value and regarded as a highly important multipurpose medicinal herb extensively used in traditional systems of medicine such as Ayurveda, Siddha, and diverse folk traditions. In Ayurveda it is classified as *Rasayan* (Rejuvenating agent) and *Vajikaran* (aphrodisiac) herb, it traditionally employed to restore vitality and promote overall well-being. "Kuilekha" is especially renowned for its therapeutic benefit in managing male sexual health disorders.it is also believed to enhance reproductive health by improving sperm count, increasing sperm motility,

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and boosting overall sexual performance. Owing to these properties, the plant continues to be an important component in Ayurvedic formulations aimed at strengthening reproductive system and enhancing general vitality (Chauhan *et al*., 2011).

Despite its extensive traditional use, *Hygrophila auriculata* has received limited attention in terms of taxonomic evaluation and conservation assessment. Its synonyms are *Asteracantha longifolia* (L.) Nees, *Hygrophila spinosa* T. Anderson. Misidentification and confusion with related species within the genus *Hygrophila* often hinder accurate documentation and pharmacological research. Detailed morphological characterization, supported by herbarium studies, is therefore essential for confirming its taxonomic identity and for its distinguishing it from morphologically similar taxa.

In recent years, the natural habitats of *H. auriculata*, particularly marshy and wetland areas, have been increasingly degraded due to urbanization, agricultural expansion, and unsustainable harvesting practices. These threats have resulted in a decline of wild populations, emphasizing the need for effective in situ and ex situ conservation strategies. Integrating local knowledge with scientific methods can play a pivotal role in formulating sustainable management plans for this species.

The present study aims to (i) document the traditional knowledge associated with *H. auriculata* among local and tribal communities, (ii) examine its diagnostic taxonomic features for accurate identification, and (iii) assess the conservation status and suggest suitable measures for its sustainable utilization and preservation. This integrative approach bridges ethnobotany, taxonomy, and conservation biology to enhance understanding of *H. auriculata* as a key medicinal resource of ecological and cultural importance.

Hygrophila auriculata (Schumach.) Heine in Kew Bull. 16(2): 172. 1962; *Asteracantha longifolia* (L.) Nees in Wall., Pl. As. Rar. 3:90. 1832; Haines, Bot. Bihar & Orissa Pt. IV: 671 1922; Mooney, Suppl. Bot. Bihar & Orissa 108. 1950; Saxena & Brahmam, Fl. Orissa III: 1352. 1995.

Classification of *Hygrophila auriculata*

Kingdom:	Plantae
Phylum:	Streptophyta
Class:	Equisetopsida
Subclade:	Magnoliidae
Order:	Lamiales
Family:	Acanthaceae
Genus:	Hygrophila
Species:	H. auriculata

Brief description

Stout annual herbs, with axillary spines. Leaves oblong-lanceolate, entire, acute-acuminate, base tapering. Flowers purple, in axillary whorls; bracts leafy; bracteolate linear-lanceolate. Capsules linear-oblong, 4-8 seeded. Flowering & Fruiting: October-February

Distribution: The plant is widely distributed in India, Sri Lanka, Burma, Malaysia, and Nepal. Common in moist places and along the drains, ponds, ditches and in rice fields.

MATERIALS AND METHODS

The study was conducted in selected regions of western Odisha, India, where *Hygrophila auriculata* naturally occurs in marshy fields, ditches, pond margins, and seasonally waterlogged habitats. Ethnomedicinal data were collected through field surveys and semi-structured interviews with traditional healers, tribal priests and local practitioners. Morphological characters and herbarium verification were performed to confirm species identification. The plant identification was done with the regional flora books (Haines, 1991-25; Mooney; 1950; Saxena and Brahmam, 1995). The Internet Archive database was extensively utilized during preparation of this research paper to obtain relevant documents and supporting references. Relevant research articles and authoritative books were identified, selected and critically reviewed to inform this study (Dhury, 1873; Kirtikar and Basu, 1935; Chopra *et al*., 1956; Jain; 1991; Warrier, 1996; Khare, 2007; Sharma and Kumar, 2016; Tomar, 2017, Yadav *et al*., 2017).

Ethnomedicinal Uses:

Gout: Leaf extract (1-2 teaspoons) is taken twice a day after food for 5-7 days to treat gout.

Increase Sperm count: Leaf extract (2 teaspoon) is taken with honey (1 teaspoon) twice a day on an empty stomach for 20-30 days to increase sperm count. Seed (2 gm) is crushed to powder and taken with honey on an empty stomach in the morning to increase sperm count.

Kidney stone: Leaf extract (2 teaspoons) is taken 2 times daily after food for 10-15 days to cure kidney stone.

Jaundice: Equal amount of leaves of the plant and *Tinospora cordifolia* are crushed together and the extract (10 – 20 ml) is taken once daily on an empty stomach to manage jaundice.

Oedema: Whole plant ash (250 -300 mg) with honey (1/2 teaspoon) is taken 2 times daily on an empty stomach to treat oedema.

Rheumatism: Crushed root is fried with *Ricinus communis* seed oil or *Brassica rapa* seed oil and is applied externally on the affected area.

Back pain: Seeds paste along with a little *Brassica rapa* seed oil is warmed and applied twice daily on the affected part to relieve back pain.

As Food: Leaves are consumed as leafy vegetable and help managing acidity.

RESULTS AND DISCUSSION

The ethnomedicinal survey revealed that *Hygrophila auriculata* plays a significant role in traditional medicine among the communities of western Odisha.

The study revealed that different plant parts are used to treat a wide range of ailments. The roots are primarily employed to relieve rheumatism, while leaves are used to treat gout, kidney stone, jaundice, and to increases sperm count. The whole plant is administered in case of oedema indicating its possible inflammatory properties. Additionally, the seeds are utilized to treat back pain and to enhance sperm count. These findings highlight the medicinal importance species and demonstrate its potential therapeutic value. However, further pharmacological and clinical investigations are essential to validate these traditional claims and to ensure safe and effective use.

From taxonomic viewpoint, *H. auriculata* is characterized by its erect herbaceous habit, spiny stems, opposite, lanceolate leaves, and axillary clusters of purple flowers enclosed within rigid bracts which serve as diagnostic features for species identification. The presence of bristle-like spines along leaf veins and the characteristic globose reticulate seeds further assist in differentiating it from closely related taxa within the genus *Hygrophila*. These morphological characters are essential for accurate botanical identification, particularly in ethnobotanical studies and in preventing the adulteration of herbal materials in medicinal preparations.

Despite its wide adaptability to wetland and marshy habitats, increasing anthropogenic pressure, overharvesting for medicinal purposes, and alteration of aquatic ecosystems threatened its natural populations. Therefore, conservation strategies should incorporate both in *in-situ* habitat protection and *ex-situ* cultivation initiatives. Community-based awareness, promotion of sustainable harvesting techniques, and the development of nursery propagation programme could play key roles in ensuring long-term species preservation. Furthermore, systematic phytochemical and pharmacological evaluations are necessary to scientifically validate traditional uses, ensure safety, and identify bioactive compounds responsible for therapeutic effects.

CONCLUSION

The present study provides an integrative account of the ethnomedicinal uses, taxonomic features, and conservation concerns of *Hygrophila auriculata*, a valuable member of Acanthaceae. The findings reveal that the species plays an essential role in the traditional healthcare systems, particularly for the treatment of urinary, hepatic, and rhematic disorders. Its wide therapeutic applications reflect the depth of indigenous knowledge preserved among rural and tribal communities.

Taxonomic analysis confirmed the district identity of *Hygrophila auriculata* through characteristic features such as auriculate leaf bases, purple flowers, and linear-oblong capsules, helping to differentiate it from closely allied species. This classification is critical for accurate ethnobotanical documentation and preventing misidentification in herbal medicine research.

However, the species faces growing threats from habitat degradation, overexploitation and shrinking of wetland ecosystems. The study emphasizes the need for integrated conservation strategies, including sustainable harvesting, in situ and ex situ propagation efforts. Involving local communities in conservation planning can enhance both ecological protection and cultural continuity.

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