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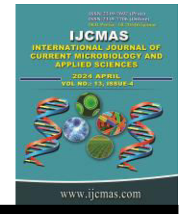

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Harnessing Plant Growth Promoting Rhizobacteria as Biostimulants for Enhancing Growth and Productivity of *Tephrosia purpurea*: A Promising Approach for Sustainable Agriculture

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A B S T R A C T

Tephrosia purpurea, commonly known as “wild indigo,” is a leguminous plant with significant ecological and agricultural importance due to its medicinal properties, soil-improving abilities, and potential as a forage crop. In recent years, there has been growing interest in utilizing plant growth-promoting rhizobacteria (PGPR) as biostimulants to enhance crop growth, productivity, and stress tolerance. This research paper explores the potential of PGPR as biostimulants for *Tephrosia purpurea*, highlighting their mechanisms of action, beneficial effects on plant growth and development, and implications for sustainable agriculture.

Introduction

Tephrosia purpurea is a versatile plant species with diverse applications in traditional medicine, soil conservation, and livestock feeding. Despite its potential, challenges such as limited growth under suboptimal conditions, susceptibility to biotic and abiotic stresses, and nutrient deficiencies can hamper its productivity.

Plant growth-promoting rhizobacteria (PGPR) have emerged as promising biostimulants capable of enhancing plant growth, nutrient uptake, and stress tolerance through various mechanisms. This research explores the role of PGPR as biostimulants for *Tephrosiapurpurea*, aiming to elucidate their potential in improving its growth and productivity (Gopalakrishnan, *et al.*, 2015; Aloo, *et al.*, 2020).

Tephrosia purpurea, commonly known as “wild indigo,” is a species of flowering plant belonging to the Fabaceae family. It is native to tropical and subtropical regions of Asia, Africa, and Australia. *Tephrosia purpurea* is characterized by its upright growth habit, compound leaves with three leaflets, and showy clusters of pink to purple pea-like flowers. Here are some key characteristics and uses of *Tephrosia purpurea* (Dutta, *et al.,* 2010; Khatoon, *et al.,* 2020).

Botanical Features

Tephrosia purpurea is a perennial herbaceous plant that can grow up to 1-2 meters in height. Its leaves are alternate, pinnately compound, with three oval-shaped leaflets. The flowers are arranged in terminal racemes and have a papilionaceous structure typical of leguminous plants, consisting of five petals: one banner, two wings, and two keels. The flowers are typically pink to purple, but variations in flower colour have been observed.

Ecological Role

Tephrosia purpurea plays a vital ecological role in its native habitats. It is often found growing in disturbed areas, open grasslands, and along roadsides. As a leguminous plant, *Tephrosia purpurea* is capable of nitrogen fixation through its symbiotic relationship with nitrogen-fixing bacteria (*rhizobia*), thereby enriching the soil with nutrients and contributing to ecosystem health and fertility (Kalam, *et al.,* 2017).

Traditional Uses

Tephrosia purpurea has a long history of traditional use in herbal medicine systems around the world. Various parts of the plant, including the leaves, roots, and seeds, are used in traditional remedies for a wide range of ailments. In traditional Ayurvedic medicine, *Tephrosia purpurea* is known as "Sarapunkha" and is used to treat liver disorders, jaundice, asthma, fever, and skin diseases. Additionally, the plant has been used traditionally as a diuretic, laxative, and anthelmintic.

Phytochemistry

Phytochemical studies have revealed the presence of bioactive compounds in *Tephrosia purpurea*, including flavonoids, alkaloids, saponins, tannins, and terpenoids. These compounds are responsible for the plant's medicinal properties and pharmacological activities, such as hepatoprotective, anti-inflammatory, antioxidant, antimicrobial, and antidiabetic effects (Rao, *et al*., 2020).

Agricultural Applications

In addition to its medicinal uses, *Tephrosia purpurea* has agricultural significance. The plant is used as a green manure and cover crop to improve soil fertility, control weeds, and prevent erosion. Its ability to fix nitrogen makes it valuable in crop rotation systems, where it can enhance soil nitrogen levels and reduce the need for synthetic fertilizers. *Tephrosia purpurea* is also utilized as fodder for livestock due to its high protein content and palatability. Overall, *Tephrosia purpurea* is a versatile plant species with ecological, medicinal, and agricultural importance. Its diverse uses and adaptability make it a valuable resource for sustainable agriculture, ecosystem restoration, and traditional medicine practices. However, conservation efforts are needed to ensure the sustainable management and preservation of *Tephrosia purpurea* populations in the wild (Palbag, *et al*., 2014).

Selection of Plant Growth Promoting Rhizobacteria (PGPR)

PGPR strains were selected based on their known ability to promote plant growth, nitrogen fixation, phosphate solubilization, and production of phytohormones.

Isolation and characterization of PGPR strains from rhizosphere soil of *Tephrosia purpurea* were conducted using selective media and biochemical assays.

Preparation of PGPR Inoculants

Selected PGPR strains were cultured in suitable liquid media under optimal conditions to obtain a high-density bacterial suspension.

The bacterial cells were harvested by centrifugation, washed, and resuspended in a carrier solution such as sterile distilled water or a biopolymer gel for inoculant formulation.

Experimental Design

Pot experiments were conducted under controlled environmental conditions, such as a greenhouse or growth chamber, to evaluate the effects of PGPR inoculants on *Tephrosia purpurea* growth and productivity.

Randomized complete block design (RCBD) or factorial design with appropriate replicates and treatments was employed.

Plant Growth Conditions

Tephrosia purpurea seeds were surface sterilized and germinated in sterile conditions. Uniformly germinated seedlings were transplanted into pots filled with sterilized soil or growth medium supplemented with PGPR inoculants at specified concentrations.

Treatment Application

PGPR inoculants were applied to the rhizosphere of *Tephrosia purpurea* seedlings at different growth stages, such as seedling establishment, vegetative growth, and flowering stages. Control treatments without PGPR inoculation were included for comparison.

Parameters Assessed

Plant growth parameters, including shoot height, root length, biomass accumulation (both shoot and root), and leaf area, were measured at regular intervals during the experiment.

Nutrient uptake (nitrogen, phosphorus, potassium) by *Tephrosia purpurea* plants was analyzed using appropriate analytical methods. Physiological parameters such as chlorophyll content, photosynthetic rate, and stomatal conductance were determined using non-destructive measurement techniques (Sharma, *et al*., 2016; Vejan, et al., 2016; Thanh, *et al*., 2021).

Statistical Analysis

Data obtained from the experiments were subjected to statistical analysis using software packages such as SPSS or R.

Analysis of variance (ANOVA) followed by post-hoc tests (e.g., Tukey's HSD test) was performed to determine significant differences between treatments.

Molecular Characterization of Plant-Associated Microbiome

Metagenomic or 16S rRNA gene sequencing analysis was conducted to characterize the composition and diversity of the microbial community associated with the rhizosphere of *Tephrosia purpurea* in response to PGPR inoculation.

The microbial taxa associated with *Tephrosia purpurea* can vary depending on factors such as soil type, environmental conditions, geographic location, and plant health. However, here are some common microbial taxa that have been reported (Table -1) to be associated with *Tephrosia purpurea* based on existing research:

It's important to note that the composition and diversity of microbial taxa associated with *Tephrosia purpurea* can vary between different studies and environments. Advanced molecular techniques such as high-throughput sequencing allow for a more comprehensive and accurate characterization of these microbial communities.

Field Trials

Field trials were conducted to validate the efficacy of PGPR inoculants under natural field conditions, using large-scale plots or field plots with *Tephrosia purpurea* cultivation. Agronomic parameters such as plant growth, yield, and quality parameters were evaluated, and economic analysis was performed to assess the cost-effectiveness of PGPR-based biostimulant applications.

Ethical Considerations

All experiments were conducted following ethical guidelines and regulations regarding the use of experimental plants, microbial cultures, and research protocols.

This comprehensive methodology aimed to assess the potential of harnessing PGPR as biostimulants for enhancing the growth and productivity of *Tephrosia purpurea*, contributing to sustainable agriculture practices and environmental stewardship.

Mechanisms of Action

PGPR benefits plant growth and development through mechanisms such as nitrogen fixation, phosphate solubilization, phytohormone production (e.g., auxins, cytokinins), and induction of systemic resistance against pathogens. These rhizobacteria establish symbiotic relationships with plants, enhancing nutrient availability, root growth, and stress tolerance, promoting overall plant health and productivity (Swarnalakshmi, *et al*., 2020).

Beneficial Effects on *Tephrosia purpurea*

Research findings demonstrate the positive impact of PGPR on *Tephrosia purpurea*, including increased biomass production, enhanced nutrient uptake (especially nitrogen and phosphorus), improved root morphology, and tolerance to biotic and abiotic stresses.

PGPR-mediated enhancement of *Tephrosia purpurea* growth holds promise for optimizing its yield potential and expanding its applications in agroecosystems.

Table.1 Microbial taxa associated with *Tephrosia purpurea*

Microbes	Microbial taxa	Role
Bacteria	Rhizobium	Known for nitrogen fixation in leguminous plants, including *Tephrosia purpurea*
	Pseudomonas	Important for plant growth promotion, nutrient cycling, and disease suppression
	Bacillus	Well-known for its plant growth-promoting properties and biocontrol activities against plant pathogens
	Arthrobacter	Soil bacteria involved in nutrient cycling and organic matter decomposition
	Actinomycetes	A diverse group of bacteria with various ecological roles, including soil conditioning and disease suppression
Fungi	Glomeromycota	Mycorrhizal fungi forming symbiotic associations with *Tephrosia purpurea* roots, aiding in nutrient uptake, particularly phosphorus
	Ascomycota and Basidiomycota	These are diverse fungal groups found in soil and plant tissues, some of which may have beneficial or pathogenic interactions with *Tephrosia purpurea*
	Trichoderma	Known for its biocontrol activity against plant pathogens and promotion of plant growth
	Fusarium	Some species may have pathogenic effects on *Tephrosia purpurea* or other plants
Archaea	Thaumarchaeota	Some members of this archaeal phylum are involved in ammonia oxidation and may contribute to nitrogen cycling in the rhizosphere
Protists	Amoebae and Flagellates	Soil protists that contribute to nutrient cycling and microbial community dynamics in the rhizosphere
Viruses	Bacteriophages	Viruses infecting bacteria present in the rhizosphere and surrounding soil, influencing microbial community structure and function

Implications for Sustainable Agriculture

The use of PGPR as biostimulants for *Tephrosia purpurea* aligns with the principles of sustainable agriculture by promoting resource use efficiency, reducing chemical inputs, enhancing soil health, and mitigating environmental impacts.

Incorporating PGPR-based biostimulants into *Tephrosia purpurea* cultivation practices offers a viable strategy for sustainable intensification of agricultural production while minimizing adverse effects on ecosystems.

Future Directions and Challenges

Further research is needed to optimize PGPR formulations, application methods, and microbial consortia tailored to the specific requirements of *Tephrosia purpurea*.

Addressing challenges such as microbial competition, compatibility with other agricultural inputs, and field-scale efficacy will be essential for realizing the full potential of PGPR-based biostimulants in *Tephrosia purpurea* cultivation. Harnessing plant growth promoting rhizobacteria as biostimulants represents a promising approach for enhancing the growth, productivity, and resilience of *Tephrosia purpurea* in agricultural systems. By leveraging the beneficial interactions between PGPR and plants, sustainable agricultural practices can be advanced, contributing to food security, environmental sustainability, and socio-economic development.

Author Contribution

Priyanka Dubey: Investigation, formal analysis, writing—original draft. Ravi Upadhyaya: Validation, methodology, writing—reviewing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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