



Original Research

Field Evaluation of a Plant Growth Promoting Bacterium for Enhancing the Vegetative Growth of Sri Lankan Cinnamon (*Cinnamomum verum*)

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ABSTRACT

This study investigated the effect of a local Plant Growth Promoting Bacterium (PGPB strain I-II) on the vegetative growth of *Cinnamomum verum* under field conditions. A field trial was conducted using a Randomized Complete Block Design (RCBD) in the Low Country Wet Zone of Sri Lanka. Three treatments were tested: an untreated control, the recommended dose of inorganic fertilizer, and the PGPB strain I-II. Four-month-old cinnamon plants were established in two blocks, with four replicates per treatment in each block. Inorganic fertilizer was applied twice a year according to standard recommendations. For the bacterial treatment, a suspension of PGPB strain I-II (10^9 CFU mL⁻¹) was sprayed on the foliage every two weeks. After 18 months, data were collected on plant height, stem circumference, number of leaves, internodal length, and chlorophyll content index (CCI). Plants treated with PGPB strain I-II did not differ significantly in plant height (104.13 ± 7.31 cm) and CCI (42.73 ± 1.96) compared to those treated with inorganic fertilizer (92.75 ± 6.63 cm and 35.95 ± 4.33 , respectively; $p > 0.05$). However, the total number of leaves in the PGPB strain I-II treatment (238.75 ± 49.49) was significantly higher than that of the fertilizer (121.75 ± 27.81) and control (118.38 ± 35.29) treatments. The positive impact of PGPB strain I-II on vegetative growth enhancement suggests its potential as an alternative to inorganic fertilizer, warranting further validations across diverse cinnamon-growing regions.

Keywords: Alternative to inorganic fertilizer, PGPB strain I-II, *Cinnamomum verum*, vegetative growth.

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INTRODUCTION

Plant Growth Promoting Bacteria (PGPB) are capable of a variety of processes such as phosphate solubilization, phytohormone production, nitrogen fixation, siderophore production, and biotic and abiotic stress tolerance, which are instrumental in plant growth promotion (Tiwari et al., 2019; Mahapatra et al., 2022; Fanai et al., 2024). *Rhizobium* spp. establish symbiotic associations with legumes to facilitate biological nitrogen fixation. Several plant growth-promoting bacteria, including *Azospirillum brasilense*, *Pseudomonas fluorescens*, *Bacillus amyloliquefaciens*, and *Enterobacter cloacae*, are known to

synthesize the hormone, indole-3-acetic acid (IAA). IAA is an important plant hormone involved in root development and nutrient uptake (Bashan and de-Bashan, 2010; Idris et al., 2007; Patten and Glick, 2002). *Bacillus* spp., due to their spore-forming ability and versatility in producing antibiotics, enzymes, and phytohormones, are increasingly being explored for their application in sustainable agriculture.

The agricultural industry is continually focused on sustainable methods to improve crop yield while minimizing the negative environmental impacts of chemical fertilizers. In this context, PGPB is an alternative to inorganic agrochemicals (Sales and Rigobelo, 2024). By reducing dependency on synthetic fertilizers, PGPBs can help mitigate the long-term environmental damage associated with these costly chemicals, including soil acidification and eutrophication of water bodies (Di Benedetto et al., 2017). PGPB as biofertilizers is used in a wide array of crops for yield increment through various direct methods such as phytohormone production, phosphate solubilization, ammonia production, nitrogen fixation, and zinc solubilization

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Table 1: Soil chemical properties of two blocks in the experimental field.

Block	pH	Electrical conductivity (dSm ⁻¹)	Organic matter (%)	Phosphorus (ppm)	Potassium (ppm)	Nitrogen (%)
Block 1	4.59±0.35	0.12±0.02	3.45±0.58	5.03±0.85	63.32±10.79	0.10±0.04
Block 2	5.47±0.20	0.07±0.00	3.57±0.15	4.46±0.55	50.95±6.05	0.12±0.04

Values presented are mean values of four replicates ± standard error.

Table 2: Effect of treatments on vegetative growth parameters of *Cinnamomum verum* after 18 months of plant establishment.

Treatment	Plant height (cm)	Stem circumference (cm)	Number of leaves per plant	Internodal length (cm)	Chlorophyll content index (CCI)
Control	75.75±12.01 ^b	3.17±0.63 ^a	118.38±35.29 ^b	3.13±0.31 ^a	31.50±2.08 ^b
Inorganic fertilizer	92.75±6.63 ^{ab}	2.46±0.25 ^a	121.75±27.81 ^b	3.48±0.35 ^a	35.95±4.33 ^{ab}
PGPB strain I-II	104.125±7.31 ^a	3.60±0.26 ^a	238.75±49.49 ^a	3.58±0.25 ^a	42.73±1.96 ^a

Significantly different values for each treatment are in different letters. Values presented are mean values of four replicates ± standard error.

and indirect methods such as production of amylase, phytic acids, siderophores, important spice crop based on export hydrogen cyanide, etc. PGPB is applied to crops through a variety of bioformulations of liquid or solid-based wet and dry products (Fanai et al., 2024). Meanwhile, there are a few reports of the effect of PGPB on spice crops such as *Capsicum annum* and cardamom (Caamal-Chan et al., 2023; Panchami et al., 2020).

Cinnamon contributes to the Sri Lankan economy as the most important spice crop based on export earnings (SLEDB, 2023). Disna and Lindara (2006) reported that cinnamon farmers in major growing districts apply more fertilizer than recommended, averaging 1031 kg ha⁻¹ compared to the advised 900 kg ha⁻¹. The heavy dependence on synthetic fertilizers leads to environmental issues such as soil acidification, increased greenhouse gas emissions, and reduced yield quality and economic issues (Pathania et al., 2020). There are reports on providing subsidies for inorganic fertilizers for cinnamon by Sri Lankan government on several occasions in the recent past, which reflects the economic burden on farmers (Ministry of Agriculture, Livestock, Land and Irrigation, 2025). Therefore, PGPB offers a sustainable and eco-friendly alternative for improving cinnamon cultivation. Except for the report on the application of PGPB in *Cinnamomum tamala* seeds increasing seed germination potential and vegetative growth of seedlings in India, there is a knowledge gap on the exploitation of PGPB for cinnamon (Prakash et al., 2023). This research aims to evaluate the potential of PGPB strain I-II in promoting the growth of Sri Lankan cinnamon (*Cinnamomum verum*) under field conditions, comparing its effects with the recommended inorganic fertilizers. PGPB strain I-II was isolated from Sri Lankan soils and reported to be growth-promoting in rice under greenhouse conditions (Chathurika et al., 2024). According to the best of our knowledge, this is the first report on a field-based study of PGPB for cinnamon.

MATERIALS AND METHODS

Bacterial inoculum

The Sri Lankan PGPB strain I-II, for which the *16s rRNA* (GenBank: PV174565) and *Gyrase A* (GenBank: PV253968) sequence information is available, was used in this study. The PGPB strain I-II was obtained from the bacterial collection available at the Department of Agricultural Biology, Faculty of

Agriculture, University of Ruhuna, which was known for phosphate solubilization, indole acetic acid production, swarming ability and catalase activity (our unpublished data).

Experimental site and design

This study was conducted in the field at the Faculty of Agriculture, University of Ruhuna, Sri Lanka, in the agroecological zone WL2 of the Low Country Wet Zone (LCWZ), from June 2023 to December 2024. The experiment followed a Randomized Complete Block Design (RCBD) with two blocks and four plants were used as replicates in each block. Plants were established at a spacing of 90 cm x 90 cm in each block. A block was surrounded by 12 border plants. The dimensions of each block were 2.7 m x 4.5 m.

Planting material and growth conditions

Four-month-old vegetatively propagated cinnamon seedlings of accession GK 17 were established in loamy topsoil (Prathibhani et al., 2020). The soil pH, electrical conductivity, organic matter percentage, available phosphorus, available potassium, and total nitrogen percentage were measured in the two blocks prior to the seedling establishment (Sparks, 1996). The daytime environmental temperature and rainfall were obtained from the weather station of the Department of Agricultural Engineering and Environmental Technology, Faculty of Agriculture, University of Ruhuna, during the experimental period.

Treatment applications

Three treatments were applied to evaluate their effects on vegetative growth of *C. verum*: the control, inorganic fertilizer and PGPB strain I-II. The control (C) was maintained without any fertilizer treatment, while the inorganic fertilizer (F) was applied according to the recommendation of the Department of Cinnamon Development, Sri Lanka. It was a combination of Urea, Triple Super Phosphate (TSP), and Muriate of Potash (MOP) at a 2:1:1 ratio (148, 74 and 74 kg ha⁻¹, respectively). Accordingly, 23 g of the fertilizer mixture was added per plant twice per year. For the bacterial treatment, the PGPB strain I-II was grown in Luria-Broth (LB) medium overnight and diluted in sterile distilled water to a final concentration of 10⁹ colony forming units (CFU) per mL, which was then applied every 14 days as a continuation for 18 months from the field establishment of

plants at a rate of 200 mL per plant. All treatments were applied consistently, and irrigation was managed to prevent water stress.

Data collection and measurement

To assess plant performance of different treatments, the following vegetative growth parameters were recorded after 18 months: Plant height (cm), Stem circumference at 5 cm from the base (cm), Number of leaves per plant, Internodal length (cm) and Chlorophyll Content Index (CCI) using a CCM-200 plus Chlorophyll Content Meter by Opti-Sciences. CCI was measured in the first five mature leaves from the shoot apex.

Statistical analysis

Soil biochemical parameters, including pH, electrical conductivity (EC), and nitrogen (N), phosphorus (P), and potassium (K) contents, were compared between Block 1 and Block 2 using the Independent Samples t-test in SPSS (IBM SPSS Statistics, version 25). Plant trait data were analyzed using two-way ANOVA to assess the effects of block and treatment. When significant differences were detected, Duncan's Multiple Range Test was used for post-hoc pairwise comparisons. All statistical analyses were performed at the 95% level of significance ($p < 0.05$).

The statistical model:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + \epsilon_{ijk}$$

Where:

Y_{ijk} = the observed value of the dependent variable for the i^{th} treatment, j^{th} block, and k^{th} replicate.

μ = overall mean of the response variable (the grand mean of all observations).

α_i = the effect of the i^{th} treatment, which is the difference between the mean of treatment i and the overall mean μ .

β_j = the effect of the j^{th} block, representing the difference between the block means and the overall mean μ .

ϵ_{ijk} = the random error term (residual), assumed to be independent and normally distributed with mean zero and constant variance.

The statistical model assumes independence between observations across blocks, normal distribution of error terms, and homogeneity of variance across treatments and blocks.

RESULTS

Variation of daytime temperature and rainfall during the experimental period

The highest daily daytime temperature of a month was recorded in March 2024 (35.15°C), while the lowest temperature was in October 2024 (30.516°C) during the experimental period. The average monthly temperature was around 32°C. In 2023, temperatures fluctuated between 30.67°C (September) and 32.82°C (November). Temperature increased from January to March, peaking in March (35.15°C) in 2024. The lowest temperatures (30.5°C - 30.95°C) were consistently recorded from June to October 2024. The lowest average daily rainfall (2.95 mm) was in July 2023. The highest average daily rainfall

was recorded in September 2023 with 29.45 mm (Fig. 1).

Variation of soil chemical properties in the experimental field

Soil pH (4.59 ± 0.35 and 5.47 ± 0.20), electrical conductivity (0.12 ± 0.02 dSm⁻¹ and 0.07 ± 0.00 dSm⁻¹), organic matter percentage ($3.57 \pm 0.15\%$ and $0.12 \pm 0.04\%$), phosphorus (5.03 ± 0.85 ppm and 4.46 ± 0.55 ppm), potassium (63.32 ± 10.79 ppm and 50.95 ± 6.05 ppm) and nitrogen percentages ($0.10 \pm 0.04\%$ and $0.12 \pm 0.04\%$) in block 1 and block 2 of the experimental field, are given Table 1. Based on the independent t-tests, none of the soil chemical properties were statistically significant between block 1 and block 2 ($p > 0.05$).

Effect of bacterial strains on the growth of cinnamon plants

Plant growth under the three treatments is displayed in Figures

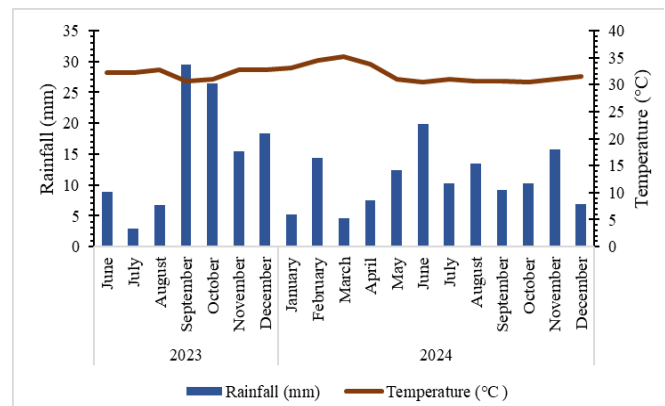


Figure 1: Average day time temperature (°C) and monthly rainfall (mm) at Faculty of Agriculture, University of Ruhuna, Mapalana, Kamburupitiya, Sri Lanka from June 2023 to December 2024.



Figure 2: Field of *Cinnamomum verum* plants at Faculty of Agriculture, University of Ruhuna, Sri Lanka.



Figure 3: Effect of PGPB strain I-II on cinnamon plants after 18 months. a. Control, b. Inorganic fertilizer treatment, and c. PGPB strain I-II treatment.

2 and 3. Plant growth parameters among the three treatments are compared in Table 2. PGPB strain I-II significantly increased the plant height (104.125 ± 7.31 cm) in contrast to control plants (75.75 ± 12.01), while the plants of inorganic fertilizer treatment were not significantly different to either of them (92.75 ± 6.63). However, there was no significant difference among control, inorganic fertilizer and PGPB strain I-II for stem circumference (3.17 ± 0.63 cm, 2.46 ± 0.25 cm and 3.60 ± 0.26 cm, respectively) and internodal length (3.13 ± 0.31 cm, 3.48 ± 0.35 cm and 3.58 ± 0.25 cm respectively). PGPB strain I-II produced significantly higher number of leaves per plant (238.75 ± 49.49) than control plants (118.38 ± 35.29), while inorganic fertilizer treatment was not different to either of other two treatments (121.75 ± 27.81). The chlorophyll content index (CCI) of PGPB strain I-II was significantly different (42.73 ± 1.96) from that of the control (31.50 ± 2.08). The inorganic fertilizer treatment (35.95 ± 4.33) was not different to either of treatments.

DISCUSSION

The soil of both blocks in the experimental field contained moderate levels of available phosphorus of 5.03 ± 0.85 and 4.46 ± 0.55 according to the Department of Agriculture (2008). Phosphate solubilization is particularly important in phosphorus-deficient soils, common in tropical agriculture in Sri Lanka (Palihakkara et al., 2024). The phosphate-solubilizing ability of the PGPB strain I-II may have contributed to increased plant height and stem circumference, which are economically important traits of cinnamon. The PGPB strain I-II enhanced the vegetative growth and yield of Sri Lankan rice under greenhouse conditions, demonstrating its potential versatility across crops (Chathurika et al., 2024). IAA production promotes root elongation and plant health, while swarming behavior and catalase activity support plant stress tolerance (Wagi and Ahmed, 2019; Connelly et al., 2004). Notably, PGPB strain I-II was more effective over the recommended inorganic fertilizer doses in improving vegetative growth parameters of the number of leaves, chlorophyll content index (CCI) and plant height. However, the strain did not improve the stem circumference and internodal length.

This study suggests the potential of PGPB strain I-II as an alternative to inorganic fertilizers in sustainable agriculture based on our initial field-level findings. Our results align with the review by Pathania et al. (2020), who highlighted the importance of PGPB in the above context.

However, future research should evaluate the effectiveness of PGPB strain I-II across diverse environments and soil types to determine its broader applicability. Long-term studies on its impact on cinnamon yield, disease resistance, and soil health are also essential to assess its potential as a sustainable agricultural input fully.

CONCLUSION

PGPB strain I-II effectively promotes plant growth in cinnamon, improving vegetative parameters of plant height, leaf number, and chlorophyll content. These results suggest that PGPB strain I-II has the potential to be a sustainable, eco-friendly alternative to conventional fertilizers.

DECLARATION OF COMPETING INTERESTS

The authors declare no conflict of interest.

AUTHOR CONTRIBUTION STATEMENT

Polwatte Koralalage Darshika Sandamini: Investigation, data curation, writing, original draft preparation, software, validation. **Ines Mandić Mulec:** Supervision. **Eva Grabner:** Data curation. **Hewa Widhana Kattadige Sanjeewa Lalith Kumara:** Resources, data curation. **Ranawaka Achchige Aruna Kumara Ranawaka:** Resources. **Nadugala Vithanage Thilini Jayaprada:** Supervision. **Sudarshanee Geekiyanage:** Conceptualization, resources, writing – reviewing and editing, investigation, supervision.

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ETHICAL STATEMENT

Not applicable.

AVAILABILITY OF DATA AND MATERIAL

All data is published in this research article.

INFORMED CONSENT

Not applicable.

CONSENT FOR PUBLICATION

All authors have submitted consent to publish this research article in the 'Journal of Horticulture Science and Technology'.

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