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Effect of Plant Growth-Promoting Rhizobacteria in the Hydroponic Cultivation of Red Amaranthus (Amaranthus Tricolor L.)

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Abstract

The present study was conducted to evaluate the effect of Plant Growth-Promoting Rhizobacteria (PGPR), particularly*Azospirillumbrasilense***,** on the hydroponic cultivation of red amaranthus (*Amaranthus tricolor* L.). The experiment was carried out in the Laboratory of Agricultural Microbiology, Imayam Institute of Agriculture and Technology (IIAT),Thuraiyur. Red amaranthus plants were cultivated using a floating root hydroponic system, in which plants were supported by perforated plates placed over nutrient solution with roots continuously immersed.Four treatments were evaluated: T1 – Control (without PGPR application), T2 – *Azospirillumbrasilense*, T3 – Commercial PGPR solution, and T4 – *Azospirillumbrasilense*+ Commercial PGPR solution. The experiment was conducted in a Completely Randomized Design (CRD) with three replications. Growth and yield parameters, including plant height, root length, fresh weight of aerial parts, and dry biomass, were recorded at harvest. The results revealed that PGPR application significantly enhanced the growth and biomass production of red amaranthus compared with the untreated control. Plants treated with *Azospirillumbrasilense* combined with commercial PGPR solution (T4) exhibited superior growth performance, recording higher plant height, root development, and fresh weight compared with individual PGPR treatments and control plants. The improved growth response may be attributed to the ability of PGPR to enhance nutrient availability, stimulate root development, and promote plant growth through biological nitrogen fixation and phytohormone production.The study demonstrates that integrating *Azospirillumbrasilense* with commercial PGPR solution in a floating root hydroponic system is an effective approach for improving red amaranthus production. This technology has potential for sustainable vegetable cultivation by enhancing plant growth, reducing dependence on chemical fertilizers, and supporting the production of safe and nutritious food.

Keywords: *Azospirillumbrasilense*, Plant Growth-Promoting Rhizobacteria (PGPR), hydroponics, floating root system, red amaranthus, biofertilizer, sustainable agriculture.

1. Introduction

Red amaranthus (*Amaranthus tricolor* L.) is an important leafy vegetable cultivated widely due to its rapid growth, high nutritional value, and adaptability to different production environments. It is rich in vitamins, minerals, dietary fiber, antioxidants, and bioactive compounds, making it an important component of human nutrition. Due to its short crop duration and high biomass production, red amaranthus is considered suitable for intensive cultivation systems, including hydroponic production.

Hydroponics is a modern crop production technology in which plants are grown without soil by supplying essential nutrients through a nutrient solution. Hydroponic systems provide several advantages, including efficient use of water and fertilizers, reduced soil-borne diseases, better control of plant nutrition, and increased productivity in limited spaces. The floating root hydroponic system is one such technique where plants are supported on perforated plates while their roots remain continuously immersed in nutrient solution, allowing direct absorption of water and nutrients.

However, the absence of natural soil microbial communities in hydroponic systems may limit beneficial microbial interactions that normally contribute to plant growth. The introduction of beneficial microorganisms, particularly Plant Growth-Promoting Rhizobacteria (PGPR), has gained importance as a biological approach to enhance crop productivity under soilless cultivation systems.

PGPR are beneficial bacteria that colonize plant roots and promote plant growth through various mechanisms, including biological nitrogen fixation, phosphate solubilization, production of phytohormones such as indole-3-acetic acid (IAA), siderophore production, improved nutrient uptake, and enhancement of plant tolerance to stress. According to Vessey (2003)**,** PGPR act as biofertilizers by improving nutrient availability and stimulating plant development.

Among PGPR, *Azospirillum* species are widely studied because of their ability to associate with plant roots, fix atmospheric nitrogen, and stimulate root development through hormone production. *Azospirillum* inoculation has been reported to improve plant height, root growth, nutrient absorption, and biomass production in several crops. Bashan and de-Bashan (2010) reported that *Azospirillum* promotes plant growth mainly through improved root system development and enhanced nutrient acquisition.

The use of microbial inoculants in hydroponic systems is receiving increasing attention because beneficial microorganisms can improve plant growth even in the absence of soil. Recent studies have demonstrated that *Azospirillumbrasilense* inoculation in hydroponically grown leafy vegetables improved plant height, fresh and dry biomass, root development, nutrient accumulation, and leaf yield.

Therefore, the present investigation was undertaken to evaluate the effect of different PGPR treatments, including *Azospirillum*, commercial PGPR solution, and their combined application, on growth parameters and yield attributes of red amaranthus cultivated under a floating root hydroponic system.

2. Review of Literature

2.1 Hydroponic Cultivation and Its Importance

Hydroponic cultivation is considered an efficient alternative production system for vegetable crops because it allows precise management of nutrients, water, and environmental conditions. Leafy vegetables are particularly suitable for hydroponics due to their short growth cycle and high market demand.

Hydroponic systems provide improved nutrient availability compared with conventional cultivation; however, the absence of beneficial microorganisms may affect nutrient cycling and plant–microbe interactions. Therefore, microbial inoculation has been explored as a strategy to improve plant growth and nutrient efficiency in soilless systems. Recent reviews indicate that microbial inoculants in hydroponic crops can enhance plant growth, biomass production, and nutritional quality, although their effectiveness depends on crop species, microbial strain, and cultivation conditions.

2.2 Plant Growth-Promoting Rhizobacteria (PGPR)

PGPR are free-living beneficial bacteria that inhabit the rhizosphere and stimulate plant growth through direct and indirect mechanisms. They improve plant performance by increasing nutrient availability, producing growth regulators, suppressing pathogens, and enhancing stress tolerance.

Vessey (2003) reported that PGPR have potential as biological fertilizers because they improve nutrient uptake and increase plant productivity while reducing dependence on chemical fertilizers.

Bhattacharyya and Jha (2012) described PGPR as an important component of sustainable agriculture due to their ability to improve plant growth through multiple mechanisms, including nitrogen fixation, phosphate solubilization, hormone production, and biological control of plant pathogens.

2.3 Role of *Azospirillum* in Plant Growth Promotion

The genus *Azospirillum* is one of the most extensively studied groups of plant growth-promoting bacteria. These bacteria associate with plant roots and enhance plant growth through nitrogen fixation, phytohormone production, and improvement of root architecture.

According to Bashan and de-Bashan (2010)**,***Azospirillum* increases root surface area and nutrient absorption by stimulating lateral root formation and root elongation. The improved root system contributes to increased shoot growth and biomass accumulation.

A review by Vendruscolo and Lima (2021) highlighted that *Azospirillum* applications have beneficial effects on vegetable crops by improving growth, productivity, and quality characteristics.

2.4. PGPR Application in Hydroponic Systems

The application of PGPR in hydroponic systems has shown promising results due to their ability to establish beneficial associations with plant roots. In nutrient solutions, PGPR may enhance nutrient uptake efficiency and stimulate plant physiological processes.

Oliveira et al. (2023) evaluated different inoculation methods of *Azospirillumbrasilense* in hydroponically cultivated lettuce and arugula. They reported that bacterial inoculation improved plant height, shoot and root biomass, leaf yield, chlorophyll content, and nutrient accumulation.

2.5. Effect of PGPR on Vegetable Growth and Yield

Several studies have reported positive effects of PGPR on vegetable crops. PGPR-treated plants generally show increased plant height, leaf number, root development, fresh weight, and dry biomass compared with untreated plants.

Microbial consortia or combined inoculation of different beneficial microorganisms may provide greater benefits than single bacterial strains because different microorganisms contribute through complementary mechanisms. The combined use of *Azospirillum* with commercial PGPR formulations may therefore improve plant growth more effectively under controlled hydroponic conditions.

3. Materials and Methods

3.1. Experimental Site

The trial was conducted in the Laboratory of Agricultural Microbiology, Imayam Institute of Agriculture and Technology (IIAT),Thuraiyur. The study was carried out to evaluate the influence of different PGPR treatments on the growth performance and yield attributes of red amaranthus cultivated under hydroponic conditions.

3.2. Plant Material and Seedling Establishment

Seeds of red amaranthus (*Amaranthus tricolor* L.) were used as the experimental crop. The seeds were sown inphenolic foam cubes for initial germination and seedling development. Healthy and uniform seedlings were maintained for 15 days under suitable conditions. After 15 days, the seedlings were carefully selected and transferred to the hydroponic system for further growth and evaluation.

3.3.Hydroponic System

The crop was cultivated using a floating root hydroponic system. In this system, plants were supported by perforated plates placed over plastic containers filled with nutrient solution. The roots of the seedlings were directly immersed in the nutrient solution, allowing continuous uptake of water and essential nutrients throughout the growing period.

The nutrient solution was maintained at suitable levels to support plant growth, and the hydroponic containers were managed under controlled laboratory conditions.

4. Results and Discussion

4.1. Effect of PGPR Treatments on Growth Parameter of Red Amaranthus under Hydroponic Conditions

The application of Plant Growth-Promoting Rhizobacteria (PGPR) significantly influenced the growth and biomass production of red amaranthus cultivated under a floating root hydroponic system. The different PGPR treatments showed considerable variation in plant height, leaf production, root development, fresh weight, and dry weight compared with the untreated control.

Table 1. Effect of PGPR Treatments on Growth Parameters of Red Amaranthus at Harvest

Treatment	**Plant Height (cm)**	**Number of Leaves plant^{-1}**	**Stem Diameter (mm)**	**Root Length (cm)**
T1 – Control	24.5 ± 1.2	18.4 ± 1.0	4.1 ± 0.2	12.6 ± 0.7
T2 – *Azospirillum brasilense*	30.8 ± 1.4	23.6 ± 1.2	5.0 ± 0.3	15.8 ± 0.8
T3 – Commercial PGPR Solution	28.9 ± 1.3	22.1 ± 1.1	4.8 ± 0.2	15.2 ± 0.7
T4 – *Azospirillum brasilense* + Commercial PGPR Solution	34.6 ± 1.6	27.8 ± 1.4	5.7 ± 0.3	18.4 ± 0.9

The present study demonstrated that PGPR application significantly enhanced the growth and biomass production of red amaranthus under hydroponic cultivation. All PGPR-treated plants showed superior performance compared with the control treatment, indicating the beneficial role of microbial inoculation in improving plant growth.Among the treatments, the combined application of *Azospirillumbrasilense* **+** Commercial PGPR Solution (T4) recorded the highest values for all growth parameters. The maximum plant height (34.6 cm**),** number of leaves (27.8 plant^{-1}**),** stem diameter **(**5.7 mm**),** and root length **(**18.4 cm**)** were observed in T4-treated plants. The improved growth response may be attributed to the synergistic activity of PGPR microorganisms, which enhance nutrient availability, stimulate root development, and promote plant growth through the production of phytohormones such as indole-3-acetic acid (IAA).

Treatment 1(Control)

Treatment 2(Azospirillum)

Treatment 3 (Commercial solution)

Treatment 4 (Commercial solution +Azospirillum)

Plant height comparison in different treatments

4.1. Effect of PGPR Treatments on Biomass Production and Yield Attributes of Red Amaranthus under Hydroponic Conditions

The Effect of PGPR Treatments, the highest biomass production was recorded in T4, with fresh weight **(**57.4 g plant^{-1}**)** and dry weight **(**6.71 g plant^{-1}**),** followed by T2 and T3. The increased fresh and dry biomass indicates enhanced photosynthetic activity, nutrient assimilation, and overall plant vigor due to PGPR application. In contrast, control plants recorded the lowest fresh weight **(**38.6 g plant^{-1}**)** and dry weight **(**4.25 g plant^{-1}**),** indicating limited growth in the absence of microbial stimulation. Overall, the results confirm that PGPR application, particularly *Azospirillumbrasilense*+ Commercial PGPR Solution (T4), effectively enhanced growth parameters, biomass production, and yield attributes of red amaranthus under hydroponic conditions. The integration of PGPR with hydroponic cultivation can be considered a promising sustainable approach for improving leafy vegetable production.

Table 2. Effect of PGPR Treatments on Biomass Production and Yield Attributes of Red Amaranthus at Harvest

Treatment	**Fresh Weight (g plant^{-1})**	**Dry Weight (g plant^{-1})**
T1 – Control	38.6 ± 1.8	4.25 ± 0.20
T2 – *Azospirillumbrasilense*	49.8 ± 2.1	5.62 ± 0.2
T3 – Commercial PGPR Solution	46.5 ± 2.0	5.28 ± 0.22
T4 – *Azospirillumbrasilense* + Commercial PGPR Solution	57.4 ± 2.4	6.71 ± 0.28

5. Conclusion

The present study concluded that the application of Plant Growth-Promoting Rhizobacteria (PGPR) significantly improved the growth performance, biomass production, and yield attributes of red amaranthus (*Amaranthus tricolor* L.) cultivated under a floating root hydroponic system. All PGPR treatments showed better plant growth compared with the untreated control, demonstrating the positive role of beneficial microorganisms in enhancing plant development.

Among the different treatments, the combined application of *Azospirillumbrasilense* **+** Commercial PGPR Solution (T4) was found to be the most effective treatment, recording the highest values for plant height **(**34.6 cm**),** number of leaves **(**27.8 plant^{-1}**),** stem diameter (5.7 mm**)**, root length **(**18.4 cm**),** fresh weight **(**57.4 g plant^{-1}**),** and dry weight **(**6.71 g plant^{-1}**).** The superior performance of T4 indicates a synergistic effect between *Azospirillumbrasilense* and other beneficial microorganisms present in the commercial PGPR formulation.

The study demonstrated that integrating PGPR inoculation with hydroponic cultivation is an effective and sustainable approach for improving red amaranthus production. The combined application of *Azospirillumbrasilense* **+** Commercial PGPR Solution can be recommended as an efficient microbial biofertilizer strategy for achieving higher growth, biomass accumulation, and productivity of red amaranthus under hydroponic conditions.

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