



RESEARCH COMMUNICATION

Enhancement of growth, yield and quality of potato through application of biofertilizers

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Abstract

Potato is one of the world's leading food crops and plays a significant role in global food security. To reduce the adverse effects associated with excessive use of chemical fertilizers, biofertilizers have emerged as a sustainable alternative. The study evaluated the effects of different biofertilizers on growth, yield and tuber quality of potato during *rabi* season (2023-2024) under field conditions in Uttarakhand, India. The experiment was done in a Randomized Block Design, consisting of three replications and eight treatments. The treatments included individual and combined applications of *Rhizobium mililoti*, *Azotobacter chroococcum* and *Bacillus subtilis*, along with an untreated control. The results showed significant differences among treatments for growth, yield and quality parameters. The combined application of *Rhizobium mililoti* (200 g/10 kg seed) and *Azotobacter chroococcum* (200 g/10 kg seed) resulted in the highest plant height (15.66 cm), chlorophyll content (25.50 $\mu\text{mol m}^{-1}$), number of leaves (36.86 plant⁻¹) and total yield (490.21 g plant⁻¹). The tuber quality-related characteristics such as dry matter (17.00 %), swelling power (1.26 g/g), specific gravity (1.07 g/cm³) and starch solubility (2.54 %) were also attained maximum with treatment T₃. These highlight the superiority of the combined *Rhizobium* and *Azotobacter* treatment over the other treatments. It can be concluded that seed tuber inoculation with *Rhizobium* and *Azotobacter* significantly enhances potato growth, yield and tuber quality under the studied conditions.

Keywords: *Azotobacter chroococcum*; biofertilizer; potato; *Rhizobium mililoti*; yield

Introduction

Potato (*Solanum tuberosum* L.) is one of the world's most important vegetable crops. It is important for India's food and economic security. Potato is a heavy nutrient-demanding crop and therefore requires efficient nutrient management practices (1). In Uttarakhand, potato cultivation provides a major source of income generation and employment which contributes to meeting the demand of the adjoining plains (2). It produces a high amount of edible biomass per unit area, supporting rural livelihoods and economic growth. Potato protein is reported to have a relatively high biological value compared with several cereal proteins (3).

The sustainable agriculture approach emphasizes long-term crop productivity and environmental health, which leads to optimal crop yields with low dependency on chemical inputs. Extensive and inappropriate use of chemical-based fertilizers has been found to decrease soil fertility and biological activity. This practice leads to nutrient imbalances and deficiencies, ultimately reducing crop productivity and quality (4). In this scenario, biofertilizers have emerged as economical and environmentally friendly inputs capable of increasing soil fertility and crop yield. Integrating inoculants containing microbes into nutrient management techniques can play a vital role in boosting growth, yield and tuber

quality, while decreasing dependence on inorganic fertilizers (5, 6).

Biofertilizers are formulations containing efficient strains of nitrogen-fixing, phosphorus-solubilizing, potassium-mobilizing and plant growth-promoting microorganisms. When they are given to seeds, they colonize the rhizosphere promoting plant growth by boosting the availability of essential nutrients for host plants (7). They increase nutrient availability, promote root growth, improve photosynthetic efficiency, release growth-promoting substances and inhibit harmful diseases (8). *Azotobacter*, *Rhizobium*, *Bacillus*, *Pseudomonas* and other beneficial microbes have been extensively studied for their role in enhancing growth and yield of crops (9). The combined application of *Rhizobium*, *Azotobacter* and *Bacillus* is tested for its effect on growth and yield of potato crops. *Rhizobium* is considered for fixing atmospheric nitrogen, while *Azotobacter* is beneficial in soil nitrogen fixation and when they are combined with *Bacillus*, that formulation can enhance growth, nodulation and nitrogen uptake in crops. The current study aimed to assess how different bio fertilizers and their combinations affect the growth, yield and quality of potato tubers in the agro-climatic conditions of Uttarakhand.

Material and Methods

Experimental site and season

The field experiment was conducted during the rabi of 2023-2024 at the Experimental Research Block, School of Agricultural Sciences, Shri Guru Ram Rai University, Dehradun, Uttarakhand. The research site is situated in the north-western Himalayan region at an altitude of 450 m above mean sea level. The experimental field has clay loamy texture soil, neutral in soil pH (7.3). It is slightly rich in organic carbon (2.20 %), very low in available nitrogen (190 kg/ha), high in available phosphorus (18.50 kg/ha), low in available potassium (171.2 kg/ha) and has good water retention capable of supporting potato production.

Treatments

The experiment was replicated thrice by following a Randomized Block Design (RBD) with eight treatments. Treatments were *Rhizobium mililoti* at 200 g/10 kg seed (T₁), *Azotobacter chroococcum* at 200 g/10 kg seed (T₂), *Rhizobium mililoti* at 200 g/10 kg seed + *Azotobacter chroococcum* at 200 g/10 kg seed (T₃), *Bacillus subtilis* at 150 mL/10 kg seed (T₄), *Rhizobium mililoti* at 200 g/10 kg seed + *Bacillus subtilis* at 100 mL/10 kg seed (T₅), *Azotobacter chroococcum* at 200 g/10 kg seed + *Bacillus subtilis* at 100 mL/10 kg seed (T₆), *Rhizobium mililoti* at 200 g/10 kg seed + *Azotobacter chroococcum* at 200 g/10 kg seed + *Bacillus subtilis* at 100 mL/10 kg seed (T₇), Control (T₈). The biofertilizer used for experimental work was identified and collected from biotechnology laboratory of Shri Guru Ram Rai University.

Methods and agronomic practices

The variety Kufri Jyoti was used for experimental work. The seed tubers were treated by making a slurry of biofertilizer and shade dried for 24 h under ambient condition. The tuber seed was planted with a spacing of 60 × 20 cm with net plot size of 8 m² was used. The rest of the agronomic practices like irrigation, weeding etc. were applied as per the requirement of crops.

Observations

Growth parameters were recorded at defined growth stages during the crop cycle. To ensure accuracy five plants were chosen

at random from each treatment in each replication. Plant height (45 and 90 DAS), number of leaves per plant, chlorophyll content, number of tubers per plant, tuber weight per plant and total yield were recorded. Tuber quality parameters, including dry matter content, swelling power, starch solubility and specific gravity, were determined using freshly harvested tubers. The swelling power was determined by using Leach method and starch solubility was determined using Kainuma method.

Statistical Analysis

The data recorded from different treatments were statistically examined using SPSS software for the analysis of variance (ANOVA). The critical difference (CD) values to know significance of treatments applied.

Results and Discussion

The significant response of treatments applied were observed for growth and yield attributes of potato (Table 1). The variation among yield and quality traits with different treatments were shown in (Table 2).

Plant height (cm)

Measurement of plant height at 45 and 90 days after planting (DAP) varied significantly across treatments. At 45 DAPs, the highest plant height (7.60 cm) was recorded with treatment T₃ i.e. *Rhizobium mililoti* at 200 g/10 kg seed + *Azotobacter chroococcum* at 200 g/10 kg seed and the lowest plant height (5.96 cm) with T₈ (control). Similar result was also recorded at 90 DAP, maximum plant height (15.66 cm) exhibited with treatment T₃, followed by treatment T₆ (*Azotobacter chroococcum* at 200 g/10 kg seed + *Bacillus subtilis* at 100 mL/10 kg seed) (14.66 cm). This indicates that treatment T₃ was associated with improved vegetative growth, possibly due to enhanced nutrient availability mediated by microbial inoculation. This may result from the action of biofertilizers, which are the group of free-living nitrogen-fixing bacteria. Combined inoculation with *Rhizobium* and *Azotobacter* likely enhanced nitrogen availability, contributing to improved plant growth. The lowest height (11.93 cm) was recorded with T₈ (control). It was also

Table 1. Performance of potato growth and yield attributes with application of different biofertilizers

Treatment	Plant height (cm)		Chlorophyll content (μmol m ⁻²) at 60 days	Number of leaves per plant (60 DAPs)	Number of tubers per plant			
	At 45 DAPs	At 90 DAPs			<30 g	31-60 g	61-90 g	90 g<
T ₁	6.43	12.86	20.66	30.40	1.80	2.80	2.60	1.26
T ₂	6.50	13.00	22.63	32.26	2.20	3.60	2.86	1.00
T ₃	7.60	15.66	25.50	36.86	2.26	4.00	3.13	1.33
T ₄	6.93	13.86	23.64	28.26	1.60	2.46	2.20	1.00
T ₅	7.10	14.20	19.76	28.26	1.80	2.93	2.40	1.00
T ₆	7.33	14.66	21.42	25.10	1.93	2.60	2.46	1.06
T ₇	7.23	14.46	21.03	27.33	1.66	2.60	2.26	1.00
T ₈	5.96	11.93	17.65	21.26	1.13	1.80	2.00	1.00
CD (5 %)	0.93	1.91	3.90	3.34	0.41	0.48	0.45	0.13
SE(m)±	0.66	1.35	2.75	1.09	0.13	0.15	0.14	0.04

Table 2. Performance of potato yield and quality attributes with application of different biofertilizers

Treatment	Weight of tubers per plant				Total number of tubers per plant	Total yield per plant (g)	Dry matter content (%)	Swelling power (g/g)	Starch solubility (%)	Specific gravity (g/cm ³)
	<30 g	31-60 g	61-90 g	90 g<						
T ₁	53.33	149.68	206.64	128.94	10.00	449.10	16.20	1.18	2.37	1.05
T ₂	62.34	192.80	222.89	96.70	10.92	466.90	16.43	1.21	2.42	1.06
T ₃	63.57	204.22	242.47	129.14	11.29	490.21	17.00	1.26	2.54	1.07
T ₄	42.46	128.90	166.03	97.40	7.79	343.19	15.10	0.78	1.57	1.03
T ₅	46.62	155.27	178.52	96.60	8.97	396.86	14.43	1.03	1.54	1.02
T ₆	49.12	130.26	203.71	105.56	9.21	409.45	15.83	1.09	1.78	1.04
T ₇	45.64	138.96	184.63	95.58	8.91	388.53	13.60	1.02	1.50	1.01
T ₈	23.69	86.41	146.0	91.52	6.55	298.40	12.60	0.66	1.38	1.00
CD (5 %)	16.21	17.71	27.43	11.28	0.67	29.83	0.34	0.04	0.07	0.05
SE(m) ±	3.03	5.78	8.96	3.68	0.22	9.74	0.11	0.01	0.02	0.02

reported that enhance growth of potato plant with management of nutrients applied (10). These results are also verified with the observations of another research (11).

Number of leaves per plant

A significant variation in foliage development was noted among treatments at 60 DAPs. Maximum number of leaf production was recorded (36.86 leaves plant⁻¹) with treatment *Rhizobium mililoti* at 200 g/10 kg seed + *Azotobacter chroococcum* at 200 g/10 kg seed (T₃) followed by treatment T₂ (32.26 leaves plant⁻¹). Improved leaf production under T₃ suggests enhanced canopy development, which may support greater assimilation production for tuber development (12). Treatment (T₈) produced the lowest number of leaves (21.26 leaves plant⁻¹).

Chlorophyll content (μmol m⁻²)

The maximum chlorophyll content (25.50 μmol m⁻²) was recorded under *Rhizobium mililoti* at 200 g/10 kg seed + *Azotobacter chroococcum* at 200 g/10 kg seed (T₃), which was followed by (T₄) *Bacillus subtilis* at 150 mL/10 kg seed (23.64 μmol m⁻²). High chlorophyll content has been associated with improved photosynthetic efficiency and biomass accumulation (13). Biofertilizer application enhances nitrogen fixation, phosphorus solubilization and phytohormone production, which can increase chlorophyll content, this result in better growth and yield which ultimately promote the chlorophyll content in the plant (14). The lowest chlorophyll content was recorded (17.65 μmol m⁻²) with control (T₈).

Number of tubers per plant (<30 g)

The results show the maximum number of small size tubers per plant (<30 g) was recorded (2.26 tubers/ plant) with treatment *Rhizobium mililoti* at 200 g/10 kg seed + *Azotobacter chroococcum* at 200 g/10 kg seed (T₃). The increase in tuber number with this treatment was a result of improved nutrient availability and enhanced root nodulation promoted by the synergistic effect of *Azotobacter*. These beneficial microorganisms enhance nitrogen fixation, improve root growth and increase physiological efficiency. This contributed to an increased number of tubers across different size categories. Less number of tubers per plant was recorded (1.13 tubers/ plant) under the control treatment (T₈). The similar results were reported who founds the biofertilizer application significantly improved tuber yield characteristics in potato (15).

Number of tubers per plant (31–60 g)

In the 31–60 g tuber weight category, the maximum number of tubers per plant (4.0 tubers/ plant) was recorded with treatment *Rhizobium mililoti* at 200 g/10 kg seed + *Azotobacter chroococcum* at 200 g/10 kg seed (T₃), while the minimum (1.80 tubers/ plant) was recorded with treatment T₈ (control). The higher production of medium-sized tubers indicates a direct effect of biofertilizers on carbohydrate assimilation, photosynthetic activity and nutrient translocation in the plant. This results in enhanced tuber initiation and bulking. Such improvement in yield characters supports the previous reports, who mentioned that inoculation using biofertilizers combinedly boosted tuber number and overall yield performance in potato crops (16).

Number of tubers per plant (61–90 g)

The results shows that the maximum number of tubers per plant in the 61–90 g category was reported (3.13 tubers/ plant) by using

Rhizobium mililoti at 200 g/10 kg seed + *Azotobacter chroococcum* at 200 g/10 kg seed (T₃). The significant improvement under treatment T₃ could be attributed to increased nutrient availability and root proliferation through synergistic microbial interaction, which leads to enhanced tuber bulking and these findings are in line with research, who reported that biofertilizers significantly increased tuber number across different size classes in potato (17). The minimum tuber number was recorded (2.0 tubers/ plant) with the control treatment (T₈).

Number of tubers per plant (>90 g)

In large size tubers (>90 g), the highest number (1.33 tubers/ plant) was recorded with treatment T₃ (*Rhizobium mililoti* at 200 g/10 kg seed + *Azotobacter chroococcum* at 200 g/10 kg seed). The minimum was recorded (1.0 tubers/plant) in multiple treatments including *Azotobacter chroococcum* at 200 g/10 kg seed (T₂), *Bacillus subtilis* at 150 mL/10 kg seed (T₄), *Rhizobium mililoti* at 200 g/10 kg seed + *Bacillus subtilis* at 100 mL/10 kg seed (T₅), *Rhizobium mililoti* at 200 g/10 kg seed + *Azotobacter chroococcum* at 200 g/10 kg seed + *Bacillus subtilis* at 100 mL/10 kg seed (T₇) and control (T₈). This shows that *Rhizobium* + *Azotobacter* treatment was superior in producing large-sized tubers compared to single inoculants or control. Similar findings were also demonstrated by the researchers that microbial consortia improve nutrient uptake efficiency and result in higher yields of larger tubers in potatoes (18).

Weight of tubers per plant (<30 g)

The highest number of tubers of small size (<30 g) per plant was obtained (63.57 g) with treatment *Rhizobium mililoti* at 200 g/10 kg seed + *Azotobacter chroococcum* at 200 g/10 kg seed (T₃), whereas the control treatment (T₈) produced minimum (23.69 g) tubers. This suggests that dual inoculation may improve assimilate partitioning toward tuber biomass. Similar effects were reported where biofertilizer combinations increased tuber biomass and thereby improved potato yield quality (19).

Weight of tubers per plant (31–60 g)

Throughout the 31–60 g category, the maximum weight of tubers per plant was 204.22 g with treatment *Rhizobium mililoti* at 200 g/10 kg seed + *Azotobacter chroococcum* at 200 g/10 kg seed (T₃), which were statistically at par to the treatment T₂ (*Azotobacter chroococcum* at 200 g/10 kg seed) i.e. 192.80 g. The minimum weight of tubers per plant (86.41 g) recorded with (T₈) control. This suggests that medium-sized tubers were more responsive to microbial inoculation and contribute substantially to the total yield of potato. There was a similar trend reported where the medium weight category contributed the highest proportion to yield under biofertilizer application (20).

Weight of tubers per plant (61–90 g)

The tubers per plant in 61–90 g category, maximum weight observed (242.47 g) with treatment *Rhizobium mililoti* at 200 g/10 kg seed + *Azotobacter chroococcum* at 200 g/10 kg seed (T₃), which significantly superior to all the other treatments expect T₂. Enhanced weight accumulation under treatment T₃ may be attributed to more efficient nutrient partitioning and improved photosynthetic efficiency, which collectively promoted tuber bulking. The microbial inoculants improve tuber bulking due to efficient nutrient mobilization and assimilation (21). The minimum weight of tubers per plant was recorded with treatment T₈ i.e. 146.09 g.

Weight of tubers per plant (>90 g)

The results showed that the maximum larger size (>90 g) tuber weight per plant was recorded (129.14 g) in plants which received the treatment *Rhizobium mililoti* at 200 g/10 kg seed + *Azotobacter chroococcum* at 200 g/10 kg seed (T₃), while treatment T₈ produced the minimum tuber weight per plant (91.52 g). Larger tubers respond positively to dual inoculation, reflecting the importance of prolonged nutrient absorption during later growth phases. The results obtained align with the observations, where an increase in the production of large-sized tubers in potatoes is due to the application of biofertilizers (22). The recorded increase in tuber weight may be attributed to a rise in the number of stems. The rapid development of potato tubers is due to the contributions of potassium in processes such as photosynthesis, phloem translocation and the biosynthesis of high molecular weight compounds, including starch, within the potato tuber (17).

Total number of tubers per plant

Total number of tubers per plant revealed a significant difference due to biofertilizer treatments. The maximum total tuber number (11.29 tubers plant⁻¹) was recorded with treatment T₃, whereas the minimum (6.55 tubers plant⁻¹) was recorded with control (T₈). The application of *Rhizobium* + *Azotobacter* increases the number of underground stolons and tuber development, thereby enhancing total productivity. Comparable findings were reported, suggesting that biofertilizers play a key role in stimulating tuber initiation (23).

Total yield per plant

The total yield per plant ranged from 298.40 g to 490.21 g per plant. It was recorded that the treatment *Rhizobium mililoti* at 200 g/10 kg seed + *Azotobacter chroococcum* at 200 g/10 kg seed (T₃) produced maximum yield (490.21 g/ plant) which was 39.12 % higher than the control treatment (T₈). This maximum yield with treatment T₃ was statistically at par to the treatment T₂ (*Azotobacter chroococcum* at 200 g/10 kg seed) which produced (466.90 g/plant) yield. The higher yield under T₃ reflects the combined effect of microbial inoculation on tuber number and tuber weight. The results validate the positive correlation between microbial inoculation, plant growth parameters and yield performance in potato. Application of biofertilizers significantly improved key yield components of potato (21, 24).

Dry matter content (%)

Dry matter content of potato tubers was significantly affected with the application of biofertilizers. The maximum dry matter content was found (17.00 %) with treatment *Rhizobium mililoti* at 200 g/10 kg seed + *Azotobacter chroococcum* at 200 g/10 kg seed (T₃). The higher dry matter in T₃ might be attributed to higher tuber maturity and starch accumulation due to enhanced growth with beneficial microbial inoculants. A higher nutrient uptake resulted in improved photosynthetic efficiency which were likely supportive of starch biosynthesis and storage in the tuber tissues. It was reported that biofertilizers were beneficial in terms of dry matter accumulation in potato tubers (25).

Swelling power (g/g)

The swelling power of potato starch varied from minimum 0.66 g/g with control (T₈) to maximum 1.26 g/g with treatment *Rhizobium mililoti* at 200 g/10 kg seed + *Azotobacter chroococcum* at 200 g/10 kg seed (T₃). Maximum swelling power was recorded with treatment T₃. These improvements in starch functional properties

may be indirectly influenced by enhanced nutrient availability under combined biofertilizer application. The increase in amylopectin concentration predominantly, governs starch swelling capacity in potatoes (26).

Starch water solubility

The starch water solubility varies significantly with application of different biofertilizers. The highest starch solubility was recorded (2.54 %) with treatment *Rhizobium mililoti* at 200 g/10 kg seed + *Azotobacter chroococcum* at 200 g/10 kg seed (T₃). Enhanced solubility in T₃ was likely due to partial disruption of starch granule crystalline structures caused by increased assimilate partitioning, as well as improved interaction with water molecules. This indicates that starch extracted from potatoes under combined biofertilizer treatment presents enhanced functional quality. The minimum starch solubility was recorded (1.38 %) with control treatment (T₈). The microbial inoculation positively influenced starch granule structure and improved water solubility indices in potato (24).

Specific gravity (g/cm³)

The specific gravity is an important quality indicator of potato tuber primarily associated with dry matter and starch concentration. Specific gravity ranged was recorded from minimum 1.00 g/cm³ with control (T₈) to maximum 1.07 g/cm³ with treatment *Rhizobium mililoti* at 200 g/10 kg seed + *Azotobacter chroococcum* at 200 g/10 kg seed (T₃). Increased specific gravity in T₃ may be associated with higher stored carbohydrate, which is promoted by improved nutrient management, particularly nitrogen and phosphorus. The biofertilizers application increases the specific gravity of tubers by enhancing physiological maturity and starch accumulation in potato tubers (27).

Conclusion

Based on the present study, seed tuber inoculation with *Rhizobium mililoti* (200 g/10 kg seed) and *Azotobacter chroococcum* (200 g/10 kg seed) resulted in superior growth, yield and tuber quality of potato compared with other treatments. This combined biofertilizer treatment shows potential for improving potato productivity under the agro-climatic conditions of Doon Valley. Further multi-season and multi-location studies are required to validate these findings and to assess the long-term agronomic and soil health impacts of biofertilizer application in potato-based cropping systems.

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Authors' contributions

GT carried out the field experiment under his supervision, checked the plagiarism of the manuscript, AR and P contributed to data collection, literatures and investigations, PB contributed in statistical analysis and writing, SG helped in conceptualizing and editing the manuscript. All authors read and approved the final version of manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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