Effect of Plant Growth Promoting Bacteria on Growth and Nutrient Content of Rice

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ABSTRACT

Aims: The application of a huge number of chemical fertilizers for crop production alters the sustainability of the environment and creates pollution. This problem can be minimized by the application of Plant Growth Promoting Bacteria (PGPB). Plant Growth Promoting Bacteria (PGPB) are beneficial bacteria that promote plant growth and development through a variety of mechanisms. Therefore, a pot experiment was conducted at the department of Soil Science, BSMRAU to investigate the effect of different PGPB isolates on growth, nutrient content, and uptake by rice.

Materials and Methods: The experiment was carried out following a completely randomized design (CRD) with four replicates. Twenty bacterial isolates were used as treatments with a control treatment. Thirty-five days old seedlings of rice were inoculated with different bacterial isolates for thirty minutes and planted in a plastic pot. Broth culture was applied at one-month intervals and crops were harvested 65 days after planting.

Results: Experimental results disclose that application of PGPB isolates resulted in a significant increase in plant height, SPAD value, root length, root volume, straw fresh weight, straw dry weight, root fresh weight, root dry weight, nutrient content and uptake by the rice plant compare to control. The highest values of most of the parameters were recorded from the plant inoculated with the isolate BU Ls 28.

Conclusion: The present study suggests that the use of PGPB isolate BU Ls 28 might be used as a suitable inoculant for rice production due to the ability of this isolate to promote plant growth.

Keywords: Growth, isolate, nutrient content, PGPB, rice.

1. INTRODUCTION

Rice (*Oryza sativa*) is an important cereal crop being a staple food for a large part of the world's human population including Bangladesh. Proteins, phosphate, and iron are all found in good amounts in rice. Additionally, it contains vitamins and minerals like calcium, fiber, thiamine, vitamin B, and vitamin D [1]. In terms of production, Bangladesh is the fourth largest rice producer in the world [2]. In the fiscal year of 2019-2020 total production of rice in Bangladesh was estimated about 36,604 metric tons from 28213 acres [3]. In Bangladesh, about 74.85 % of the total cultivable land is used for rice cultivation [4]. The contribution of rice in the daily dietary energy is almost 69 percent and in the daily protein intake contribution of rice is 55 percent [2]. Rice production depends on a large number of chemical fertilizers which leads to health hazards and environmental pollution in the rice growing areas. Therefore, for maintaining environmental sustainability, there is a need to think about eco-friendly approaches to minimize the use of chemical fertilizers by application of beneficial microorganisms [5]. Soil is abundant with many types of microorganisms and microorganisms especially in the rhizosphere play an important role in plant growth and development through various mechanisms [6]. Plant growth promoting bacteria (PGPB) that are beneficial to the plant, are capable of associating with many plants and are mainly classified into two types: free-living rhizosphere bacteria and endophytic bacteria [7, 8]. By producing plant growth regulators like auxins, gibberellins (GAs), and cytokinins, supplying biologically fixed nitrogen, and increasing the phosphorous uptake by solubilizing inorganic phosphates, plant growth-promoting bacteria can directly cause seed emergence, plant growth, or an improvement in crop yields [9]. Indirect mechanisms involve the suppression of bacterial, fungal, viral, and nematode pathogens [10]. The microbial population is closely related to the improvement of soil fertility [11] which ultimately favors the growth of the plant. PGPB have been used on a variety of crops to improve seed emergence, growth, and yield of crops. The results of [12] showed that plant growth-promoting rhizobacteria (PGPR) strains significantly increased the length and biomass of rice shoots and roots. A significant increase in shoot N content (up to 76%) and root N content (up to 32%) was observed over the un-inoculated control. [13] reported that root length, shoot length and fresh and dry biomass of rice were significantly increased over control due to inoculation with different *Rhizobium* strains. It has been demonstrated that most of the parameters i.e. number of tillers/plant (46%), yield (43%), plant biomass (18%), straw dry weight (45%) and 1000-grain weight (25%) were improved in rice due to inoculation with *R. leguminosarum* [14].

Very little work has so far been done in Bangladesh regarding the effect of PGPB on growth of rice. Thus, the objectives of our study were to assess the effectiveness of PGPB on growth enhancement, nutrient content as well as nutrient uptake by the rice plant.

2. MATERIAL AND METHODS

2.1 Experimental details

A pot experiment was carried out in the net house of the Department of Soil Science, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur-1706, Bangladesh during the boro rice growing season of 2017 (9 February to 11 May 2017). Geographically the experimental site is located at 24.09° North Latitude and 90.25° East Longitudes with an elevation of 8.2 m from mean sea level [15].

The soil used for the experiment was collected from the experimental field of the Department of Soil Science, BSMRAU. The soil belongs to Shallow Red Brown Terrace Soil (Salna series) of the Madhupur Tract (AEZ 28) and is classified as Inceptisols [16]. This soil is characterized by clay within 50 cm of the surface and is slightly acidic in nature. The pH value of the soil sample collected from the study site was 5.70. This soil contained 0.75% organic carbon (OC), 1.30% organic matter (OM), 0.07% nitrogen (N), 2.57 ppm phosphorus (P) and 0.212 meq 100 g^{-1} soil exchangeable potassium (K). The collected soil sample was sterilized by autoclaving. An amount of 1 kg sterilized soil was placed into a 12.9 cm x 12.7 cm plastic pot. The experiment was conducted in a CRD design with four replications.

Twenty bacterial isolates viz. BU Ca 14, BU Ca 15, BU Ca 16, BU Ca 17, BU Ps 6, BU Ps 7, BU Ps 8, BU Ps 9, BU Ls 26, BU Ls 27, BU Ls 28, BU Ls 29, BU Ls 30, BU Ls 31, BU Le 16, BU Le 17, BU Le 18, BU Le 19, BU Le 20 and BU Le 21 isolated from the different leguminous crop viz. chickpea (*Cicer arietinum*), pea (*Pisum sativum*), grasspea (*Lathyrus sativus*) and lentil (*Lens esculentus*) were collected from Soil Microbiology Laboratory of BSMRAU. A loopful of the respective PGPB isolate was transferred to the liquid medium of 100 mL conical flask and incubated for 2 days on a rotary shaker. Two days old broth cultures of *Rhizobium* isolates were centrifuged at 8000 rpm, the supernatant was discarded then the cell pellet was re-suspended in sterile distilled water. Bacterial cells per milliliter were adjusted (10^8cfu /ml) by taking absorbance using a spectrophotometer. An un-inoculated control was also maintained. BRRI dhan 28, a high yielding rice variety was used as the test crop in the boro season. Thirty-five days old rice seedlings were washed with sterile water seven times and then treated with bacterial isolates for 30 min. Inoculated seedlings with each strain were transplanted into the pots. Uninoculated seedlings were designated as control. Broth cultures of *Rhizobium* isolates were also applied in the root zone after transplantation of rice up to tillering stage @ 1 ml /plant at one month interval. Hoagland solution was applied to the soil for supplying plant nutrients. All intercultural operations like weeding, irrigation, etc. were done as and when needed.

2.2 Harvesting of the plants and analysis

After 65 days after sowing, rice plants were harvested by removing them from the soil. The plants were cleaned by immersing them in a container. Plant height (cm plant^{-1}), leaf greenness (SPAD Value), root length (cm), root volume (cm^3), fresh weight and dry weight of shoot and root (g) of each plant were recorded.

The dry weight of shoot and root were recorded after drying in an oven for 48 hours at 70°C. By using the Micro-Kjeldahl method, the total nitrogen content of plant samples was calculated [17]. The amount of phosphorus in digested samples was evaluated using a spectrophotometer by following the Vanadomolybdophosphoric yellow color technique [18] at a wavelength of 440 nm. Following the proper dilution, potassium in the aliquot was calculated using a flame photometer [17]. Sulfur content in the digest was determined by adding acid solution and then precipitation with $BaCl_2$ and measuring the turbidity calorimetrically at 420 nm wavelength [19].

The nutrient uptake by rice straw was measured by using the following formula:

$$\text{Nutrient Uptake} = \frac{\%\ \text{Nutrient x Y (g plant}^{-1})}{100}$$

Here,

Y (g plant^{-1}) = Total dry matter production of plant

Data were analyzed statistically by using the computer package Statistix 10 program. Mean separation was done by LSD (Least significant Difference Test) at 5% level of probability. Graph preparation and computation were carried out using the Microsoft Excel 2010 application.

3. RESULTS AND DISCUSSION

1. 3.1 Influence of PGPB on growth parameters of rice

3.1.1 Plant height

Results presented in Figure 1 demonstrate that all the treatments produced significantly higher plant height compared to the control treatment where no bacterial isolate was applied. The treatment that received isolate BU Ls 28, produced the tallest plant height (80.48 cm). The effect of BU Ls 28 was statistically similar to the isolates BU Ca 14, BU Ca 16, BU Ps 6, BU Ps 7, BU Ps 9, BU Ls 26, BU Ls 29, BU Ls 30 and BU Ls 31. The control treatment produced the smallest plant height (54.95 cm). The synthesis of growth-promoting compounds by the bacterial isolates may account for the higher plant height in treatments receiving PGPB isolates. Through the production and release of various secondary metabolites (plant growth regulators/ phytohormones/ biologically active substances), the PGPR can influence plant growth by limiting the negative effects of phytopathogenic organisms in the rhizosphere, enhancing the availability and uptake of specific nutrients from the root environment, and more [20]. This outcome is consistent with that of [13], who discovered that inoculating rice with *Rhizobium* increased plant height.

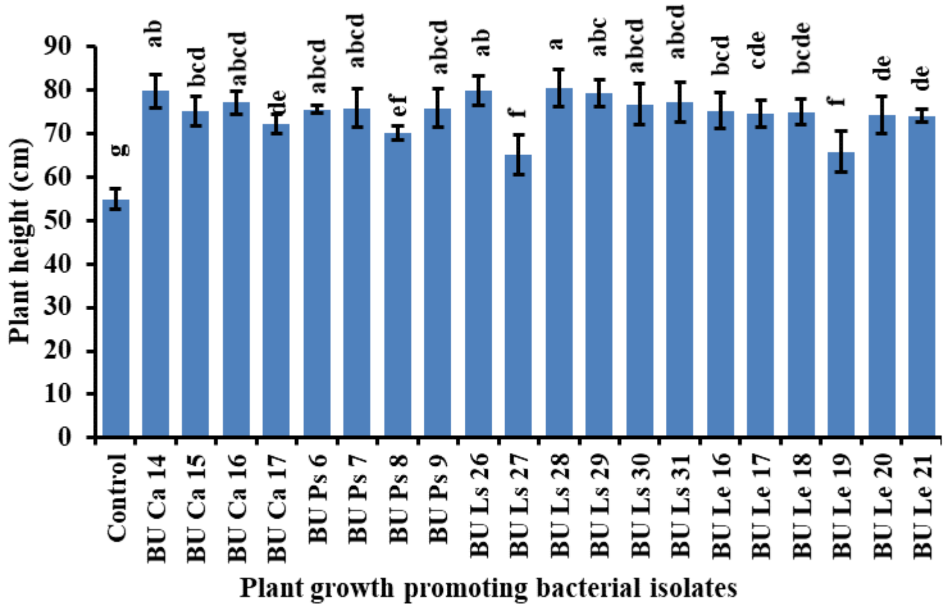

Fig. 1. Influence of plant growth promoting bacteria on plant height of rice (Error bar indicates the standard deviation of the mean)

3.1.2 Leaf greenness (SPAD value)

All the treatments produced significantly higher SPAD values than the control (Figure 2). The highest leaf greenness (46.1) was obtained from the treatment receiving isolate BU Ls 28 while the control (without inoculation) produced the lowest (36.5). The effect of BU Ls 28 was statistically identical to the isolates BU Ca 14, BU Ls 26, BU Ls 29 and BU Ls 31. The SPAD value is correlated with leaf chlorophyll content which represents the greenness of the leaf. It has been demonstrated that leaf nitrogen content significantly influences the SPAD value [21]. The nitrogen fixing ability from the atmosphere and nutrient uptaking capability from the root zone of the PGPB might have enhanced chlorophyll content in rice plants as compared to the un-inoculated control treatment. This outcome supports the research of [22], who found that *Rhizobium* inoculation significantly increased SPAD values in rice.

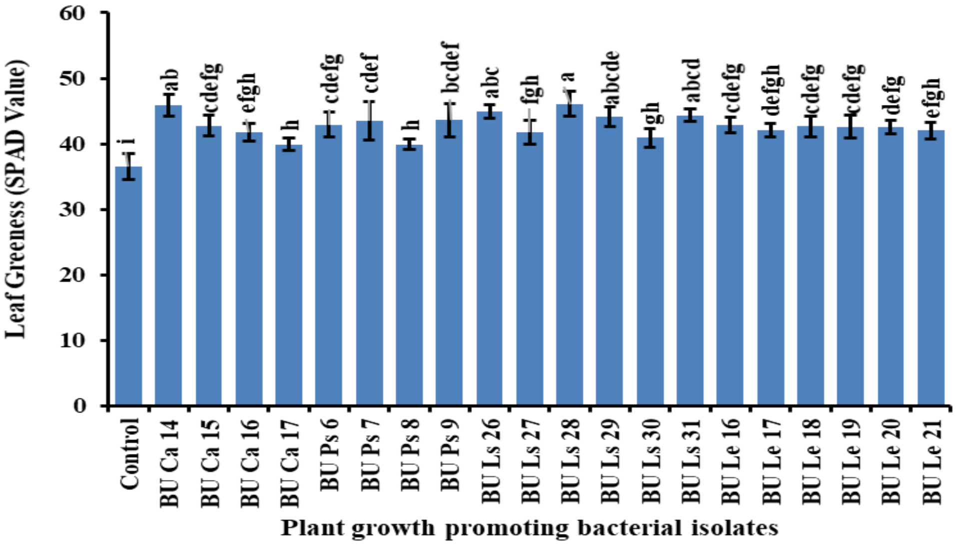

Fig. 2. Influence of plant growth promoting bacteria on leaf greenness (SPAD Value) of rice (Error bar indicates the standard deviation of the mean)

3.1.3 Root length

Inoculation of plants with different bacterial isolates resulted in higher root length compared to uninoculated control plants (Table 1). The maximum root length was found in treatment receiving isolates BU Ls Ca 14 (26.75 cm) followed by the treatment receiving BU Ls 28 (24.18 cm) and BU Ls 26 (23.25 cm). The control treatment that was not inoculated produced the shortest root length (14.6 cm). The increased root length in *Rhizobium* inoculated treatments might be due to the production of phytohormones by the bacterial isolates which encourage root elongation in rice. This result corroborates with the findings of [23] who reported that *Rhizobium* inoculation significantly increased the root length of rice. These results are also in harmony with that of [13] who found higher root length with *Rhizobium* inoculation in rice. [24] also reported significantly higher root length of chickpea with bacterial inoculation as compared to the control treatment.

3.1.4 Fresh biomass yield of shoot and root

Fresh biomass yield of shoot and root of rice plant was increased significantly over control due to different plant growth promoting bacterial inoculation (Table 1). The highest fresh biomass yield of rice shoot (52.35 g) and root (26.54g) were obtained from treatment receiving isolate BU Ls 28. In case of shoot, the lowest (16.15 g) biomass yield was obtained from the control treatment. The lowest root fresh biomass (4.26 g) was also obtained from the control treatment. This result correlates with the finding of [13] who reported that inoculation of rice with *Rhizobium* resulted in noticeably higher shoot fresh biomass output.

3.1.5 Dry biomass yield of shoot and root

A significant increase in dry biomass yield of rice shoot and root was observed in bacterial inoculated plants in comparison to the untreated control plants (Table 1). The highest dry biomass yields both for the shoot (12.56 g) and root (6.37 g) were obtained from treatment receiving BU Ls 28 followed by BU Ca 14 and BU Ls 26. The lowest shoot biomass (3.88 g) and root biomass (1.02 g) were obtained from the control (Table 1) treatment where no PGPB isolate was applied. This result was at par with the findings of [25] who reported that PGPR inoculants boost shoot and root dry matter yield in rice which also corroborates with the findings of [14]. Increased plant growth promotion brought on by bacterial inoculation is closely correlated with an increase in the shoot and root dry mass. In our investigation, bacterial treatments increased plant height, leaf greenness and root length thereby suggesting that the amount of photosynthates produced in rice plant may have been higher in the bacterial inoculated plants in comparison to the uninoculated control plants, thus, resulting in an increase in the shoot and root biomass of the rice plants. Moreover, PGPB changes the physico-chemical properties of the soils surrounding the host plant's root which facilitate better nutrient acquisition by the host plant at the cost of minimum input [25] and therefore obtained higher dry biomass yield of rice plants. [26] also reported a higher dry matter yield of bottle gourd due to inoculation with *Trichoderma*.

Table 1. Influence of plant growth promoting bacteria on root length, fresh and dry biomass yield of rice

PGPB isolates	Root length (cm)	Shoot Fresh Weight (g)	Root fresh weight (g)	Shoot Dry Weight (g)	Root Dry Weight (g)
Control	14.6 j	16.15 n	4.26 m	3.88 l	1.02 m
BU Ca 14	26.75a	41.88 b	19.98 c	10.05 b	4.59 c
BU Ca 15	20.5fg	31fgh	11.32 g	7.44ghi	2.60 h
BU Ca 16	21.25 def	36 d	14.28 f	8.64 de	3.28 f
BU Ca 17	17.75i	24.61 kl	7.95ijk	5.91 j	1.83jkl
BU Ps 6	20.63ef	32.3efg	11.79g	7.75fgh	2.83gh
BU Ps 7	20.93ef	32.75ef	12.13g	7.86fgh	2.91 g
BU Ps 8	17.98i	23.9 kl	7.46jkl	5.92 j	1.79 kl
BU Ps 9	20.8ef	32.55ef	12.04g	8.06efg	2.89 g
BU Ls 26	23.25bc	40.875bc	21.82 b	9.81bc	5.24 b
BU Ls 27	17.65i	21.75lm	6.54 l	5.22jk	1.57 l
BU Ls 28	24.18b	52.35a	26.54a	12.56 a	6.37a
BU Ls 29	22.88bcd	38 cd	17.93 d	9.12 cd	4.30 d
BU Ls 30	21.23 def	35 de	13.27 f	8.4 def	3.18 f
BU Ls 31	22.25cde	36.63 d	16.44 e	8.79 de	3.95 e
BU Le 16	20.13fgh	30.48fghi	9.63 h	7.31ghi	2.31i
BU Le 17	18.5hi	28.88hij	8.99 hi	7.22 hi	2.07ij
BU Le 18	18.88ghi	29.28ghij	9.06 hi	7.32ghi	2.08ij
BU Le 19	17.35i	19mn	6.85 kl	4.75 k	1.58 l
BU Le 20	18.1i	27.75ij	8.67hi	6.94i	1.99jk
BU Le 21	18.05i	26.75jk	8.08ij	6.69i	1.86jk
SE (±)	0.85	1.57	0.56	0.38	0.13
CV (%)	5.95	7.07	6.50	7.08	6.50

SE and CV mean Standard Error and co-efficient of variation respectively. Means followed by common letter(s) are not significantly different at 5% level of probability by LSD

3.2 Influence of PGPB on nutrient content and nutrient uptake by rice plant

3.2.1 Nitrogen content and uptake by rice shoot

Plant growth promoting bacterial inoculation had a positive effect on nitrogen content and uptake by rice shoot (Tables 2-3). The highest nitrogen content in shoot (1.80 %) was obtained from treatment receiving isolate BU Ls 28. The effect of the isolate BU Ls 28 was statistically similar to the rest of the treatments except BU Le 20, BU Le 21 and control. The lowest nitrogen content in rice shoot (1.00%) was obtained from the control treatment. This result was in harmony with that of [14] who reported that nitrogen content of rice grain was increased significantly with inoculation of *Rhizobium* isolates as compared to uninoculated control. Our findings are also supported by the findings of [27], [28] who found higher nitrogen content in *Rhizobium* inoculated chickpea shoot as compared to the un-inoculated control plants.

The highest nitrogen uptake by rice shoot (225.78 mg/plant) was obtained from treatment BU Ls 28 followed by BU Ca 14 and BU Ls 26. The lowest nitrogen uptake by rice shoot (38.94 mg /plant) was obtained from the control treatment where no bacterial isolates were applied. Higher nitrogen content in rhizobacterial inoculated treatments might be due to fixation of atmospheric nitrogen by rhizobacteria and which eventually might lead to higher nitrogen content in rice plants and also increased N uptake by increasing availability of this element by different metabolites produced by rhizobacteria. [12] found higher nitrogen content in the shoot of rice plant due to *Rhizobium* inoculation which also corroborates with the findings of [29] as well. These results are also in harmony with that of [30] who reported that N uptake was increased by rice plants inoculated with rhizobia.

3.2.2 Phosphorus content and uptake by rice shoot

Results presented in Tables 2 and 3 reveal that phosphorus content and uptake by rice shoot were increased significantly over control due to inoculation of plant growth promoting bacteria. Treatment receiving isolate BU Ls 28 showed higher phosphorus content in rice shoot (0.489%) whose effect was statistically similar to BU Ca 14, BU Ca 16, BU Ls 26, BU Ls 29 and BU Ls 31. The lowest phosphorus content in rice shoot (0.286%) was obtained from the control. The highest phosphorus uptake by rice shoot (61.35 mg/plant) was also obtained from BU Ls 28 followed by BU Ca 14 and BU Ls 26. The lowest phosphorus uptake by rice shoot (11.09 mg/ plant) was obtained from the control treatment. This result is in agreement with that of [31] who discovered increased phosphorus content and uptake by chickpea shoots as a result of *Rhizobium* inoculation. Higher phosphorus content and uptake by shoot as reported might be due to increased availability of this element by different mechanisms mediated by rhizobacteria. The soil of the present study was slightly acidic in reaction. In acidic soil, phosphorus fixation is a common phenomenon. It has been reported that the phosphorus solubilizing ability of the PGPB [9] which might improve P availability in the studied soil and thereby obtain higher P content as well as higher P uptake by the rice plants inoculated with PGPB isolates as compared to the un-inoculated control plants. The results confirm the findings of [14], who reported a significant increase in phosphorus content in rice after inoculation with the *Rhizobium* strain compared to uninoculated controls.

Table 2. Influence of plant growth promoting bacteria on nitrogen, phosphorus, potassium and sulfur contents in rice shoot

PGPB isolates	%N	%P	% K	%S
Control	1.00 c	0.286i	1.41 g	0.139 n
BU Ca 14	1.79 a	0.486a	2.6a	0.362 ab
BU Ca 15	1.61ab	0.372g	2.02 def	0.244 kl
BU Ca 16	1.71ab	0.473ab	2.42 ab	0.331cdef
BU Ca 17	1.61ab	0.373g	2 def	0.247 kl
BU Ps 6	1.67ab	0.442cd	2.34abc	0.302fgh
BU Ps 7	1.70ab	0.456bc	2.38 ab	0.316 def
BU Ps 8	1.72ab	0.457bc	2.39 ab	0.329cdef
BU Ps 9	1.67ab	0.447c	2.35abc	0.311efg
BU Ls 26	1.75ab	0.488 a	2.44 ab	0.352abc
BU Ls 27	1.67ab	0.425 de	2.28bcd	0.286ghi
BU Ls 28	1.80a	0.489 a	2.62 a	0.382 a
BU Ls 29	1.73ab	0.484 a	2.42 ab	0.341bcd
BU Ls 30	1.58ab	0.366 g	1.97ef	0.237 kl
BU Ls 31	1.73ab	0.475 ab	2.42 ab	0.334bcde
BU Le 16	1.65ab	0.408ef	2.28bcd	0.279hij
BU Le 17	1.62ab	0.394 f	2.08cdef	0.261 ijk
BU Le 18	1.62ab	0.402 f	2.18bcde	0.266ijk
BU Le 19	1.62ab	0.400 f	2.04 def	0.250jk
BU Le 20	1.57 b	0.358 g	1.89 f	0.218 l
BU Le 21	1.56 b	0.320 h	1.91ef	0.182 m
SE (±)	0.09	0.01	0.14	0.015
CV (%)	8.32	3.45	9.22	7.49

SE and CV mean Standard Error and co-efficient of variation respectively. Means followed by common letter(s) are not significantly different at 5% level of probability by LSD

3.2.3 Potassium content and uptake by rice shoot

Potassium content and uptake by rice shoot were increased significantly over control due to bacterial inoculation (Tables 2-3). The highest potassium content in rice shoot (2.62%) was obtained from treatment receiving isolate BU Ls 28. The effect of BU Ls 28 was statistically similar to BU Ca 14, BU Ca 16, BU Ps 6, BU Ps 7, BU Ps 8, BU Ps 9, BU Ls 26, BU Ls 29 and BU Ls 31. On the other hand, the lowest potassium level (1.41 %) in rice shoot was obtained from the control treatment. The highest potassium uptake by rice shoot (328.40 mg/plant) was obtained from treatment receiving isolate BU Ls 28 followed by BU Ca 14 and BU Ls 26. The lowest potassium uptake (54.48 mg/ plant) by rice shoot was obtained from uninoculated control treatment whose effect was statistically inferior to all other treatments receiving different PGPB isolates. Higher potassium content and uptake as found might be due to increased availability of this element by the activity of rhizobacteria. This result is in harmony with that of [32] who found higher potassium content in rice shoot due to *Rhizobium* inoculation. These findings support the findings of [33], who found that the application of *Rhizobium* improved the K-uptake by pea.

Table 3. Influence of plant growth promoting bacteria on nitrogen, phosphorus, potassium and sulfur uptake by rice shoot

PGPB isolates	N (mg/ plant)	P (mg/ plant)	K (mg/ plant)	S (mg/ plant)
Control	38.94 m	11.09 j	54.48 l	5.40 k
BU Ca 14	179.76 b	48.81 b	261.49 b	36.32 b
BU Ca 15	119.89 ghi	27.63efg	150.31 hi	18.15 hi
BU Ca 16	147.64 def	40.82 c	208.56 de	28.57 de
BU Ca 17	94.99jkl	22.02 hi	118.12jk	14.55 j
BU Ps 6	129.21 fgh	34.22 d	180.76 fg	23.41fg
BU Ps 7	133.32efg	35.80 d	187.27ef	24.82 f
BU Ps 8	101.45ijk	27.01fg	141.03hij	19.51 h
BU Ps 9	135.22efg	35.95 d	188.93ef	25.02ef
BU Ls 26	171.89bc	47.88 b	240.19bc	34.57 bc
BU Ls 27	87.13 kl	22.19 hi	119.02 jk	14.93 ij
BU Ls 28	225.78 a	61.35 a	328.40 a	47.81 a
BU Ls 29	157.70 cd	44.10 c	220.30 cd	31.13 cd
BU Ls 30	132.68efg	30.73 e	165.48fgh	19.91 gh
BU Ls 31	152.38cde	41.74 c	212.02 de	29.40 d
BU Le 16	121.19 ghi	29.86ef	166.64fgh	20.39gh
BU Le 17	116.66ghi	28.41ef	150.29 hi	18.83 h
BU Le 18	118.46 ghi	29.42ef	159.29 gh	19.50 h
BU Le 19	76.75 l	19.02 i	96.85 k	11.87 j
BU Le 20	109.21hij	24.81 gh	131.3ij	15.12 ij
BU Le 21	104.74ijk	21.37 hi	127.73 ij	12.17 j
SE (±)	10.29	1.72	13.61	1.79
CV (%)	11.52	7.48	11.21	11.29

SE and CV mean Standard Error and Co-efficient of variation respectively. Means followed by common letter(s) are not significantly different at 5% level of probability by LSD

3.2.4 Sulfur content and uptake by rice shoot

Inoculation of plant growth-promoting bacteria had a substantial impact on rice shoot sulfur content and uptake (Tables 2-3). Treatment receiving isolate BU Ls 28 showed higher sulfur content in the shoot (0.382 %) of rice. This outcome is consistent with the findings of [29], who found that *Rhizobium* inoculation increased the sulfur content of rice shoots. The effect of the isolate BU Ls 28 was statistically similar to the treatments BU Ca 14 and BU Ls 26. The lowest sulfur content (.139%) was obtained from the control. The highest sulfur uptake by shoot (47.81 mg/plant) of rice was obtained from *Rhizobium* isolate BU Ls 28. The lowest sulfur uptake (5.40 mg/plant) was found in the control treatment. [29] reported higher sulfur uptake by the shoot of rice due to *Rhizobium* inoculation. There was an increase in the sulfur content of the shoots as well as a higher sulfur uptake by the rice shoot in the PGPB inoculation over the un-inoculated control. The enhanced sulfur content and uptake might be due to the enhanced root volume due to bacterial inoculation thereby leading to an increase in the translocation of sulfur from root to shoot, consequently shoot sulfur content was also found to be increased. Additionally, higher dry biomass production of the rice plant as a result of bacterial inoculation might be caused by better nutrient uptake by the rice plant.

4. CONCLUSION

Results of the present study show that inoculating rice plants with plant growth-promoting rhizobacteria not only boosted their vegetative development but also allowed them to accumulate more dry matter. In addition to improving the growth of the plants, inoculation with PGPR also resulted in improving the nutrient content in the rice plant as well as ensuring higher nutrient uptake by the plant. Among the twenty bacterial isolates, BU Ls 28 performed better than all other isolates in improving the different growth parameters, nutrient content and uptake by the rice plant which may imply that this isolate could be used as PGPB for promoting rice growth followed by BU Ca 14 and BU Ls 26. Therefore, the study provides an insight into utilizing PGPB isolates as a sustainable and eco-friendly approach for enhancing rice production and ensuring food security. However, further studies at the field level are needed to confirm their potential.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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