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ORIGINAL RESEARCH

Field evaluation of consortium of bacterial inoculants producing ACC deaminase on growth, nutrients and yield components of rice and wheat

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Abstract

Bacterial isolates *Achromobacter*, *Ochrobactrum Pseudomonas*, and *Variovorax* have often been isolated from plant roots, and most of them have been described as growth enhancing rhizobacteria. These rhizobacteria have been used to boost crops productivity in varied region of agro-climatic regions. To lessen the usage of chemical fertilizers inputs and improve the sustainability of rice–wheat crops, this study was planned to investigate the impacts of bacterial consortium inoculants producing 1-aminocyclopropane-1-carboxylate (ACC) deaminase on plant growth, nutrient content and grain yield in a field trial. Rice and wheat plants subjected to plant growth-promoting rhizobacteria (PGPR) consortia of strain DPC9 (*Ochrobactrum anthropi*) + DPB13 (*Pseudomonas palleroniana*) + DPB15 (*Pseudomonas fluorescens*) + DPB16 (*Pseudomonas palleroniana*) gave the best results with reference to macronutrient—nitrogen, phosphorus, potassium, calcium and sodium content and yield-related parameters including 1000 grain weight (10.2%, 40.7%), number of grains per panicle/spike (45.5%, 60.6%), and tillers (32.2%, 106.6%). This inoculants significantly increased grain yield (65.6%, 74.4%), straw yield (26.8%, 36.9%) and harvest index (14.9%, 13.8%) of rice–wheat crops, respectively, when compared to their counterpart control plants. Significant positive correlation in parameters which contribute in producing high grain yield in rice–wheat include plant height ($r = 0.938$, $r = 0.852$), tillers ($r = 0.968$, $r = 0.881$), panicle/spike length ($r = 0.844$, $r = 0.912$), number of grains per panicle/spike ($r = 0.969$, $r = 0.815$), 1000 grain weight ($r = 0.833$, $r = 0.931$), straw yield ($r = 0.920$, $r = 0.918$) and harvest index ($r = 0.909$, $r = 0.847$) and also surge nutrient enhancement in rice and wheat were observed in consortium treated plants. It can be concluded that consortium of DPC9 + DPB13 + DPB15 + DPB16-producing ACC deaminase can serve as a useful bio-inoculant for sustainable rice–wheat production in diverse agro-ecosystem.

Keywords Rice–wheat cropping system · PGPR · ACC deaminase · Consortia · Nutrient

Introduction

An approximately 13.5 million hectare area of Indo-Gangetic Plains is utilized for RWCS (rice–wheat cropping system) in south Asian countries. The proportion of this area is 10.0 million ha in India and rest 3.5 (2.2, 0.8, 0.5) shared in Pakistan, Bangladesh and Nepal, respectively. RWCS covers about 33% of the total rice area and 42% of the total wheat area and this is dominant cropping system in most of the Indian states (Mahajan and Gupta 2009; Kumar et al. 2014a, b; Sharma et al. 2015). Rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) are the staple food crops for more than 50% and 35% of the world's population, respectively. Global production of wheat and rice is 772 millions of tonnes (FAOSTAT 2017) and 688.2 millions of tonnes (FAOSTAT 2018), respectively. Rice

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and wheat have contributed enormously to global food security and sustain humanity largely by enhancing the yields and by making them more robust in the face of abiotic and biotic stresses. Increased applications of chemical fertilization and pesticides have a negative effect on soil quality and soil microbial community. Moreover, excessive chemical fertilizer exaggerates the deterioration of soil organic matter and fertility and hastens soil acidification, which in turn reduces crop productivity (Li et al. 2017). The application of bio-inoculants in agricultural system is of strategic concern for their potential to lessen the usage of synthetic chemical fertilizers and pesticides and improve environment sustainability (Cortivo et al. 2020; Kantachote et al. 2016). Plant beneficial microbes referred to as PGPR that interact with roots of plants and augmented plant growth by enhancing nutrition acquisition and imparting resistance and tolerance to various stresses (Nadeem et al. 2013; Gupta et al. 2015).

PGPR's are an essential part of rhizospheric biota that colonizes root of plants and escalate the growth and productivity of crops (Jorquera et al. 2012; Qessaoui et al. 2019; Chandra et al. 2019b). They improve plant growth through direct and indirect mechanisms (Adesemoye et al. 2009; Chandra et al. 2015, 2018a,b). Numerous studies revealed that substantial evidence for the beneficial effects of PGPR on plant growth under controlled conditions (Chandra et al. 2019a, 2020), and not efficient in the field conditions possibly due to unable to adequate colonization with plant roots and/or to compete with the inhabitant root microbiome (Kamilova et al. 2005; Dal Cortivo et al. 2017). The growth-promoting microorganisms need to be introduced in appropriate quantities that efficiently colonize roots of plant, as this is decisive step for their success in agroecosystems (Bishnoi 2015; Dal Cortivo et al. 2020). Subsequent biofertilizers application, it can be expected no interaction, positive and negative interaction with the resident bacterial population (Brimecombe et al. 2007).

Microbial inoculants represent a viable tool for improving growth and productivity of crops including rice and wheat. Different researchers reported the beneficial impact of rhizobacteria on rice are *Bacillus* spp. (Guyasa et al. 2018; Rais et al. 2018), *Pseudomonas fluorescens* (Guyasa et al. 2018), *Serratia* spp. (Nascente et al. 2019), *Serratia nematodiphila* (Chakraborty et al. 2013) and on wheat are *Azotobacter chroococcum* N9 (Wang et al. 2020), *Achromobacter insolitus* IAC-HT-11 (da Silveira et al. 2016), *Pseudomonas* sp. UW4, *Pseudomonas palleroniana* DPB16 and *Variovorax paradoxus* RAA3 (Chandra et al. 2019b). Therefore, this study evaluated the impact of bacterial consortia producing ACC deaminase together with other plant growth-promoting attributes on growth, nutrients and yield components of rice and wheat.

Materials and methods

Bacterial strain

Of the total ten bacterial strains were taken, out of eight described by Chandra et al. (2019a, b) and other two bacterial strain R81 (*Pseudomonas synxantha*) described by Mathimaran et al. (2012) and UW4 (*Pseudomonas* sp.) described by Duan et al. (2013) were used in different combination based on their compatibility. These strains exhibited multiple growth-promoting attributes such as ACC deaminase, indole 3-acetic acid (IAA) production, P-solubilization, ammonia production, N_2 fixation and siderophore production are given in Supplementary Table SI.

Plant material and seed sterilization

In this experiment, two different varieties of rice (Swarna and Swarna Sub1) and wheat (WH 1105 and HD 2733) were taken to see the response of rice and wheat toward inoculation with PGPR consortia having ACC deaminase activity and other PGP (plant growth promoting) traits in field conditions. Seeds of rice and wheat were obtained from IRRI, New Delhi, India and DWR Karnal, Haryana, India, respectively. For the trial, the seeds were surface decontaminated by dipping the seeds in 0.1% of $HgCl_2$ for 3 min followed by washing with 3–4 times and then 70% ethanol for 1 min followed by rinsing with sterile distilled water 5–6 times.

Soil physicochemical analysis

The field trial was conducted on vertisol clay soil of BSPC GBPUA&T Pantnagar and have physicochemical properties—pH (7.26), organic carbon (1.36%), nitrogen (261.61 kg/ha), phosphorus (18.57 kg/ha) and potassium (230.72 kg/ha). Before seeding, soil physiochemical properties (0–20 cm) from experimental fields were done using established methods. The soil pH was done according to the method of Beckman Glass electrode pH meter (Jackson 1973), organic carbon as per Walkley and Black (1934), total nitrogen by Kjeldahl digestion (Pelican Kelplus Kelvac VA equipment), available potassium by Flame photometery and available phosphorus by Olsen's method (Olsen 1954).

Organic manure used

Before designing the experiment, *Sesbenia aculeata* (Dhaincha) as organic manure was sown in the field @ 20 kg/ha. The above-ground biomass of 45 days of standing crop of *Sesbenia* puddled properly into the pre-irrigated field 10 days before rice planting with the help of tractor. After harvesting of rice, for wheat trial, each plot of previously sown rice were dug out with the help of Grubbing hoe (phawda) to prevent the mixing of soil between plots. Same treatments were applied in each plot as in previously sown rice.

Raising nursery

Eighteen raised nursery beds for two varieties of rice having a dimension of 4 m^2 providing 50 cm channels all around were prepared well before sowing of seed. The nursery beds were prepared with a massive mixture of soil. The seeds were sown @ 100 kg/ha in the raised bed, whereas the seeding rate for wheat was 90 @ kg/ha. The seeds were primed with PGPB containing ACC deaminase activity before sowing.

Experimental detail

The experiment was carried out during kharif and rabi season of 2015–2016 for the rice and wheat, respectively, at the BSPC, GBPUA&T, Pantnagar, U.S. Nagar, Uttarakhand, India. The experiment was accomplished in a randomized block design (RBD) with eight treatments and three replicates (Table 1).

Field preparation for transplanting

In the month of July, after proper mixing of standing crop of *Sesbenia* into soil field was properly levelled. Thereafter, the layout was made and bunds were constructed for separating the plots to prevent leaching of PGPB between the plots having different treatments. One day before transplanting, the field was flooded with water and puddled manually with the help of Grubbing hoe.

Bio-inoculants

On the basis of glass house study (Chandra et al. 2019a), seven bacterial consortium were further taken (Table 1) for the field trials to see the response of rice and wheat toward inoculation with PGPB containing ACC deaminase trait. The bacterial treatment for rice was given twice, at the time of seed sowing (seed treatment) and at the time of transplantation (seedling treatment) while for the wheat, bacterial treatment were given only once. The seeds (rice and wheat) were coated with charcoal-based PGPB cultures (10^7–10^8 cfu g^{-1} carrier) and left for 30 min for air drying then sowing in the prepared plot of each treatment. Another treatment was given to rice seedling at the time of transplantation. The rice seedlings were uprooted and roots of plants coated with charcoal-based PGPB cultures (10^7–10^8 cfu g^{-1} carrier).

Transplanting

After treatments, the seedlings were sown in their respective plots. Two seedlings were transplanted per hill and the distance between two hills was 25 cm. Light irrigation was given after 2 days of transplanting while for wheat, treated seeds were directly sown.

Water management and weed control

Soil was kept moist or slightly flooded during all the growth phase of rice. Water supply was stopped just before harvesting. The weeds were removed from field by hand at regular intervals.

Harvesting and threshing

At the maturity of rice–wheat crops, growth- and yield-related parameters were measured. A sampling area of 1 m^2 in the centre of each experimental plot (area left after removing border plants) was harvested manually and day after the

Table 1 List of bacterial treatments used in the experiments

Designation	Combination of bacterial strains
T1 (control)	Uninoculated
T2 (DPC9 + DPC12)	*Ochrobactrum anthropi* DPC9 + *Pseudomonas* sp. DPC12
T3 (DPB13 + PSA7)	*Pseudomonas palleroniana* DPB13 + *Achromobacter marplatensis* PSA7
T4 (DPB15 + PSB8)	*Pseudomonas fluorescens* DPB15 + *Achromobacter* sp. PSB8
T5 (DPB16 + RAA3)	*Pseudomonas palleroniana* DPB16 + *Variovorax paradoxus* RAA3
T6 (R81 + UW4)	*Pseudomonas synxantha* R81 + *Pseudomonas* sp. UW4
T7(DPC9 + DPB13 + DPB15 + DPB16)	*Ochrobactrum anthropi* DPC9 + *Pseudomonas palleroniana* DPB13 + *Pseudomonas fluorescens* DPB15 + *Pseudomonas palleroniana* DPB16
T8 (DPC12 + PSA7 + PSB8 + RAA3)	*Pseudomonas* sp. DPC12 + *Achromobacter marplatensis* PSA7 + *Achromobacter* sp. PSB8 + *Variovorax paradoxus* RAA3

harvesting the plants from each plots were threshed by Pullman thresher and individual plot yields were noted.

Nutrient analysis of rice and wheat straw

For both the crops, straw sample were taken for nutrients (N, K, P, Ca and Na) analysis. Phosphorus content of straw was estimated as per the method described by Jackson (1973). The K, Ca and Na contents were estimated by Flame photometry and N content was determined by Kjeldahl digestion.

Statistical analysis

The collected data were subjected to two way ANOVA using SPSS (IBM SPSS statistics 20). Treatment comparisons of mean values were carried out using DMRT at a significance level of $p < 0.05$.

Results

Present study deals with ten bacterial strains that were used in different combination/consortium for their contribution to the growth promotion, nutrient content and yield components of both RWCS. In this experiment, two varieties of rice (Swarna and Swarna sub1) and wheat (WH 1105 and HD 2733) were taken.

Growth and yield components of rice and wheat

ANOVA results revealed that irrespective of treatments, Swarna variety showed significant differences for the plant height, total tillers, effective tillers, number of grains/panicle and grain yield. Among treatments, irrespective of varieties, treatment T8 (a consortium of DPC12 (*Pseudomonas* sp.) + PSA7 (*A. marplatensis*) + PSB8 (*Achromobacter* sp.) + RAA3 (*V. paradoxus*) and T7 (a consortium of DPC9 (*Ochrobactrum anthropi*), DPB13 (*Pseudomonas palleroniana*), DPB15 (*Pseudomonas fluorescens*), DPB16 (*Pseudomonas palleroniana*) producing ACC deaminase showed maximum increase 22.8% and 22.4%, respectively, in plant height when compared to non-treated control plants. We also noticed that treatment T7-treated plants exhibited 32.2% increase in numbers of tillers, 49.7% increase in effective tillers, 45.5% increase in numbers of grains/panicle, 21.0% increase in panicle length (Table 2), 10.2% increase in test weight/1000 grain weight, 65.6% increase in grain yield, 26.8% increase in straw yield and 14.9% increase in harvest index as compared to control plants (Fig. 1). When we compared all the treatments within varieties, treatment T8-treated plant indicated maximum enhancement in plant height and effective tillers and treatment T7-treated plants displayed grains/panicle, higher panicle length, grain yield, straw yield and 1000 grain weight, in Swarna, whereas T7-treated plants of Swarna sub1 showed the higher HI (data not shown).

Table 2 Effect of bacterial consortium inoculation producing ACC deaminase on growth parameters of two varieties of rice (viz. Swarna, Swarna sub1) under field conditions

Factors	Plant height (cm)	Total tillers/m^2	Effective tillers/m^2	Panicle length (cm)	No. of grains/panicle
Varieties (A)					
Swarna	92.36 ^{b}	253.79 ^{b}	195.67 ^{b}	22.33 ^{a}	327.18 ^{b}
Swarna sub1	87.82 ^{a}	238.79 ^{a}	181.38 ^{a}	21.74 ^{a}	310.89 ^{a}
SEm ±	0.92	2.98	3.39	0.29b	3.47
LSD ($p \leq 0.05$)	2.66	8.60	9.80	0.84	10.04
Treatments (B)					
T1	77.40 ^{a}	204.17 ^{a}	143.33 ^{a}	19.23 ^{a}	246.50 ^{a}
T2	88.57 ^{b}	238.83 ^{bc}	176.00 ^{b}	21.93 ^{b}	319.97 ^{c}
T3	89.67 ^{bc}	239.17 ^{bc}	185.00 ^{bc}	22.60 ^{b}	293.94 ^{b}
T4	90.57 ^{bc}	235.50 ^{b}	182.83 ^{bc}	21.83 ^{b}	323.10 ^{c}
T5	91.67 ^{bc}	249.50 ^{bc}	184.17 ^{bc}	22.40 ^{b}	329.10 ^{c}
T6	93.03 ^{bc}	252.33 ^{c}	196.17 ^{c}	22.57 ^{b}	334.17 ^{cd}
T7	94.73 ^{c}	283.33 ^{d}	229.50 ^{d}	23.27 ^{b}	363.50 ^{e}
T8	95.07 ^{c}	267.50 ^{c}	211.17 ^{c}	22.43 ^{b}	342.03 ^{d}
Mean	90.09	246.29	188.52	22.03	319.27
SEm ±	1.84	5.25	5.96	0.59	6.95
LSD ($p \leq 0.05$)	5.32	15.18	17.21	1.69	20.09
CV%	5.01	5.23	7.74	6.50	5.34

(A) Varietal effect, irrespective of PGPB (B) PGPB effect, irrespective of varieties. Values with different letters (a–e) are significantly different at $p < 0.05$ (Duncan's test)

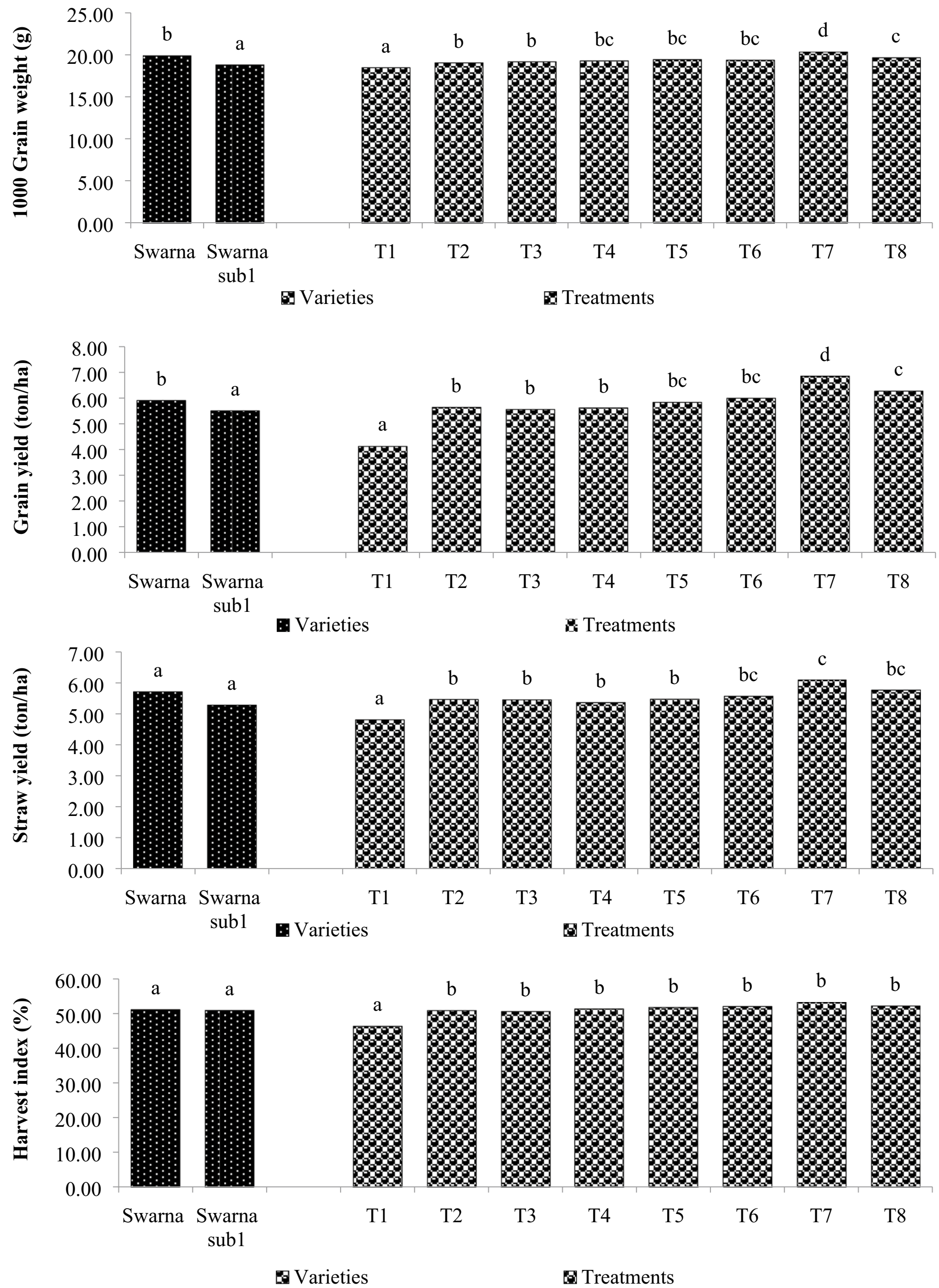


Fig. 1 Effect of bacterial consortium inoculation producing ACC deaminase on 1000 grain weight, grain yield, straw yield and harvest index of two rice varieties (viz. Swarna and Swarna sub1) under field conditions. Values with different letters (**a**–**c**) are significantly different at $p < 0.05$ (Duncan's test)

Similarly, the ANOVA results revealed that irrespective of treatments, WH 1105 showed significant differences for 1000 grain weight, plant height, numbers of grains/spike, total tillers/plant, grain yield and straw yield than HD 2733. These wheat varieties showed non-significant differences for spike length and harvest index. All treated plants exhibited significant differences for plant height and spike length as compared to control. For most of the studied parameters, T7-treated plant exhibited significantly higher numbers of tillers (106.6%) and no. of grains/spike (60.6%) (Table 3) 1000 grain weight (40.7%), grain yield (74.4%), straw yield (36.9%) and harvest index (13.8%) as compared to non-inoculated control plants (Fig. 2). Among all the treatments within varieties, treatment T7 maximally increased plant height, total number of tillers, number of grains/spike, 1000 grain weight, grain yield, straw yield in WH 1105 and harvest index in HD 2733 (data not shown).

Table 3 Effect of bacterial consortium inoculation producing ACC deaminase on growth parameters of two varieties of wheat (viz. WH 1105 and HD 2733) under field conditions

Factors	Plant height (cm)	Total tillers/plant	Spike length (cm)	No. of grains/spike
Varieties (A)				
WH 1105	76.28 [b]	5.47 [b]	13.90 [a]	60.13 [b]
HD 2733	72.24 [a]	4.17 [a]	13.59 [a]	46.75 [a]
SEm ±	0.77	0.10	0.18	1.28
LSD ($p \leq 0.05$)	2.23	0.28	0.53	3.71
Treatments (B)				
T1	67.30 [a]	3.16 [a]	11.97 [a]	40.67 [a]
T2	74.70 [b]	4.65 [b]	13.53 [b]	50.33 [bc]
T3	73.97 [b]	4.64 [b]	14.00 [b]	50.00 [b]
T4	75.13 [b]	4.58 [b]	13.70 [b]	55.17 [bc]
T5	75.53 [b]	4.76 [b]	13.85 [b]	55.00 [bc]
T6	74.67 [b]	4.81 [b]	13.90 [b]	53.50 [bc]
T7	76.53 [b]	6.53 [d]	14.51 [b]	65.33 [d]
T8	76.23 [b]	5.43 [c]	14.48 [b]	57.50 [c]
Mean	74.26	4.82	13.74	53.44
SEm ±	1.54	0.19	0.37	2.57
LSD ($p \leq 0.05$)	4.47	0.56	1.06	7.41
CV%	5.11	9.89	6.51	11.77

(A) Varietal effect, irrespective of PGPB (B) PGPB effect, irrespective of varieties. Values with different letters (a–e) are significantly different at $p < 0.05$ (Duncan's test)

Correlation coefficient among yield and yield components in rice

We have noticed the positive correlation between the rice–wheat grain yield and yield-related components indicate that parameters which contribute in producing high grain yield include plant height ($r = 0.938$, $r = 0.852$), tillers ($r = 0.968$, $r = 0.881$), panicle/spike length ($r = 0.844$, $r = 0.912$), number of grains per panicle/spike ($r = 0.969$, $r = 0.815$), 1000 grain weight ($r = 0.833$, $r = 0.931$), straw yield ($r = 0.920$, $r = 0.918$) and harvest index ($r = 0.909$, $r = 0.847$) (Tables 4, 5).

Path coefficient analysis for rice and wheat

In this study, the response variable grain yield (GY) and seven predictor variables (plant height, tillers, panicle/spike length, no. of grains per panicle/spike, test weight (1000 grain weight), straw yield and harvest index) were taken for path coefficient analysis in rice and wheat. This analysis is performed to unveil the causes and effects of chain relationships of different yield contributing characters with grain yield. Assessments of direct and indirect effects of yield contributing characters on grain yield are presented in Tables 6 and 7.

Nutrient analysis of rice and wheat straw (N, P, K, Ca and Na)

Both rice varieties, irrespective of treatments, showed non-significant differences for sodium and phosphorus content, while Swarna variety showed significant differences for nitrogen and potassium, and Swarna sub1 for calcium content. However, the maximum NPK content in response of bacterial application was observed in the treatment T7 (2.75-, 2.12-, 2.09-fold) as compared to control. However, the maximum calcium and sodium content was found in the treatment T8 (1.45-fold) and T3 (1.62-fold), respectively, as compared to control plants (Table 8). When we compared all the treatments within varieties, T7-treated plants of Swarna showed maximum NPK content than Swarna sub 1, whereas T6- and T7-treated plants of Swarna sub1 showed maximum calcium and sodium content, respectively, than Swarna (data not shown).

In case of wheat, irrespective of treatments, variety WH 1105 showed significant differences for foliar nitrogen, potassium and calcium content and non-significant differences for phosphorus and sodium content. However, the maximum NPK content in response of bacterial application was observed in the treatment T7 (3.39-, 5.00-, 2.04-fold) as compared to control (Table 9). Within treatment bio-inoculant-treated plants exhibited little bit higher calcium

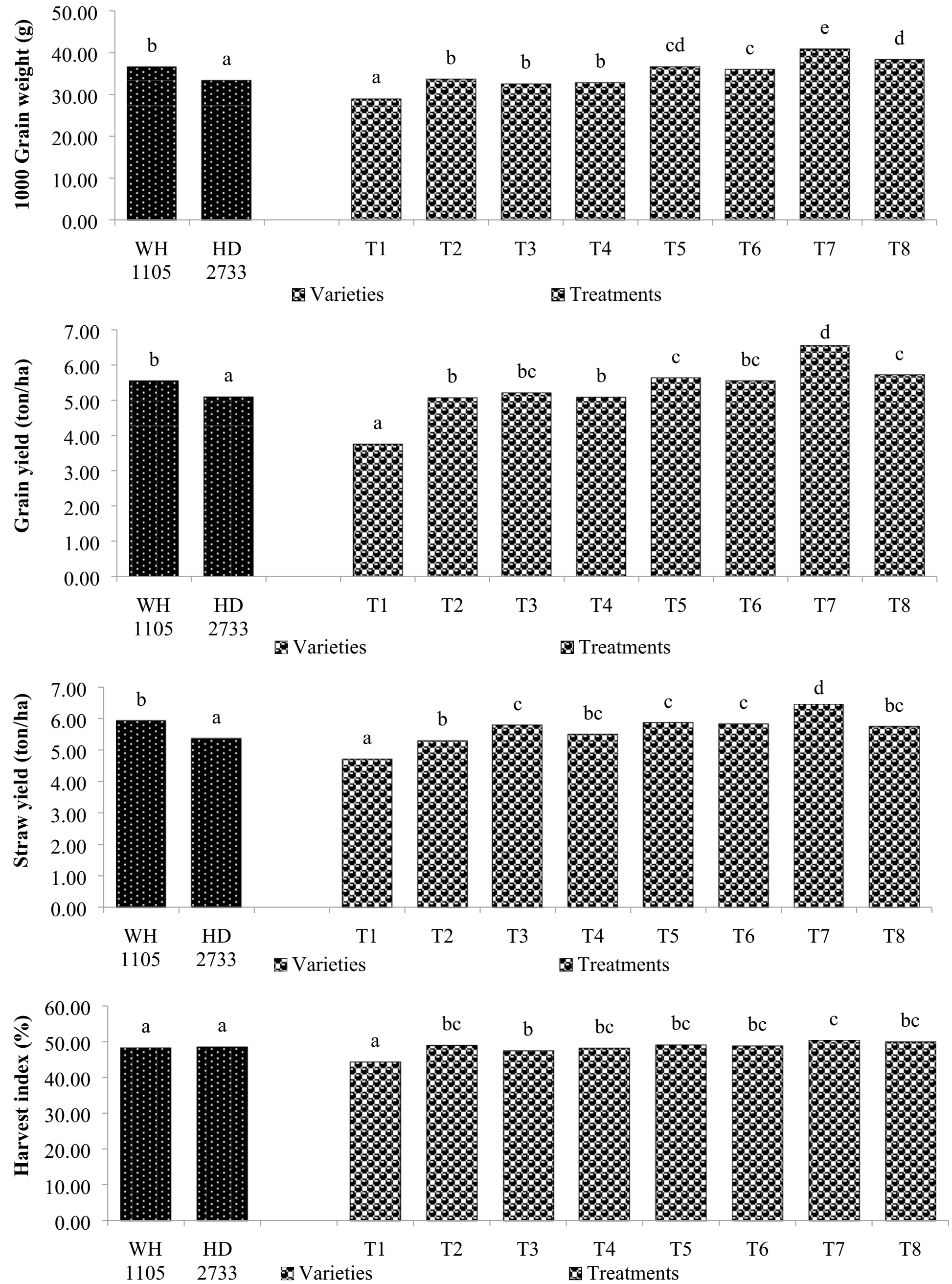


Fig. 2 Effect of bacterial consortium inoculation producing ACC deaminase on 1000 grain weight, grain yield, straw yield and harvest index of two wheat varieties (viz. WH 1105 and HD 2733) under field conditions. Values with different letters (**a**–**c**) are significantly different at $p < 0.05$ (Duncan's test)

Table 4 Correlation coefficient between growth, yield and yield components of rice grown in field conditions

	PH	TPS	PL	GPP	TW	GY	SY	HI
PH	1							
TPS	0.900**	1						
PL	0.791**	0.819**	1					
GPP	0.913**	0.926**	0.795**	1				
TW	0.809**	0.824**	0.602*	0.760**	1			
GY	0.938**	0.968**	0.844**	0.969**	0.833**	1		
SY	0.863**	0.904**	0.782**	0.858**	0.898**	0.920**	1	
HI	0.879**	0.850**	0.804**	0.919**	0.608*	0.909**	0.682**	1

PH Plant height, *TPS* tiller/m^2, *PL* panicle length, *GPP* grains/panicle, *TW* test weight (1000 grain weight), *GY* grain yield, *SY* straw yield, *HI* Harvest index

Table 5 Correlation coefficient between growth, yield and yield components of wheat grown in field conditions

	PH	TPP	SL	GPS	TW	GY	SY	HI
PH	1							
TPP	0.868**	1						
SP	0.858**	0.774**	1					
GPS	0.899**	0.935**	0.708**	1				
TW	0.803**	0.908**	0.804**	0.859**	1			
GY	0.852**	0.881**	0.912**	0.815**	0.931**	1		
SY	0.852**	0.892**	0.832**	0.858**	0.831**	0.918**	1	
HI	0.670**	0.627**	0.803**	0.538*	0.796**	0.847**	0.576*	1

PH Plant height, *TPP* tiller per plant, *SL* spike length, *GPS* no. of grains/spike, *TW* test weight (1000 grain weight), *GY* grain yield, *SY* straw yield, *HI* Harvest index, *NS* non-significant

*Significant at 5% level, **Significant at 1% level

Table 6 Path analysis showing direct and indirect effects of yield contributing characters on rice yield

Traits	Direct effects	Indirect effects							
		PH	TPS	PL	GPP	TW	SY	HI	Pearson correlation with yield
PH	−0.116	–	0.140	−0.060	−0.023	0.018	0.473	0.506	0.938**
TPS	0.155	−0.105	–	−0.062	−0.024	0.018	0.496	0.490	0.968**
PL	−0.076	−0.092	0.127	–	−0.020	0.013	0.429	0.463	0.844**
GPP	−0.025	−0.106	0.143	−0.060	–	0.016	0.471	0.530	0.969**
TW	0.022	−0.094	0.128	−0.046	−0.019	–	0.493	0.350	0.833**
SY	0.549	−0.100	0.140	−0.059	−0.022	0.019	–	0.393	0.920**
HI	0.576	−0.102	0.132	−0.061	−0.023	0.013	0.374	–	0.909**

Residual factor = 0.008

PH Plant height, *TPS* Tillers/m^2, *PL* panicle length, *GPP* grains/panicle, *TW* test weight (1000 grain weight), *GY* grain yield, *SY* straw yield, *HI* Harvest index

**Significant at 1% level of probability

Table 7 Path analysis showing direct and indirect effects of yield contributing characters on wheat yield

Traits	Direct effects	Indirect effects							
		PH	TPP	SL	NG	TW	SY	HI	Pearson correlation with yield
PH	−0.162	–	−0.003	0.050	0.100	0.036	0.520	0.310	0.852**
TPP	−0.004	−0.141	–	0.045	0.104	0.041	0.545	0.290	0.881**
SL	0.059	−0.139	−0.003	–	0.079	0.036	0.508	0.372	0.912**
NG	0.112	−0.146	−0.003	0.042	–	0.039	0.524	0.249	0.815**
TW	0.045	−0.130	−0.003	0.047	0.096	–	0.508	0.369	0.931**
SY	0.611	−0.138	−0.003	0.049	0.096	0.037	–	0.267	0.918**
HI	0.463	−0.109	−0.002	0.047	0.060	0.036	0.352	–	0.847**

Residual factor = 0.0036

PH Plant height, *TPP* tillers/plant, *SL* spike length, *GPS* No. of grains/spike, *TW* test weight (1000 grain weight), *GY* grain yield, *SY* straw yield, *HI* Harvest index

**Significant at 1% level of probability

Table 8 Effect of bacterial consortium inoculation producing ACC deaminase on nutrient contents of rice straw under field conditions

Factors	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Calcium (%)	Sodium (%)
Varieties (A)					
Swarna	1.34 [b]	1.22 [a]	1.09 [b]	0.73 [a]	0.85 [a]
Swarna sub1	1.17 [a]	1.26 [a]	0.95 [a]	0.81 [b]	0.81 [a]
SEm ±	0.03	0.03	0.07	0.06	0.05
LSD ($p \leq 0.05$)	0.09	0.10	0.21	0.18	0.14
Treatments (B)					
T1	0.78 [a]	0.82 [a]	0.63 [a]	0.62 [a]	0.56 [a]
T2	0.83 [ab]	1.01 [ab]	1.06 [c]	0.68 [ab]	0.81 [b]
T3	1.11 [bc]	1.14 [b]	0.88 [bc]	0.71 [ab]	0.91 [b]
T4	1.01 [b]	1.12 [b]	0.98 [bc]	0.79 [b]	0.88 [b]
T5	1.52 [d]	1.28 [b]	1.04 [bc]	0.80 [b]	0.81 [b]
T6	1.28 [c]	1.30 [b]	1.16 [cd]	0.87 [b]	0.90 [b]
T7	1.90 [e]	1.74 [d]	1.32 [d]	0.83 [b]	0.89 [b]
T8	1.62 [d]	1.54 [c]	1.10 [c]	0.90 [b]	0.85 [b]
Grand mean	1.25	1.24	1.02	0.77	0.83
SEm ±	0.06	0.07	0.15	0.12	0.10
LSD ($p \leq 0.05$)	0.18	0.20	0.42	0.35	0.28
CV%	9.39	11.70	17.07	13.05	16.62

(A) Varietal effect, irrespective of PGPB (B) PGPB effect, irrespective of varieties. Values with different letters (a–e) are significantly different at $p < 0.05$ (Duncan's test)

Table 9 Effect of bacterial consortium inoculation producing ACC deaminase activity on nutrient contents of wheat straw under field conditions

Factors	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Calcium (%)	Sodium (%)
Varieties (A)					
WH 1105	1.46 [b]	0.97 [a]	0.87 [b]	0.54 [b]	0.21 [a]
HD 2733	1.22 [a]	1.04 [a]	0.77 [a]	0.47 [a]	0.19 [a]
SEm ±	0.03	0.03	0.02	0.01	0.01
CD at 5%	0.10	0.10	0.06	0.03	0.01
Treatments (B)					
T1	0.58 [a]	0.36 [a]	0.51 [a]	0.42 [a]	0.18 [a]
T2	1.03 [b]	0.90 [b]	0.67 [b]	0.52 [b]	0.20 [ab]
T3	1.23 [b]	0.90 [b]	0.66 [b]	0.51 [b]	0.20 [ab]
T4	1.15 [b]	1.18 [b]	0.89 [c]	0.53 [b]	0.21 [b]
T5	1.62 [e]	0.94 [c]	0.97 [cd]	0.51 [b]	0.21 [b]
T6	1.44 [d]	0.92 [b]	0.88 [c]	0.53 [b]	0.22 [b]
T7	1.97 [e]	1.44 [d]	1.04 [d]	0.50 [b]	0.21 [b]
T8	1.69 [e]	1.42 [bc]	0.93 [cd]	0.52 [b]	0.21 [b]
Mean	1.34	1.01	0.82	0.50	0.20
SEm ±	0.07	0.07	0.04	0.02	0.01
CD at 5%	0.19	0.20	0.13	0.06	0.02
CV%	12.25	17.00	13.07	10.61	8.88

(A) Varietal effect, irrespective of PGPB (B) PGPB effect, irrespective of varieties. Values with different letters (a–e) are significantly different at $p < 0.05$ (Duncan's test)

and sodium content as compared to untreated control. When we compared all the treatments within varieties, T7-treated plants of WH 1105 showed higher nitrogen and potassium content, treatment T4- and T6 (both 0.59%)-treated plants of WH 1105 showed higher calcium content, whereas T7-treated plants of HD 2733 showed higher phosphorus content. Many of the treatments showed similar effect for sodium content when comparing treatments within varieties (data not shown).

Discussion

The consortium application of bacterial strains put forth a significant impact on rice and wheat growth parameter, increased nutrient accessibility, and also benefits the plant health. Numerous studies have been reported that consortium application of bacteria efficiently increased the plant growth parameters and productivity of rice (Lavakusha et al. 2014; Bisht and Chauhan 2020; Ríos-Ruiz et al. 2020) and wheat (Otanga et al. 2018; Wang et al. 2020). In this study, height of plant was significantly higher in all consortia treated plants of rice and wheat under field conditions over non-inoculated plants. Several studies stated that combined application of PGPB have more positive effect on plant height over uninoculated control (Jha et al. 2010; Abbasi et al. 2011; Kumar et al. 2014a, b; Yasmin et al. 2016). In response to application of bacterial consortia, an increase of productive tillers, panicle/spike length, test weight, harvest index, grain yield and straw yield was noticed. The results of Naureen et al. (2015) revealed that most of the individual inoculants significantly augment the yield and yield-related traits, and when four bacterial inoculants used in a consortium (*Aeromonas hydrophila* BPS10, *Bacillus cereus* Z2-7, *Enterobacter* sp. B41 strain SPR7, *Enterobacter* sp. BPS12) produced a better synergistic effect on plant growth. In our study, the average higher rice–wheat grain (6.84 ton/ha, 6.96 ton/ha) and straw yield (6.09, 6.25 ton/ha) was obtained in the consortia of *O. anthropi* DPC9 + *P. palleroniana* DPB13 + *P. palleroniana* DPB15 + *P. fluorescens* DPB16 (T7) treated plants. Kumar et al. (2014a, b) also observed that consortium application of *A. chlorophenolicus* + *B. megaterium* + *Enterobacter* significantly increased test weight (17.6%), grain yield (27.5%) and straw yield (29.5%) of wheat under field conditions. Turan et al. (2012) also reported that mixed inoculation of OSU-142 (*Bacillus subtilis*), M3 (*B. megaterium*), or Sp245 (*Azospirillum brasilense*) significantly increased grain yield (33.0%) relative to untreated control plants.

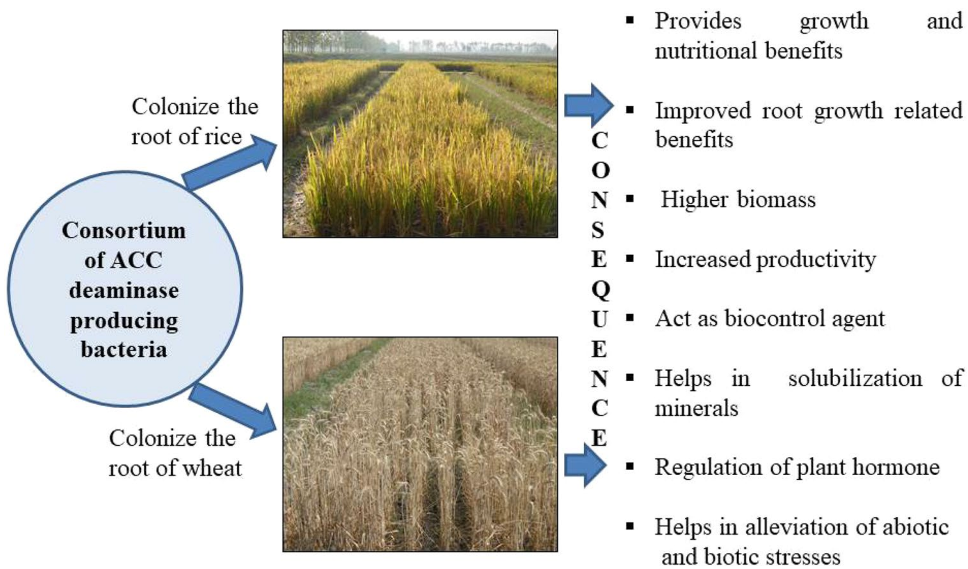
The results obtained with respect to correlation study among rice–wheat yield and yield components are in agreement with those of several other researchers who reported that positive and significant correlation of grain yield with number of tillers, test weight, panicle/spike length, number of grains per panicle/spike and harvest index (Khaliq et al. 2004, Yogameenakshi et al. 2004; Ajmal et al. 2009; Akhtar et al. 2013; Dhurai et al. 2016). Path coefficient analysis of rice revealed that greater positive effect on grain yield are possessed by grains/panicle and total tillers followed by plant height and straw yield. This indicates that more filled grains in panicle are highly reliable component of grain yield. Another important character with high direct effect on grain yield is harvest index followed by panicle length and 1000 grain weight which showed direct effect on grain yield. The direct positive effects of various characters on grain yield observed in the present study are in agreements with the findings of Madhavilatha et al. (2005), Reddy et al. (2013), Basavaraja et al. (2011) and Ratna et al. (2015). In case of wheat direct and indirect effect of spike length, grains per spike, 1000 grain weight, straw yield and harvest index on grain yield was positive, while the direct and indirect effect of plant height and tillers on grain yield was negative. This study indicates that 1000 grain weight and straw yield possessed the highest positive effect on grain yield followed by spike length and tillers. Study of Ahmad et al. (2003), Khokhar et al. (2010), Iftikhar et al. (2012) and Khan et al. (2013) supports the present findings. Hence, harvest index, test weight, straw yield and panicle or spike length should be given prior attention in rice and wheat improvement program because of their major influence on yield.

The obtained results indicated that application of rice and wheat with bacterial consortia improved the nutrient contents under field conditions. The higher NPK content was found in the consortium inoculation of treatment T7-treated plant of both rice and wheat crops as compared to untreated control plants. Our result, with respect to NPK strongly supports the study of Kalita et al. (2015) and Rana et al. (2015) who revealed that bacterial consortia showed higher nutrient uptake than the non-inoculated plants. PGPB inoculants in our study showed multiple PGP characteristic (phosphorus solubilization, siderophore, IAA, NH_3 and production), which facilitate rice and wheat plant growth, thereby enhancing the accessibility of nutrients. The compatible nature of bacterial strains used in the present study has shown the synergistic interactions. The inoculation of rice and wheat seeds with treatment T7-exhibited maximum phosphorus content as compared to other treatment over untreated control since all strains in this combination are P-solubilizers might be a reason of increased content of phosphate. Moreover, PGPR produces the antifungal metabolites such as siderophores, antibiotics and hydrolytic enzymes, these metabolites protect plants from pathogen (Chowdhury et al. 2015). Hence, PGPR could be exploited as substitute to the synthetic chemical fertilizers and serve as a viable tool for sustainable agriculture. This argument is strongly supported by previous reports where PGPR inoculation has resulted in the vigorous plant growth, improved nutrition and high productivity of crops (El-Sayed et al. 2014; Majeed et al. 2015). Therefore, inoculation with a consortium of several bacterial strains could be an alternative to inoculation with individual strains, likely reflecting the different mechanisms used by each strain in the consortium.

Conclusion

This study has shown that bacterial consortium inoculation having ACC deaminase activity and other plant growth-promoting attributes augmented rice–wheat growth and grain yield and also enhanced the nutrient availability of plants (Fig. 3). The most promising results were obtained in the consortium application of DPC9 (*O. anthropi*) + DPB13 (*P. palleroniana*) + DPB15 (*P. palleroniana*) + DPB16 (*P. fluorescens*) that could be used as a potential biofertilizers and a promising option for sustainable agriculture.

Fig. 3 Conceptual diagram of consortium inoculation of ACC deaminase producing bacteria augmented the growth parameters of rice and wheat



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Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interests.

References

Abbasi MK, Sharif S, Kazmi M, Sultan T, Aslam M (2011) Isolation of plant growth promoting rhizobacteria from wheat rhizosphere and their effect on improving growth, yield and nutrient uptake of plants. Plant Biosyst 145:159–168

Adesemoye AO, Torbert HA, Kloepper JW (2009) Plant growth-promoting rhizobacteria allow reduced application rates of chemical fertilizers. Microb Ecol 58:921–929

Ahmad HM, Khan BM, Khan S, Kissana N, Laghari S (2003) Path coefficient analysis in bread wheat. Asian J Plant Sci 2:491–494

Ajmal SU, Zakir N, Mujahid MY (2009) Estimation of genetic parameters and character association in wheat. J Agric Biol Sci 1:15–18

Akhtar N, Arshad I, Shakir MA, Qureshi MA, Sehrish J, Ali L (2013) Coinoculation with *Rhizobium* and *Bacillus* sp. to improve the Phosphorus availability and yield of wheat (*Triticum aestivum* L.). J Anim Plant Sci 23:190–197

Basavaraja T, Gangaprasad S, Dhusyantha Kumar BM, Hittlamani SH (2011) Correlation and path analysis of yield and yield attributes in local rice cultivars (*Oryza sativa* L.). Electron J Plant Breed 2:523–526

Bishnoi U (2015) PGPR interaction: an ecofriendly approach promoting the sustainable agriculture system. Adv Bot Res 75:81–113

Bisht N, Chauhan PS (2020) Comparing the growth-promoting potential of *Paenibacillus lentimorbus* and *Bacillus amyloliquefaciens* in *Oryza sativa* L. var. Sarju-52 under suboptimal nutrient conditions. Plant Physiol Biochem 146:187–197

Brimecombe MJ, De Leij FAAM, Lynch JM (2007) Rhizodeposition and microbial populations. In: Pinton R, Varanini Z, Nannipieri P (eds) The rhizosphere: biochemistry and organic substances at the soil-plant interface. CRC Press, Boca Raton, pp 73–109

Chakraborty U, Chakraborty BN, Chakraborty AP, Sunar K, Dey PL (2013) Plant growth promoting rhizobacteria mediated improvement of health status of tea plants. Indian J Biotechnol 12:20–31

Chandra D, Srivastava R, Sharma AK (2015) Environment-friendly phosphorus biofertilizer as an alternative to chemical fertilizers. In: Pati BR, Mandal SM (eds) Recent trends in biofertilizers. IK International Publishing House, New Delhi, pp 43–71

Chandra D, Srivastava R, Glick BR, Sharma AK (2018a) Drought-tolerant *Pseudomonas* spp. improve the growth performance of finger millet (*Eleusine* coracana (L.) Gaertn.) under non-stressed and drought-stressed conditions. Pedosphere 28:227–240

Chandra D, Srivastava R, Sharma A (2018b) Influence of IAA and ACC deaminase producing fluorescent pseudomonads in alleviating drought stress in wheat (*Triticum aestivum*). Agric Res 7:290–299

Chandra D, Srivastava R, Gupta VVSR, Franco CM, Paasricha N, Saifi SK, Tuteja N, Sharma AK (2019a) Field performance of bacterial inoculants to alleviate water stress effects in wheat (*Triticum aestivum* L.). Plant Soil 44:261–281

Chandra D, Srivastava R, Gupta VVSR, Franco CM, Sharma AK (2019b) Evaluation of ACC-deaminase-producing rhizobacteria to alleviate water-stress impacts in wheat (*Triticum aestivum* L.) plants. Can J Microbiol 65:1–17

Chandra D, Srivastava R, Glick BR, Sharma AK (2020) Rhizobacteria producing ACC deaminase mitigate water-stress response in finger millet (*Eleusine coracana* (L.) Gaertn.). 3 Biotech 10:65

Chowdhury PS, Hartmann A, Gao X, Borriss R (2015) Biocontrol mechanism by root-associated *Bacillus amyloliquefaciens* FZB42—a review. Front Microbiol 6:780

da Silveira APD, Sala VMR, Cardoso EJBN, Labanca EG, Cipriano MAP (2016) Nitrogen metabolism and growth of wheat plant under diazotrophic endophytic bacteria inoculation. Appl Soil Ecol 107:313–319

Dal Cortivo C, Barion G, Visioli G, Mattarozzi M, Mosca G, Vamerali T (2017) Increased root growth and nitrogen accumulation in common wheat following PGPR inoculation: assessment of plant-microbe interactions by ESEM. Agric Ecosyst Environ 247:396–408

Dal Cortivo C, Ferrari M, Visioli G, Lauro M, Fornasier F, Barion G, Panozzo A, Vamerali T (2020) Effects of seed-applied biofertilizers on rhizosphere biodiversity and growth of common wheat (*Triticum aestivum* L.) in the field. Front Plant Sci 11:72

Dhurai SY, Reddy DM, Ravi S (2016) Correlation and path analysis for yield and quality characters in rice (*Oryza sativa* L.). Rice Genomics Genet 7:1–6

Duan J, Jiang W, Cheng Z, Heikkila JJ, Glick BR (2013) The complete genome sequence of the plant growth-promoting bacterium *Pseudomonas putida* UW4. PLoS ONE 8:e58640

El-Sayed WS, Akhkha A, El-Naggar MY, Elbadry M (2014) In vitro antagonistic activity, plant growth promoting traits and phylogenetic affiliation of rhizobacteria associated with wild plants grown in arid soil. Front Microbiol 5:651

Gupta G, Parihar SS, Ahirwar NK, Snehi SK, Singh V (2015) Plant growth promoting rhizobacteria (PGPR): current and future prospects for development of sustainable agriculture. J Microb Biochem Technol 7:096–102

Guyasa IM, Sadimantara GR, Khaeruni A, Sutariati GAK (2018) Isolation of *Bacillus* spp. and *Pseudomonas fluorescens* from upland rice rhizosphere and its potential as plant growth promoting rhizobacteria for local upland rice (*Oryza sativa* L.). Biosci Res 15:3231–3239

Iftikhar R, Khaliq I, Ijaz M, Rashid MAR (2012) Association analysis of grain yield and its components in spring wheat (*Triticum aestivum* L.). J Agric Environ Sci 12:389–392

Jackson MC (1973) Soil chemist analysis. Prentice Hall Pvt. Ltd., India

Jha Y, Subramanian RB, Patel S (2010) Combination of endophytic and rhizospheric plant growth promoting rhizobacteria in *Oryza sativa* shows higher accumulation of osmoprotectant against saline stress. Acta Physiol Plant 33:797–802

Jorquera MA, Shaharoona B, Nadeem SM, de la Luz MM, Crowley DE (2012) Plant growth-promoting rhizobacteria associated with ancient clones of creosote bush (*Larrea tridentata*). Microb Ecol 64:1008–1017

Kalita M, Bharadwaz M, Dey T, Gogoi K, Dowarah P, Unni BG, Ozah D, Saikia I (2015) Developing novel bacterial based bioformulation having PGPR properties for enhanced production of agricultural crops. Indian J Exp Biol 53:56–60

Kamilova F, Validov S, Azarova T, Mulders I, Lugtenberg B (2005) Enrichment for enhanced competitive plant root tip colonizers selects for a new class of biocontrol bacteria. Environ Microbiol 7:1809–1817

Kantachote D, Nunkaew T, Kantha T, Chaiprapat S (2016) Biofertilizers from *Rhodopseudomonas palustris* strains to enhance rice yields and reduce methane emissions. Appl Soil Ecol 100:154–161

Khaliq I, Parveen N, Chowdhry MA (2004) Correlation and path coefficient analyses in bread wheat. Int J Agric Biol 4:633–635

Khan AA, Alam MA, Alam MK, Alam MJ, Sarker ZI (2013) Correlation and path analysis of durum wheat (*Triticum turgidum* L. Var. Durum). Bangladesh J Agric Res 38:515–521

Khokhar MI, Hussain M, Zulkiffal M, Ahmad N, Sabar W (2010) Correlation and path analysis for yield and yield contributing characters in wheat (*Triticum aestivum* L.). Afr J Plant Sci 4:464–466

Kumar A, Maurya BR, Raghuwanshi R (2014a) Isolation and characterization of PGPR and their effect on growth, yield and nutrient content in wheat (*Triticum aestivum* L.). Biocatal Agric Biotechnol 3:121–128

Kumar S, Shivani KU, Manibhushan (2014b) Productivity and economics of rice-wheat cropping system as affected by methods of sowing and tillage practices in the eastern plains. J AgriSearch 1:145–150

Lavakusha YJ, Verma JP, Jaiswal DK, Kumar A (2014) Evaluation of PGPR and different concentration of phosphorus level on plant growth, yield and nutrient content of rice (*Oryza sativa*). Ecol Eng 62:123–128

Li XG, Jia B, Lv J, Ma Q, Kuzyakov Y, Li FM (2017) Nitrogen fertilization decreases the decomposition of soil organic matter and plant residues in planted soils. Soil Biol Biochem 112:47–55

Madhavilatha L, ReddiSekhar M, Suneetha Y, Srinivas T (2005) Genetic variability, correlation and path analysis for yield and quality traits in rice (*Oryza sativa* L.). Res Crops 6:527–534

Mahajan A, Gupta RD (2009) Integrated nutrient management (INM) in a sustainable rice-wheat cropping system. Springer Science & Business Media, Berlin

Majeed A, Abbasi MK, Hameed S, Imran A, Rahim N (2015) Isolation and characterization of plant growth-promoting rhizobacteria from wheat rhizosphere and their effect on plant growth promotion. Front Microbiol 6:198

Mathimaran N, Srivastava R, Wiemken A, Sharma AK, Boller T (2012) Genome sequences of two plant growth-promoting fluorescent *Pseudomonas* strains, R62 and R81. J Bacteriol 194:3272–3273

Nadeem SM, Zahir ZA, Naveed M, Nawaz S (2013) Mitigation of salinity induced negative impact on the growth and yield of wheat by plant growth-promoting rhizobacteria in naturally saline conditions. Ann Microbiol 63:225–232

Nascente AS, Lanna AC, de Sousa TP, Chaibub AA, de Souza ACA, de Filippi MCC (2019) N fertilizer dose-dependent efficiency of *Serratia* spp. for improving growth and yield of upland rice (*Oryza sativa* L.). Int J Plant Prod 13:217–226

Naureen Z, Hafeez FY, Hussain J, Al Harrasi A, Bouqellah N, Roberts MR (2015) Suppression of incidence of *Rhizoctonia solani* in rice by siderophore producing rhizobacterial strains based on competition for iron. Euro Sci J 11:1857–7431

Olsen SR (1954) Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA, Washington, p 18

Otanga RR, Yobo KS, Laing MD (2018) Response of two wheat cultivars to inoculation of diazotrophic bacteria in combination with reduced nitrogen fertilisation under field conditions. S Afr J Plant Soil 35:343–350

Qessaoui R, Bouharroud R, Furze JN, El Aalaoui M, Akroud H, Amarraque A, Van Vaerenbergh J, Tahzima R, Mayad EH, Chebli B (2019) Applications of new rhizobacteria *Pseudomonas* isolates in agroecology via fundamental processes complementing plant growth. Sci Rep 9:1–10

Rais A, Shakeel M, Malik K, Hafeez FY, Yasmin H, Mumtaz S, Hassan MN (2018) Antagonistic Bacillus spp. reduce blast incidence on rice and increase grain yield under field conditions. Microbiol Res 208:54–62

Rana A, Kabi SR, Verma S, Adak A, Pal M, Shivay YS, Prasanna R, Nain L (2015) Prospecting plant growth promoting bacteria and cyanobacteria as options for enrichment of macro-and micronutrients in grains in rice-wheat cropping sequence. Cogent Food Agric 1:1037379

Ratna M, Begum S, Husna A, Dey SR, Hossain MS (2015) Correlation and path coefficients analyses in basmati rice. Bangladesh J Agril Res 40:153–161

Reddy G, Eswara BG, Suresh ST, Reddy PA (2013) Interrelationship and cause effect analysis of rice genotypes in north-east plain zone. The Bioscan 8:1141–1144

Ríos-Ruiz WF, Torres-Chávez EE, Torres-Delgado J, Rojas-García JC, Bedmar EJ, Valdez-Nuñez RA (2020) Inoculation of bacterial consortium increases rice yield (*Oryza sativa* L.) reducing applications of nitrogen fertilizer in San Martin region, Peru. Rhizosphere 14:100200

Sharma P, Singh G, Sarkar SK, Singh RP (2015) Improving soil microbiology under rice-wheat crop rotation in Indo-Gangetic

Plains by optimized resource management. Environ Monit Assess 187:150

Turan S, Cornish K, Kumar S (2012) Salinity tolerance in plants: breeding and genetic engineering. Aus J Crop Sci 6:1337–1348

Walkley A, Black CA (1934) An examination of different methods for determining soil organic matter and proposed modifications of the chromic acid titration method. Soil Sci 37:29–38

Wang J, Li R, Zhang H, Wei G, Li Z (2020) Beneficial bacteria activate nutrients and promote wheat growth under conditions of reduced fertilizer application. BMC Microbiol 20:1–12

Yasmin S, Zaka A, Imran A, Zahid MA, Yousaf S, Rasul G, Arif M, Mirza MS (2016) Plant growth promotion and suppression of bacterial leaf blight in rice by inoculated bacteria. PLoS ONE 11:e0160688

Yogameenakshi P, Nadarajan N, Anbumalarmathi J (2004) Correlation and path analysis on yield and drought tolerant attributes in rice (*Oryza sativa* L.) under drought stress. Oryza 41:68–70