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Influence of Plant Growth Promoting Rhizobacterial Inoculation on Wheat Productivity Under Soil Salinity Stress

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Abstract: Soil salinity affects the growth and yield of crops. The stress of soil salinity on plants can be mitigated by inoculation of plant growth promoting bacteria (PGPR). The influence of PGPR inoculation on wheat (*Triticum aestivum* L.) crop productivity under salinity stress has not been properly addressed so far. Therefore, the present study was conducted to investigate the effects of various PGPR strains (W14, W10 and 6K; alone and combined) at several growth attributes of wheat plant under different soil salinity gradients (3, 6 and 9 dS m^{-1}). The growth attributes of wheat (height, roots, shoots, spikes, grains quality, biological and economical yield, nutrients nitrogen, phosphorus and potassium in grains) were highly affected by salinity and decreased with increasing salinity level. The PGPR inoculation substantially promoted growth attributes of wheat and prominent results were observed in W14 × W10 × 6K treatment at all salinity levels. The results suggest that inoculation of PGPR is a potential strategy to mitigate salinity stress for improving wheat growth and yield.

Keywords: PGPR; abiotic stress; soil salinity; ethylene; wheat

1 Introduction

Wheat (*Triticum aestivum* L.) is one of the major grain crops and staple food in Pakistan. Wheat is grown yearly on 215 million hectares worldwide [1]. In Pakistan, during 2017-2018, wheat crop was cultivated on an area of 8,734 thousand hectares showing a decrease of 2.6% compared to 8 thousand hectares during the corresponding period last year [2]. Wheat production stood at 25.492 million tonnes during 2017-2018 recording a decline of 4.4% last year. Wheat accounts for 9.1% of the value added in agriculture and 1.7% of gross domestic product (GDP) of Pakistan [2]. There are many reasons for low yield of wheat crop in Pakistan such as weeds, fertilizers unavailability, quality and unavailability of irrigation water, salinity and sodicity of soils. Soil salinity can cause ionic imbalance in plants due to the change in uptake, distribution as well as compartmentation of ions inside the plant [3]. These changes consequently induce the osmotic stress by limiting absorption associated with water from the soil [4]. Many physiological processes may be impacted by salinity stress which leads to the reduction in growth as well as productivity [3]. Salinity/sodicity leads to nutritional disproportion with an increase in uptake that associated with Na^+ or reduced uptake of Ca^{2+} as well as K^+, and also reduces the mobility and transportation of the active growing plant parts which affect the quality of both the vegetative and reproductive organ [4].

Sodicity can increase the level of Na^+ and Cl^- that lead to the osmotic and metabolic problems in plants. The leaves are more susceptible to sodicity as compared to roots, due to the fact that Na^+ accumulates in the shoots, while roots have the capability to maintain continuous amounts of NaCl by transferring the ions to soil or shoot [5]. The Na^+ causes metabolic toxicity within plants by competing with K^+ for important binding sites for their cellular function. Therefore, many enzymatic processes can

be disturbed by the high level of Na^+, or low level of K^+ to Na^+ ratio. Furthermore, protein synthesis requires higher level of K^+ [6].

The mechanism associated with salinity tolerance can vary at molecular, cellular and whole plant leaves [7]. Salt stress can affect the different features such as morphology, ultra-structure, anatomy, as well as metabolism of plant that can lead to overall reduction in yield of plant [8]. Furthermore, higher concentration of NaCl within soil solution can increase Na^+/Ca^{2+} as well as Na^+/K^+ ratio in the plant which causes the osmotic imbalance in plant [7]. This osmotic imbalance in the plants makes more vulnerable to plant for osmotic as well as specific ion injury and nutritional disorder. The specific ion injury, osmotic effect and nutritional disorder can decrease the quality and yield of plant [9].

The yield of plants cultivated at sodic/saline soils can be enhanced by genetic engineering method or by inoculation of plant with plant growth promoting rhizobacteria (PGPR) [10]. The PGPR can increase a variety of indexes such as germination rate, root growth, and biotic control of pathogenesis factors, leaf surface area, chlorophyll content, microbial activity as well as root and shoot activity [11]. The PGPR group of rhizobacteria includes different strains of genera i.e., *Bacillus*, *Azotobacter*, *Pseudomonas*, *Flavobacterium Burkholderia*, *Rhizobium*, *Azospirillium, Erwinia* and *Enterobacter* [12]. The PGPR can colonize the roots of plants and thus enhance the plant growth [8]. It is well known that PGPR can increase plant growth; however, the effect of PGPR seed inoculation under sodic soil conditions remains unclear. We hypothesized that PGPR inoculation will increase wheat yield through diminishing salinity stress. Therefore, we conducted the present study which aimed to assess the effects of selected bacterial strains of PGPR on production of wheat under salt-affected soil conditions.

2 Materials and Methods

2.1 Soil Characteristics and Analysis

Soil used in the present study was collected from farm area, Faculty of Agricultural Sciences and Technology, B.Z. University, Multan. Soil properties were analyzed before onset of the study and main characteristics of soil are presented in Tab. 1. Soil electrical conductivity and pH were determined using pH meter and EC-meter as described by Shaaban et al. [13,14]. Soil total nitrogen, phosphorus and potassium were analyzed according to the methods described by Richards [15].

Table 1: Physical and chemical properties of soil used in the study

Determination	Values	Unit
Sand	50	%
Silt	27	%
Clay	22	%
Textural class	Sandy clay loam	
$pH_{(water)}$	8.7	
Electrical conductivity	3	dS m^{-1}
Nitrogen (total)	0.8	mg kg^{-1}
Phosphorus (available)	7.23	mg kg^{-1}
Potassium (extractable)	97	mg kg^{-1}

2.2 Experimental Design

The experiment was laid out in pots forming completely randomized design (CRD) with two factorial arrangements. Pots used in the experiment were made up of plastic (diameter: 25 cm × height: 30 cm). We used three levels of soil salinity: 3 dS m^{-1}, 6 dS m^{-1} and 9 dS m^{-1}. The lowest level, 3 dS m^{-1}, is the salinity of original soil whereas other two levels, 6 dS m^{-1} and 9 dS m^{-1}, were induced by addition of

NaCl salt (detail is given below). We used three types of bacterial strains of plant growth-promoting rhizobacteria (PGPR): W10 (*Serratia ficaria*), W14 (*Pesudomonas fluorescens*) and 6K as well as their combination at each salinity level. A total of 24 treatments were designed: [salinity: 3 levels (3, 6 and 9 dSm^{-1}) × bacterial strains: 8 (control, W10, W14, 6K, W14 × W10, W14 × 6K, W10 × 6K and W14 × W10 × 6K) = 24 treatments]. Each treatment had three replicates. The weight of soil used in each pot was 8 kg.

2.3 Salinity Development in Pots

Salinity of the soil used in the study was 3 dS m^{-1}, and other two levels of salinity (6 dS m^{-1} and 9 dS m^{-1}) were induced using NaCl salt. Salinity was induced by subtracting the normal electrical conductivity (EC) with desired EC of the soil. The 2.81 g NaCl salt was required to induce salinity up to 6 dS m^{-1} for each pot having 8 kg soil, whereas 5.62 g NaCl was required to induce salinity up to 9 dSm^{-1} for each pot having 8 kg soil. The detail calculation of salinity is given below:

Normal EC of soil = 3 dS m^{-1}

Total induced salinity up to 6 dS m^{-1} = 6 - 3 = 3 dS m^{-1}

We know that total soluble salts (TSS) = 10 × EC

Hence, TSS = 10 × 3 = 30 meq L^{-1}

Molar weight of NaCl = 58.5 g

TSS = 30 × 58.5 = 1775 mg L^{-1}

Soluble percentage (SP) = 20%

SP = 20/100×1775 = 351 mg kg^{-1}

For conversion of mg into g we can divide by 1000

SP = 355/1000 = 0.351 g kg^{-1}

Salt required to induce salinity up to 6 dS m^{-1} for each pot having 8 kg soil = 0.351 × 8 = 2.81 g NaCl. Similarly, 5.62 g NaCl was required to induce salinity up to 9 dS m^{-1} for each pot having 8 kg soil.

2.4 Plant Cultivation

Pure inoculums of bacterial strains were applied on seeds of wheat (*Triticum aestivum* L., cultivar: FSD-2008) and then coated with standard carrier material (peat). Twenty seeds were sown manually per pot. After proper germination, number of seedlings was decreased up to 5 plants per pot.

Nitrogen (N), phosphorus (P) and potassium (K) were applied to each pot at 140, 100 and 60 kg ha^{-1} using urea, diammonium phosphate and sulphate of potash, respectively. All P and K were applied at sowing time and N was applied in two split doses, first at tillering and second at booting stage. Experiment was conducted in a wire-house at research farm of BZU, Multan, Pakistan under natural climatic conditions (sub-tropical to semi-arid).

2.5 Plant Analysis

Wheat crop was harvested at the maturity. Plants height, spike length and root length were measured using scale of meter rod. Root and shoot portions were separated from uprooted wheat plants and put into small brown paper bags. The roots and shoots were oven dried at 70ºC till constant dry weight was obtained and dry weight (g) was weighed on digital weight balance. Total number of spikelets per plant including mother plant spike were counted. In each spikelet, one or more than one grains were collected. Data was recorded after computing the average. The grains of each spike were threshed manually to record numbers of grains per spike. Randomly, 1000 seeds were taken from each treatment and weighed on an electrical weighed balance. Grain yield was measured after separating total grains from spikes. Grain yield (economical yield) was measured in gram. After separating grains by manual threshing, the remaining straw was weighed in grams. Numbers of tillers were counted after uprooting the plant from

pots. Biological yield was measured by taking into account the weight of whole plant including root, shoot and spike.

Nitrogen, phosphorus and potassium were determined after wet digestion of plant samples (grains and shoot). Kjeldhal's apparatus was used for determination of nitrogen content in plant (grains and shoot) [15]. Olsen's method was used for phosphorus determination by Spectrophotometer (HITACHI U-2000) at 610 nm wavelength [16]. Potassium was determined by using Jenway PFP-7 flame photometer [15].

2.6 Statistical Analysis

The collected data were analyzed for analysis of variance to determine the significance of treatment by using complete randomized design (CRD) having two factorial arrangements of analysis of variance (ANOVA) technique. The treatment means were compared by CRD two factorial tests at 0.05% probability level [17].

3 Results

3.1 Root Length and Dry Root Weight

PGPR inoculation significantly ($p < 0.001$) affected root length and dry root weight of wheat plants. The inoculation of PGPR markedly increased length and dry weight of root and the multi-strain inoculation of W14 × W10 × 6K showed highest effects as compared to the other treatments particularly the control (Tab. 2). Soil salinity also significantly ($p < 0.001$) affected root of wheat; length and weight of root decreased with increasing level of salinity. The shortest root length and lowest dry weight was observed at EC 9 dS m^{-1}. However, the W14 × W10 × 6K treatment relative to any PGPR treatment showed best results for root length (11 cm) and dry root weight (0.52 g) at EC 3 dS m^{-1}.

Table 2: Effect of single and consortia of PGPR on root length and root dry weight of wheat cultivated under various levels of salinity

Treatments	Root Length (cm)			Root Dry Weight (g)		
	Various Levels of EC (dS m^{-1})					
	3	6	9	3	6	9
Control	6.42 l	6.03 m	5.59 n	0.30 j	0.28 j	0.24 l
W10	8.80 cd	7.77 fg	6.49 jk	0.47 b	0.39 ef	0.31 hi
W14	8.53 cd	7.96 f	6.47 jk	0.44 c	0.40 de	0.32 gh
6K	8.93 c	8.13 ef	6.60 hij	0.46 bc	0.40 de	0.32 gh
W14 × W10	10.47 ab	8.49 de	7.03 ghi	0.51 a	0.42 cd	0.37 ef
W14 × 6K	9.33 bc	8.20 ef	6.60 hi	0.50 ab	0.41 cd	0.35 fg
W10 × 6K	9.87 b	8.42 de	6.97 h	0.48 b	0.41 cd	0.35 fg
W14 × W10 × 6K	11.0 a	8.58 d	7.10 gh	0.52 a	0.43 c	0.39 ef

Different letters denote significant deference ($p \leq 0.05$) between treatments.

3.2 Shoot Length and Dry Shoot Weight

Shoot length and dry shoot weight of wheat were significantly ($p < 0.001$) affected by PGPR and salinity levels. The soil salinity exerted decreasing effect on the plant height (shoot length) and dry shoot weight, and therefore the shortest plants (38 cm) and lowest dry shoot weight (0.54 g) was observed in EC 9 dS m^{-1} treatment (Figs. 1 and 2). The PGPR inoculation markedly increased both shoot length and dry shoot weight when compared to the control (Fig. 1 and 2). The maximum plant height and dry shoot weight were 75.5 cm and 1.13 g, respectively in the W14 × W10 × 6K treatment at EC 3 dS m^{-1}.

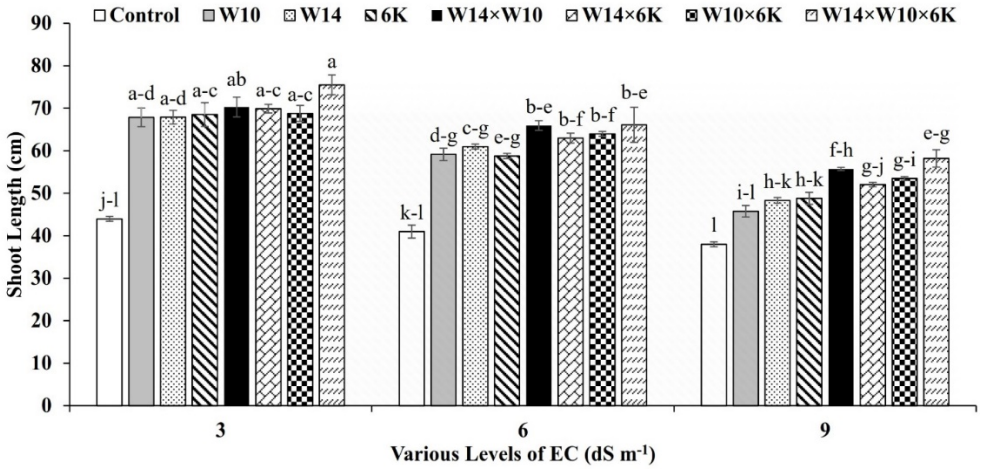

Figure 1: Effect of single and consortia inoculation of PGPR on shoot length of wheat cultivated under various levels of salinity. Different letters denote significant difference ($p \leq 0.05$). Vertical bars indicate standard error of means

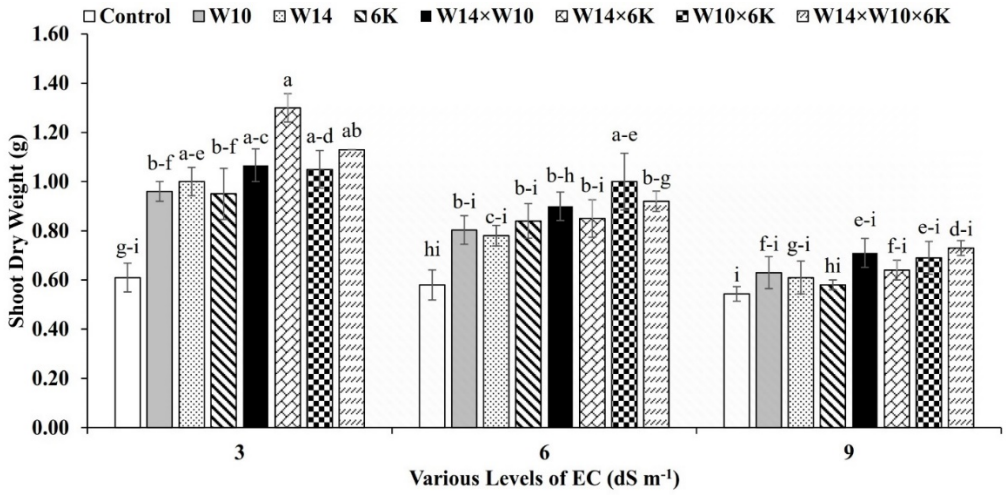

Figure 2: Effect of single and consortia inoculation of PGPR on shoot dry weight of wheat cultivated under various levels of salinity. Different letters denote significant difference ($p \leq 0.05$). Vertical bars indicate standard error of means

3.3 Spike Length and Number of Spikelets

There were significant ($p < 0.001$) effects of PGPR inoculation and salinity on the spike length and number of spikelets. Spike length decreased considerably with increasing salinity levels and thus minimum spike length was 4.92 in EC 9 dS m^{-1} treatment (Fig. 3). The PGPR obviously increased spike length and the maximum spike length (11 cm) was obtained in the W14 × W10 × 6K the treatment at EC 3 dS m^{-1}. In case of number of spikelets per spike, soil salinity significantly decreased number of spikelets and minimum number of spikelets (7.53 cm) were found at EC 9 dS m^{-1} (Tab. 3). Number of spikelets increased with PGPR inoculation and the maximum number of spikelets was14.93 in the W14 × W10 × 6K treatment.

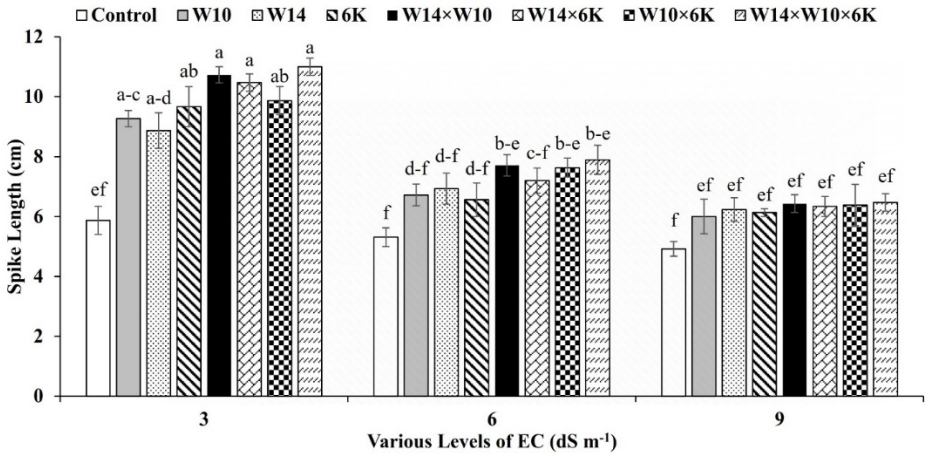

Figure 3: Effect of single and consortia inoculation of PGPR on spike length of wheat cultivated under various levels of salinity. Different letters denote significant difference ($p \leq 0.05$). Vertical bars indicate standard error of means

Table 3: Effect of single and consortia of PGPR on spikelets spike^{-1}, number of grains spike^{-1} and 1000 grains weight of wheat cultivated under various levels of salinity

Treatments	Spikelets spike^{-1}			Number of grains spike^{-1}			1000 grains weight (g)		
	Various Levels of EC (dS m^{-1})								
	3	6	9	3	6	9	3	6	9
Control	8.21 f-h	7.97 gh	7.53 gh	23.8 hi	21.2 ij	17.6 j	22.3 jk	18.0 kl	14.2 l
W10	12.8 a-e	10.1 d-h	8.43 f-h	31.6 c-f	28.1 d-h	23.9 hi	32.0 b-e	29.0 d-h	25.2 h-j
W14	14.1 a-c	10.6 b-g	8.31 f-h	31.9 c-e	28.0 e-h	24.1 hi	35.0 a-c	28.0 e-i	26.0 g-j
6K	14.0 a-d	10.5 c-h	8.97 e-h	31.5 c-f	28.2 d-h	26.3 gh	31.0 c-f	28.9 d-h	24.0 ij
W14 × W10	14.5 ab	12.2 a-f	6.58 h	37.8 ab	30.5 c-g	27.8 e-h	38.3 a	30.4 d-f	28.5 e-h
W14 × 6K	14.2 a-c	11.1 a-g	9.27 e-h	33.0 b-d	29.9 c-g	27.7 e-h	36.0 ab	29.6 d-g	27.1 f-i
W10 × 6K	14.3 a-c	11.4 a-g	9.38 e-h	33.5 bc	30.1 c-g	26.7 f-h	33.0 b-d	29.3 d-h	28.0 e-i
W14 × W10 × 6K	14.39 a	12.5 a-e	9.77 e-h	40.3 a	31.0 c-g	27.9 e-h	38.3 a	30.7 c-f	28.7 e-h

Different letters denote significant deference ($p \leq 0.05$) between treatments.

3.4 Number of Grains and Weight of 1000 Grain

Soil salinity and PGPR inoculation significantly ($p < 0.001$) influenced the number of grains and 1000 grain weight. Soil salinity noticeably decreased the number of grains and 1000 grain weight with the increasing level of EC (Tab. 3). The minimum number of grains per spike and 1000 grain weight were observed in the treatment with EC 9 dS m^{-1}. The inoculation of PGPR substantially increased the number of grains and 1000 grain weight and the maximum number of grains and 1000 grain weight were found in the W14 × W10 × 6K at EC level of 3 dS m^{-1} (Tab. 3).

3.5 Number of Tillers and Biological Yield

Soil salinity and PGPR inoculation had significant ($p < 0.001$) effects on number of tillers per plant and biological yield per pot. Number of tillers and biological yield decreased with increasing soil salinity level and minimum number of tillers and lowest biological yield were 2.88 per plant and 89.9 g per pot, respectively in the EC 9 dS m^{-1} treatment (Figs. 4 and 5). Whereas number of tillers and biological yield were increased by the PGPR inoculation and the maximum number of tillers were 4.73 per plant and the maximum biological yield was 200.19 per pot obtained in the W14 × W10 × 6K treatment at EC dS m^{-1} (Figs. 4 and 5).

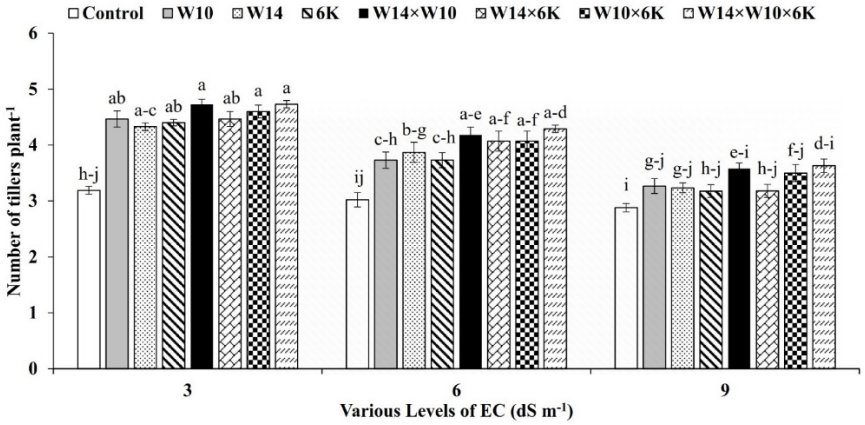

Figure 4: Effect of single and consortia inoculation of PGPR on number of tillers $plant^{-1}$ of wheat cultivated under various levels of salinity. Different letters denote significant difference ($p \leq 0.05$). Vertical bars indicate standard error of means

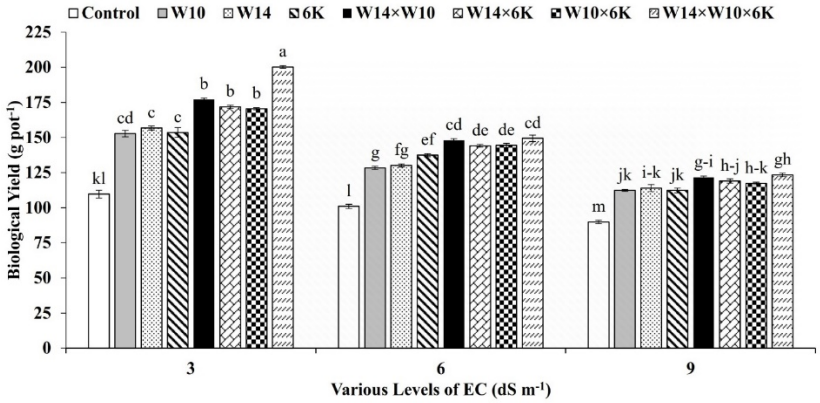

Figure 5: Effect of single and consortia inoculation of PGPR on biological yield of wheat cultivated under various levels of salinity. Different letters denote significant difference ($p \leq 0.05$). Vertical bars indicate standard error of means

3.6 Economical Yield and Straw Yield

Economical and straw yield of wheat were significantly ($p < 0.001$) affected by soil salinity and PGPR inoculation. Soil salinity noticeably decreased both economical and straw yield, and thus minimum economical and straw yield were 38 and 58 g per pot, respectively in the EC 9 dS m^{-1} treatment (Figs. 6 and 7). The maximum economical and straw yields were 88 and 111.67 g per pot, respectively in the W14 × W10 × 6K treatment.

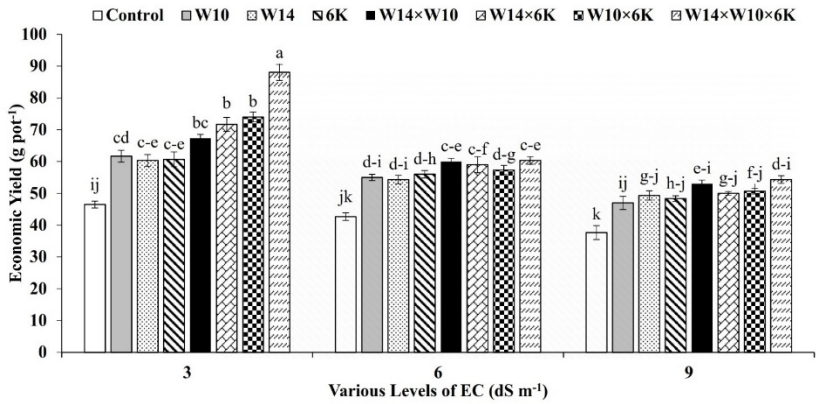

Figure 6: Effect of single and consortia inoculation of PGPR on economic yield of wheat cultivated under various levels of salinity. Different letters denote significant difference ($p \leq 0.05$). Vertical bars indicate standard error of means

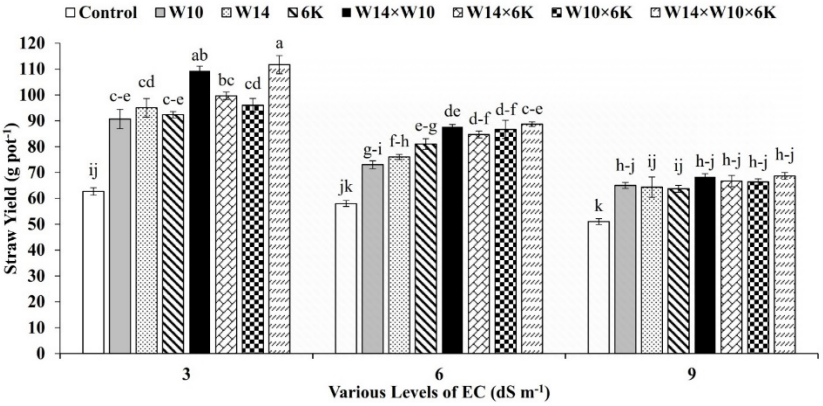

Figure 7: Effect of single and consortia inoculation of PGPR on straw yield of wheat cultivated under various levels of salinity. Different letters denote significant difference ($p \leq 0.05$). Vertical bars indicate standard error of means

3.7 Nitrogen, phosphorus and potassium contents in grains and shoot

The N, P and K contents in both grains and shoots were significantly ($p < 0.001$) influenced by soil salinity and PGPR inoculation. Lower contents of N, P and K were found in the higher levels of soil salinity (Tab. 4). The smallest contents of N, P and K in both grains and shoot were found at EC 9 dS m^{-1}. However, PGPR increased N, P and K contents in grains and shoots, and the maximum were in the W14 × W10 × 6K treatment (Tab. 4).

Table 4: Effect of single and consortia inoculation of PGPR on nitrogen, phosphorus and potassium concentration of wheat shoot and grain cultivated under various levels of salinity

Treatments	Shoot Nitrogen (%)			Shoot Phosphorus (%)			Shoot Potassium (%)		
	Various Levels of EC (dS m^{-1})								
	3	6	9	3	6	9	3	6	9
Control	1.32 o	1.21 p	1.16 p	0.17 k-m	0.14 lm	0.11 m	0.77 l	0.76 m	0.73 n
W10	1.75 de	1.61 gh	1.35 no	0.44 a-d	0.34 d-g	0.19 j-m	0.86 cd	0.82 gh	0.78 k
W14	1.80 cd	1.58 hi	1.38 n	0.46 a-c	0.31 e-i	0.22 h-m	0.86 cd	0.82 gh	0.79 ijk
6K	1.84 c	1.56 ij	1.40 mn	0.48 ab	0.33 d-h	0.21 i-m	0.87 bcd	0.81 hi	0.78 k

W14 × W10	1.92 b	1.70 ef	1.48 kl	0.53 a	0.36 c-f	0.23 g-l	0.89 ab	0.85 def	0.81 hi
W14 × 6K	1.94 b	1.62 gh	1.49 kl	0.52 a	0.39 b-e	0.26 f-k	0.88 bc	0.83 fg	0.80 ij
W10 × 6K	1.90 b	1.66 fg	1.50 lm	0.50 ab	0.40 b-e	0.25 f-l	0.88 bc	0.84 efg	0.80 ij
W14 × W10 × 6K	1.99 a	1.74 e	1.52 jk	0.54 a	0.43 a-d	0.29 e-j	0.90 a	0.85 de	0.81 hi
Treatments	**Grain Nitrogen (%)**			**Grain Phosphorus (%)**			**Grain Potassium (%)**		
Control	1.70 o	1.54 p	1.36 q	0.33 p	0.28 q	0.22 r	1.36 s	1.31 t	1.25 u
W10	2.66 d	2.30 i	1.94 lm	0.70 de	0.55 ij	0.44 mn	1.66 fg	1.55 lm	1.41 r
W14	2.60 e	2.44 gh	1.80 mn	0.74 c	0.60 gh	0.40 o	1.68 ef	1.57 kl	1.44 pq
6K	2.62 de	2.60 h	1.90 m	0.72 cd	0.57 hi	0.42 no	1.70 de	1.54 m	1.42 qr
W14 × W10	2.76 bc	2.50 f	2.16 k	0.83 a	0.64 fg	0.49 kl	1.72 d	1.62 hi	1.46 op
W14 × 6K	2.81 ab	2.53 f	2.09 l	0.76 bc	0.66 f	0.46 lm	1.78 b	1.60 ij	1.48 o
W10 × 6K	2.72 c	2.48 fg	2.18 k	0.79 b	0.62 g	0.47 lm	1.75 c	1.59 jk	1.46 op
W14 × W10 × 6K	2.84 a	2.61 de	2.24 ij	0.85 a	0.67 ef	0.52 jk	1.81 a	1.64 gh	1.51 n

Different letters denote significant deference ($p \leq 0.05$) between treatments.

4 Discussion

The inoculation of wheat seeds with selected strains of PGPR substantially improved growth and yield of wheat. Results of the present study are in accord with the findings of Dobbelaere et al. [18] as they revealed that inoculation of PGPR (*Azospirillum brasilense*) promoted the growth of spring wheat in terms of enhancing seed germination, improving vegetative and floral parts as well as increasing dry weight of both root and shoots. Previous studies have revealed that inoculation of PGPR promoted plant growth attributes including plant height, root and shoot dry weight, number of tillers, and yields of various crops [19,20]. Plant growth-promoting rhizobacteria (PGPR) inhabit plant roots and thereby enhance the plant growth [10]. In case of our present study, the inoculation of multi-strain of PGPR performed best for promoting wheat growth.

The underlying mechanism of PGPR for promoting plant growth involves in the increased nutrient cycling, reduced pathogens either producing siderophores and antibiotics or plant hormones such as ethylene. The concentration of ethylene, a key stress hormone, is increased in response to salinity stress by elevated levels of its precursor 1-aminocyclopropane-1-carboxylic acid (ACC), resulting in physiological alterations in plant tissues [21]. Higher level of ethylene biosynthesis in plants under environmental stress is one of the main causes of decrease in metabolic, biochemical processes in plants leading to declines in plant growth and yield [22,23]. The plant growth promoting rhizobacteria (PGPR) are capable to alleviate stress on roots of plants [7]. The PGPR having ability to produce 1-aminocyclopropane-1-carboxylate deaminase (ACC deaminase) can be used as an efficient amendment in reducing the stress ethylene accumulation in plants [24]. The ACC deaminase breaks the ethylene precursor, 1-aminocyclopropane-1-carboxylic acid (ACC) into α-ketobutyrate and NH_3 [22,25]. Sergeeva et al. [26] reported that PGPR under salinity stress might promote the ACC-deaminase activity and were able to metabolize ACC, a precursor of ethylene which produced in response to stress. The PGPR might reduce the ethylene content and consequently eliminate damage caused by high concentration of ethylene due to salt stress.

In the present experiment, the increased wheat production was primarily because of the PGPR inoculation that contains ACC-deaminase which could reduce salt stress by regulating the endogenous levels of ethylene in plants through their ACC-deamine activity [26]. Shaharoona et al. [27] reported that bacterial inoculation showed improvement in root length, spike length and plant height at different salinity levels as compared to the control. Príncipe et al. [28] documented that inoculation of PGPR multi-strains showed better performance as compared to single strain inoculation and showed positive effect on growth and yield of plant. Moreover, PGPR strains containing ACC-deaminase activity have the ability to hydrolyze the ACC; therefore, they eliminated the negative effect of high ethylene concentration on plant growth [28].

The inoculation of PGPR also increased nutrient contents in wheat. Results of increased nutrients in wheat by PGPR inoculation are supported by previous studies. Wu et al. [29] reported that PGPR presence showed positive effect on nitrogen and phosphorus concentration. Vivas et al. [30] demonstrated that nitrogen, phosphorus and potassium contents in lettuce inoculated with *Bacillus* sp., were increased under salinity stress as compared to un-inoculated control. It appeared that PGPR inoculation substantially increased nutrients in wheat plant which led to increased plant growth of wheat.

The PGPR were inoculated on seeds prior sowing which could efficiently promote germination. Rapid and healthy seed germination is primary stage of obtaining vigorous crop production. Early seedling growth is the critical developmental stage that has been identified the most sensitive to soil salinity [31]. Therefore, significant increase in wheat growth and yield might be associated with improved plant attributes, which was likely accomplished by alleviation of salt stress to seed germination through PGPR inoculation [32].

5 Conclusions

The results indicated that PGPR strains showed positive effect on wheat (growth and yield attributes) at all studied salinity levels. The W14 × W10 × 6K (multi strain inoculation) was the most effective treatment for alleviating salinity stress and improving wheat growth. Further research is suggested to investigate various PGPR strains for improving different crops under various soil stress conditions.

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