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Alleviation of salt stress in lettuce (*Lactuca sativa* L.) by plant growth-promoting rhizobacteria

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ABSTRACT

Purpose: The effect of *Pseudomonas* sp. rhizobacteria as plant growth-promoting rhizobacteria (PGPR) in alleviating salt stress in the lettuce plant was studied under greenhouse condition. **Research Method**: The experiment was conducted following a completely randomized design with three replicates. The treatments include four *Pseudomonas sp.* strains (B_0 (non-inoculated), B_1, B_2 and B_3) as PGPR and three levels of irrigation water salinity (0, 4 and 8 dS m^{-1} as NaCl). **Findings**: The results showed that with rising salinity levels the lettuce fresh and dry weight, chlorophyll and carotenoids content and K concentration decreased but, the content of membrane stability index (MSI), Na and Na/K ratio increased. However, inoculation of the lettuce plants by PGPR significantly increased the lettuce fresh and dry weight, chlorophyll and carotenoids content, K concentration and K/Na ratio under various salinity levels. Among the PGPR strain, the B_2 strain was more effective in the improvement of the lettuce resistance to salinity stress. **Research limitations**: If antioxidant compounds and enzymes were measured in this study, it would be helpful to interpret the results. **Originality/Value**: with regards to the useful impact of the PGPR on the lettuce plant under soil salinity, these microorganisms can be used as biofertilizer to provide nutrients and increase plant resistance to salt stress.

INTRODUCTION

Lettuce (*Lactuca sativa* L.), one year-old leafy vegetable, is a product of the cold season belonging to the Asteraceae family and is mainly used for fresh and salad applications (Labeda et al., 2007). Its production and cultivation area in recent years has been increasing due to marketability, medicinal properties and having various vitamins. This plant contains various vitamins such as A, C, B_9 and K, as well as minerals such as calcium, phosphorus, potassium, manganese and iron and also plays an important role in food digestion due to its high cellulose content. Lettuce is a rich source of antioxidants among vegetables (Rubatzky & Yamaguchi, 1997).

Salt stress is one of the most widespread environmental concerns that restricted plant growth and function, especially in arid and semi-arid regions. About 2000 ha of arable land around the world are losing their productivity daily due to salinization. Salt stress in many crops reduces yield by 10-25% (Shahid et al., 2018). Due to Iran's arid climate, a large part of agricultural soils in Iran are facing salinity. Irrigation with groundwater containing high concentrations of soluble salts, poor soil management, excessive use of chemical fertilizers and salt build-up soils are the main causes of increasing salinity in agricultural soils. Under salinity stress, plant growth is reduced due to the accumulation of toxic levels of sodium and chloride, reducing the osmotic potential of water and decreasing nutrient uptake (Azarmi et al., 2016). With increasing salinity, fresh and dry weight of shoot and root of plant decreased. Salinity also damages the stomata, reduces photosynthetic pigments and photosynthesis and thus reduces leaf growth rate (Sadak et al., 2010). Lettuce is a moderately salt-sensitive plant with a threshold electrical conductivity (EC) of 1.3 $dS.m^{-1}$ that salinity stress negatively affects its growth and yield (Fernandez et al., 2016). Also, Unlukara et al. (2008) reported that with increasing salinity of irrigation water (0.75, 1.5, 2.5, 3.5, 5.0 and 7.0 $dS.m^{-1}$) yield, leaf number per plant, plant height and accumulation of Ca and Fe in the leaves reduced, whereas plant dray matter increased.

Plant growth promoting rhizobacteria (PGPR) are a group of rhizosphere bacteria that promote plant growth by various mechanisms including biological nitrogen fixation, phosphate solubilization, production of siderofore, cyanide hydrogen HCN and phytohormones and production of 1-Aminocyclopropane-1- carboxylate (ACC) deaminase (Abbas-Zadeh et al., 2010). The use of PGPR with the ability to survive and function in saline conditions is one of the new strategies to increase plant tolerance to environmental stresses such as salinity (Egamberdieva & Kucharova, 2009). These rhizobacteria can increase plant tolerance to salt stress by developing plant root system, increasing nutrient uptake, improving soil structure, increasing water holding capacity, reducing Na uptake and increasing expression of genes responsible for resistance to environmental stresses (Karlidag et al., 2007). The most important mechanism used by rhizosphere bacteria to reduce salinity in plants is the production of ACC deaminase. The ACC-deaminase enzyme converts the root ACC into α-ketobutyrate and ammonia, thereby reducing the amount of stress ethylene production and damage to the plants (Glick et al., 1998). The *Pseudomonas* genus, one of the most important rhizosphere bacteria, is able to survive and colonize plant roots in saline and arid soils (Paul & Nair, 2008). These rhizobacteria play a vital role in increasing soil fertility and reducing salinity stress in the plant because of producing a wide range of different compounds and stimulating plant growth in saline soils (Mishra et al., 2010). Inoculation of tomato seedlings with PGPR significantly increased the fresh and dry weights, the uptake of P and K and water use efficiency in comparison with the control under salinity stress (Mayak et al., 2004). Also, Khosravi et al. (2018) reported that the use of *Pseudomonas fluorescens* bacterium enhanced shoot dry matter and uptake of different nutrients in lettuce. In another study, the use of PGPR increased lettuce germination at different NaCl levels (Hussein & Joo, 2018).

A large part of Iran's agricultural soils is exposed to various degrees of salinity due to different reasons including low precipitation, high evaporation, the salinity of irrigation water, poor soil management an excessive use of chemical fertilizers. Furthermore, the salinized areas are expanding every year. Also, the fertility and nutrient balance of Iranian agricultural soils is low. Therefore, due to the importance of lettuce in human nutrition and its relatively high sensitivity to salinity, the aim of this study was to investigate the role of PGPR on the growth and yield of lettuce at different salinity levels.

MATERIALS AND METHODS

Preparation of PGPR

In this study, *Pseudomonas sp.* bacteria were used as PGPR. These bacteria had previously been isolated from saline soils and their plant growth promoting activities were measured. After culturing bacteria on the King's B medium, they were grown on a nutrient broth (NB) medium in a shaker at 25 ºC for 48 hours. The *Pseudomonas sp.* strains were able to solubilize phosphorus ($Ca_3 (PO_4)_2$) and also to produce siderophore, auxins, HCN and ACC-deaminase in the lab (Data not shown).

Plant materials and experimental design

A greenhouse experiment was carried out as a factorial arrangement of four *Pseudomonas sp.* strains (B_0 (non-inoculated), B_1, B_2 and B_3) and three levels of irrigation water salinity (0, 4 and 8 $dS.m^{-1}$ as NaCl) in a completely randomized design with three replications. The soil sample was air-dried, crushed to pass through a 2-mm sieve and mixed thoroughly. Selected physical and chemical properties (Table1) of the soil used in this experiment were measured based on standard methods (Sparks, 1996). Six lettuce (*Lactuca sativa* cv. Ferdos) seeds were placed in each pot containing 3 kg of homogeneous soil. For inoculation, each lettuce seed was treated with bacterial suspensions (500 µL for each seed with CFU =10^8 $cell.mL^{-1}$). After germination, the number of plant was reduced to two in each pot and irrigated with distilled water for a period of 30 days. During the experiment period (50 days), the greenhouse temperature was 28±2 ºC on day and 19±2 ºC on night, and the relative humidity was 45%. The pots were irrigated with salt water prepared from NaCl based on the treatments (0, 4 and 8 $dS.m^{-1}$) to maintain the soil at field capacity until the harvest.

Table 1. Some physical and chemical properties of the used soil

Texture	pH	EC	OM	P_{av}	K_{av}	Na_s	Mg_s	Ca_s	Cl_s
		$dS.m^{-1}$	%	$mg.kg^{-1}$	$mg.kg^{-1}$	$mg.L^{-1}$	$mg.L^{-1}$	$mg.L^{-1}$	$mg.L^{-1}$
Sandy loam	7.8	1.7	0.65	8.52	184	167	108	126	96

OM: Organic matter, av: Available forms of nutrient in the soil, s: Soluble forms of nutrient in the saturated soil solution.

Plant analysis

Ten weeks after planting, the aerial parts of lettuce were collected and their fresh weights were recorded. Plant was dried at 70 ºC for 48 hours in the oven, shoot dry weight was recorded and then ground into powder for chemical analysis. The ground plant samples were dry-ashed at 500 °C and digested with 2 N HCl (Chapman & Pratt, 1961). Concentrations of K and Na in the lettuce shoot were measured by flame photometer. For the measurement of membrane stability index (MSI), the electrical conductivity of leaf leakage was recorded in deionized water at 40 °C and 100 °C (Sairam et al., 2002). In order to determine chlorophyll (Porra, 2002) and carotenoids (Lichtenthaler & Wellburn, 1983), the leaf sample was ground in acetone, centrifuged and then absorbance was measured in the supernatant using a spectrophotometer.

Statistical analysis

Experimental data were subjected to statistical analyses using ANOVA procedure and means were separated by least significant difference (LSD) at 5% level of significance using the SAS software.

RESULTS AND DISCUSSION

Shoot fresh and dry weight

The analysis of variance indicated that PGPR, salinity and PGPR × salinity interaction had a significant effect ($p \leq 0.05$) on the shoot fresh and dry weight (Table 2).

The results showed that salt stress significantly reduced shoot fresh and dry weight of the lettuce (Table 3). Salt stress and deficiency of nutrient cause different physiological changes in the plants such as ions toxicity including Na and Cl, destruction of cellular structure, decrease in the growth and yields and nutritional imbalances due to reduction in uptake and/or shoot transport. The increase of salt stress to 4 and 8 $dS.m^{-1}$, reduced shoot fresh weight by 20% and 39% compared to the control, respectively. At these salinity values, dry weight was decreased by 18 and 46% in comparison with the control, respectively. Plant growth inhibition is a common response to salinity stress. Decrease in growth factors under salt stress may be related to the rise of osmotic pressure, deficiency of nutrients and damage to some physiological mechanisms (Alqarawi et al., 2014). According to the results, inoculation with the PGPR increased shoot fresh and dry weight of lettuce (Table 3). The growth promoting ability of inoculated plants by rhizobacteria may be attributed to its ability to solubilize inorganic P compounds, having ACC-deaminase activity and production of the IAA and siderophore. The ACC-deaminase enzyme produced by the PGPR plays a key role in increasing the plant's resistance to environmental stress (Saleem et al., 2007). The results indicated that the application of B_1, B_2 and B_3 rhizobacteria significantly increased shoot fresh weight by 14, 26 and 17% in comparison with the control at non-saline conditions. In saline conditions, only B_2 strain was effective on the lettuce fresh weight. Inoculation with B_2 strain at 4 and 8$dS.m^{-1}$ significantly increased lettuce fresh weight by 14 and 12% as compared to the same salinity levels, respectively. PGPR can reduce salinity stress in plants by different mechanisms such as production of auxin. Pretreatment of the wheat plant by auxin increased plant metabolism under salt stress conditions (Iqbal & Ashraf, 2013). Also, Ali et al. (2014) reported that the use of ACC-deaminase containing PGPR significantly enhanced the fresh and dry weight and chlorophyll content in the salt-stressed tomato plant. The B_1 rhizobacteria had no significant effect on the shoot dry weight of lettuce at any salinity levels. However, treatment with B_2 and B_3 strains drastically increased shoot dry weight by 46 and 25% under non-saline conditions, respectively. Also, the use of B_2 strain at 4 and 8 $dS.m^{-1}$ significantly increased lettuce dry weight by 25 and 38% compared with the same salinity levels, respectively (Table 3). The synthesis of auxin by PGPR may promote plant growth directly by provoking plant cell division or indirectly by affecting bacterial ACC-deaminase activity (Patten & Glick, 2002). The increase in plant growth with PGPR use has been reported by several researchers. Zahir et al. (2008) indicated that the biomass of plants treated by *Pseudomonas putid* and *Pseudomonas fluorescens* increased. Also, Cipriano et al. (2016) reported that the use of *Pseudomonas* strains increased biomass yields of the lettuce plant up to 30%.

Table 2. Analysis of variance (mean of square) of measured traits

SOV	df	ShFW	ShDW	Chl. a	Chl. b	Total Chl.	Chl. a/b	Cart.	MSI	Na	K	K/Na
PGPR	3	1529^{**}	81.7^{**}	0.050^{**}	0.023^{**}	0.129^{**}	0.029^{**}	0.021^{**}	128^{**}	0.013^{**}	0.279^{**}	53.5^{**}
Salinity	2	32742^{**}	558^{**}	0.145^{**}	0.067^{**}	0.343^{**}	0.164^{**}	0.158^{**}	1002^{**}	0.158^{**}	1.51^{**}	478^{**}
PGPR × Salinity	6	215^{*}	8.12^{*}	0.007^{*}	0.002^{*}	0.016^{**}	0.002^{ns}	0.001^{ns}	13.1^{*}	0.002^{*}	0.025^{*}	7.46^{*}
Error	24	84.6	3.13	0.003	0.001	0.004	0.006	0.007	5.09	0.001	0.009	2.58
CV		5.13	8.15	3.84	3.50	3.11	4.65	7.10	4.30	9.46	4.35	15.1

SOV: Source of Variation; ShFW: Shoot Fresh Weight; ShDW: Shoot Dry Weight; Chl: Chlorophyll; Cart: Carotenoids; MSI: Membrane Stability Index.

Table 3. The effect of PGPR × Salinity interaction on the fresh weight, dry weight and Na and K concentration in the lettuce shoot

PGPR	Salinity ($dS.m^{-1}$)			Salinity ($dS.m^{-1}$)		
	0	4	8	0	4	8
	Shoot fresh weight ($g.pot^{-1}$)			Shoot dry weight ($g.pot^{-1}$)		
B_0	209^{c}	168^{e}	127^{g}	23.7^{cde}	19.5^{fg}	12.8^{i}
B_1	238^{b}	175^{e}	131^{fg}	25.8^{c}	21.1^{ef}	14.0^{i}
B_2	264^{a}	192^{d}	144^{f}	34.8^{a}	24.3^{cd}	17.8^{gh}
B_3	244^{b}	179^{de}	136^{fg}	29.6^{b}	22.3^{def}	13.9^{hi}
	Na concentration (%)			K concentration (%)		
B_0	0.17^{gh}	0.28^{cd}	0.46^{a}	2.26^{c}	2.06^{d}	1.71^{e}
B_1	0.16^{ghi}	0.25^{de}	0.39^{b}	2.54^{b}	2.14^{cd}	1.79^{e}
B_2	0.13^{i}	0.20^{fg}	0.31^{c}	2.89^{a}	2.28^{c}	2.12^{cd}
B_3	0.15^{hi}	0.23^{ef}	0.36^{b}	2.61^{b}	2.21^{cd}	1.87^{e}

B: *Pseudomonas sp.* Strains. For each parameter, values having a common letter are not significantly different ($p \le 0.05$) according to LSD test.

Chlorophyll and carotenoids content

According to the analysis of variance, PGPR, salinity and PGPR × salinity interaction had significant effects on the total chlorophyll, chlorophyll a and b content in the lettuce leaves. Also, only the carotenoids concentration and chlorophyll a/b were affected by simple effect of PGPR inoculation and salinity treatments (Table 2).

The concentration of total chlorophyll, chlorophyll a and chlorophyll b in the lettuce were reduced with the rising salinity levels (Table 4). Chlorophyll content in the stressed plants is an important parameter to predict plant's health and photosynthesis capacity under salt stress. The results showed that the content of total chlorophyll and chlorophyll b at 8 $dS.m^{-1}$ salinity level significantly reduced by 9 and 11% as compared to the control, respectively. Decrease in the concentration of chlorophyll under salt stress might also be due to the impaired biosynthesis or accelerated degradation of pigment. However, inoculation with PGPR increased chlorophyll content in the lettuce. The concentration of chlorophyll a in the lettuce inoculated with B_1, B_2 and B_3 rhizobacteria increased by 7, 15 and 23%, respectively under non-saline conditions. Although B_1 and B_2 strains had no effect on the chlorophyll a in saline conditions, but the B_3 strain increased this parameter. Inoculation with B_3 rhizobacteria at 4 and 8 $dS.m^{-1}$ salinity levels increased the chlorophyll a content by 8 and 9% in comparison with the control at the same salinity level, respectively. Also, only B_2 and B_3 strains had significant effects on the chlorophyll b content in saline conditions. According to the results, the concentration of the total chlorophyll in the lettuce plant inoculated by B_1, B_2 and B_3 rhizobacteria under non-saline conditions increased by 8, 18 and 22%, respectively. Also, treatment with B_2 and B_3 strains significantly enhanced the total chlorophyll concentration by 7 and 8% at 4 $dS.m^{-1}$ salinity level and by 8 and 9% at 8 $dS.m^{-1}$ salinity level. The B_1 strain had no significant effect on this parameter under saline conditions (Table 4). The results revealed that salt stress at low level (4 $dS.m^{-1}$) increased chlorophyll a/b by 15%, but at high level (8 $dS.m^{-1}$) had no significant effect on this ratio (Fig. 1B). In the plants grown under saline conditions, the chlorophyll b can be transformed into chlorophyll a, therefore resulting in the increased content of chlorophyll a (Eckardt, 2009). However, the effect of PGPR on this ratio was different. The B_2 strain reduced chlorophyll a/b by 15%, but B_1 and B_3 strains had no significant effect on this parameter (Fig. 1A). Also, the content of carotenoids at 8 $dS.m^{-1}$ salinity level decreased by 14% in comparison with the control (Fig. 2B). Among the PGPR, only the B_3 had significant effect on the carotenoids content. Inoculation by B_3 rhizobacteria enhanced this parameter by 11% (Fig. 2A).

Table 4. The effect of PGPR×Salinity interaction on the chlorophyll a, b, total chlorophyll and membrane stability index in the lettuce leaves

PGPR	Salinity ($dS.m^{-1}$)			Salinity ($dS.m^{-1}$)		
	0	4	8	0	4	8
	Chlorophyll a ($mg.g^{-1}$ FW)			Chlorophyll b ($mg.g^{-1}$ FW)		
B_0	1.27^{f}	1.37^{cde}	1.18^{g}	0.81^{cde}	0.76^{fg}	0.72^{g}
B_1	1.36^{de}	1.39^{bcd}	1.21^{fg}	0.88^{b}	0.79^{def}	0.76^{fg}
B_2	1.46^{b}	1.45^{bc}	1.23^{fg}	0.99^{a}	0.84^{bc}	0.81^{cde}
B_3	1.56^{a}	1.47^{ab}	1.29^{ef}	0.95^{a}	0.82^{cd}	0.77^{ef}
	Total chlorophyll ($mg.g^{-1}$ FW)			Membrane stability index (%)		
B_0	2.07^{def}	2.13^{cde}	1.89^{g}	54.6^{cd}	51.9^{de}	$37. 1^{g}$
B_1	2.24^{bc}	2.18^{cd}	1.97^{fg}	60.8^{b}	53.0^{cde}	43.1^{f}
B_2	2.45^{a}	2.29^{b}	2.04^{ef}	66.2^{a}	$55. 8^{c}$	49.3^{e}
B_3	2.51^{a}	2.29^{b}	2.06^{ef}	62.6^{ab}	53.5^{cd}	41.9^{f}

B: *Pseudomonas sp.* Strains. For each parameter, values having a common letter are not significantly different ($p \leq 0.05$) according to LSD test.

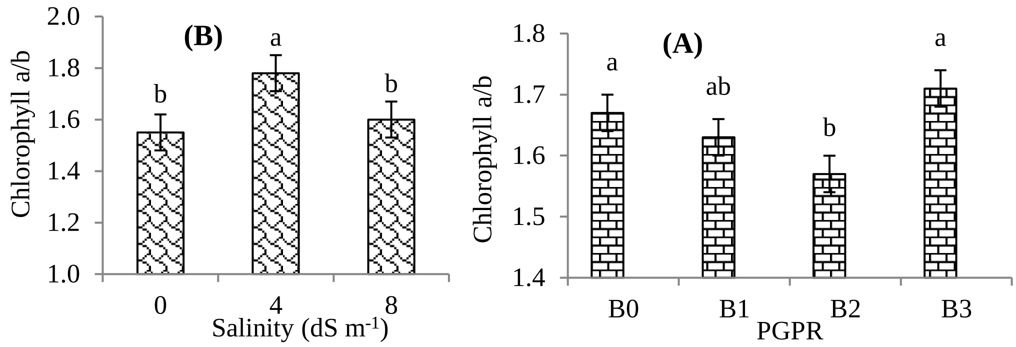

Fig. 1. Main effect of PGPR (A) and salinity (B) on the chlorophyll a/b in the lettuce leaves. Within each graph, values followed by the same letter are not significantly different (p≤0.05) according to LSD test.

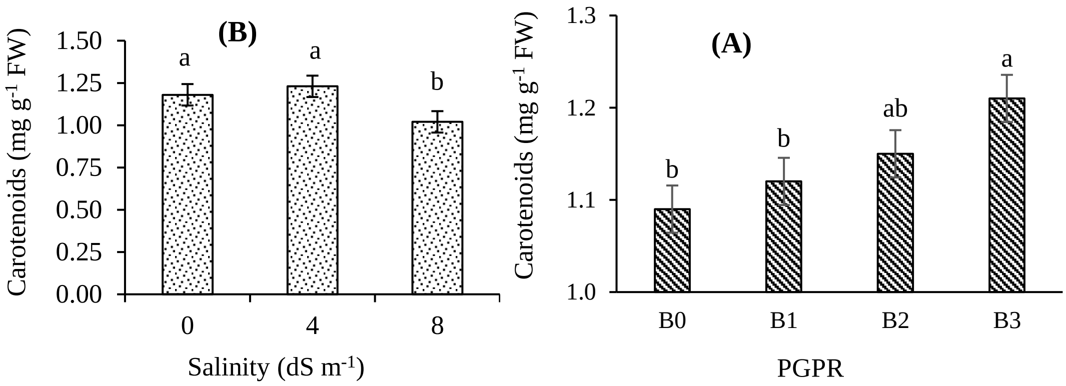

Fig. 2. Main effect of PGPR (A) and salinity (B) on the carotenoids content in the lettuce leaves. Within each graph, values followed by the same letter are not significantly different (p≤0.05) according to LSD test.

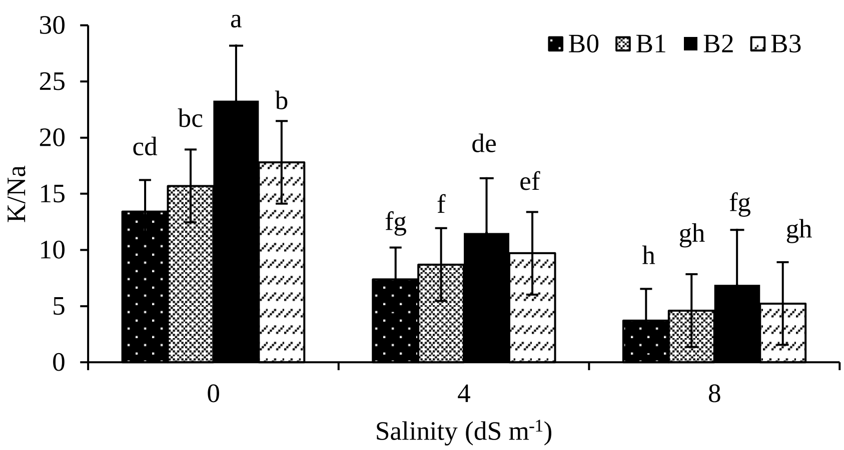

Fig. 3. Interactive effect of PGPR and salinity on the K/Na in the lettuce leaves. Within each graph, values followed by the same letter are not significantly different (p≤0.05) according to LSD test. B: Plant growth promoting rhizobacteria.

Membrane stability index (MSI)

The MSI content in leaf of the lettuce plant was significantly ($p \leq 0.05$) influenced by the PGPR inoculation, salinity levels and interaction of PGPR × salinity (Table 2).

As salinity levels increased, MSI significantly decreased. Salt stress at 8 dS m^{-1} level caused a significant decrease of 32% in the MSI in comparison with the control (Table 4). The negative effects of salinity stress first appear in the cell membranes. Therefore, MSI is an important parameter for plant defense against salinity stress (Farooq & Azam, 2006). Rao et al. (2013) reported that the MSI content in wheat decreased under salt stress. However, inoculation with PGPR significantly increased MSI in the lettuce at various salinity levels. The use of B_1, B_2 and B_3 rhizobacteria at 8 dS.m^{-1} salinity level significantly increased MSI by 16, 33 and 12% as compared to the control at the same salinity level, respectively.

Shoot Na and K concentration

The Na and K concentrations in shoot of the lettuce plants were significantly ($p \leq 0.05$) influenced by the PGPR inoculation, salinity and interaction of PGPR × salinity (Table 2).

As salinity levels increased, shoot Na concentration decreased. The shoot Na content showed 1.65 and 2.70 times increase at 4 and 8 dS.m^{-1} salinity levels, respectively (Table 3). The high concentration of Na in the plant tissues caused osmotic effects, growth inhibition, nutritional imbalance, damage to the membrane, ion toxicity and inhibition of expansion as well as division of the cell (Arzani, 2008). Inoculation with the PGPR reduced Na concentration of shoot in all salt levels. Among the PGPR, the B_2 strain was more effective in reduction of shoot Na. Application of B_1, B_2 and B_3 rhizobacteria drastically reduced shoot Na content by 15, 33 and 22% in comparison with the control at 8 dS.m^{-1} salinity levels, respectively (Table 3). Inoculation of the plant with PGPR can reduce passive flow (apoplasmic) of Na and thus limit the Na uptake by the roots (Ashraf et al., 2004). The results revealed that as salinity levels increased, the shoot K concentration decreased. At the 4 and 8 dS.m^{-1} salinity levels, shoot K content significantly decreased by 9 and 24% as compared to the control, respectively (Table 3). Excessive concentrations of external Na under saline conditions not only compete with K uptake by the roots, but also change root membranes selectivity by disrupting their integrity (Weisany et al., 2014). However, treatment with rhizobacteria increased K content in the lettuce aerial parts. Inoculation of the plant by B_2 strain at 0, 4 and 8 dS.m^{-1} salinity levels significantly increased this parameter by 28, 11 and 24% in comparison with the control respectively. The soil beneficial bacteria play an essential role in plant growth promotion via the bioavailability of nutrients such as P and K in the rhizosphere. The production of organic acids (such as oxalic acid, and citric acid) and protons and thus the reduction of rhizosphere pH is the most important mechanism of PGPR in the solubilization of unavailable forms of mineral (Hariprasad & Niranjana, 2009). Also, previous researches showed that PGPR applications increased some nutrient concentrations such as K in various plants under saline conditions (Karlding et al., 2013; Khosravi et al., 2018).

Shoot K/Na

The analysis of variance indicated that the PGPR, salinity and interaction of PGPR × salinity had a significant effect on the shoot K/Na ratio of the lettuce plant (Table 2).

The results indicated that the shoot K/Na ratio drastically decreased with an increase in the salt rates. So that, the ratio of K/Na at low (4 dS.m^{-1}) and high (8 dS.m^{-1}) levels of salt stress reduced by 44 and 72% compared to the control, respectively (Fig. 3). One of the main responses of the plant to salt stress is the net influx of Na and K outflow, which results in a decrease in the K/Na ratio in plant tissues (Qi & Spalding, 2004). In the salt-stressed plants, the competition of Na with other nutrients such as K causes nutritional imbalances (Mohamed

& Gomaa, 2012). However, the use of PGPR increased this ratio under different salinity levels. Among the PGPR, the B_2 strain was more effective in the increment of the K/Na in lettuce. Inoculation of the plant by B_2 strain at 0, 4 and 8 $dS.m^{-1}$ salinity levels significantly increased this parameter by 74, 55 and 86% in comparison with the control at the same salinity levels, respectively (Fig. 3).

CONCLUSION

In summary, the results of this study showed that salt stress reduced some growth factors of the lettuce plants such as shoot fresh and dry weights. Also, the content of Na and Na/K ratio in the salt-stressed plant increased. On the other hand, the concentration of chlorophyll and carotenoids and permeability of membranes (ion leakage) in the lettuce reduced under saline conditions. However, our results indicated that inoculation of lettuce with *Pseudomonas* rhizobacteria enhanced plant resistance to salinity by the promotion of plant growth, nutrient uptake, and water availability. The improvement of the lettuce growth treated with PGPR could be described by solubilization and bioavailability of nutrients such as P and K, having ACC-deaminase enzyme and production of siderophore, auxin, HCN, and organic acids. Thus, due to the useful influence of *Pseudomonas* rhizobacteria as PGPR on the lettuce plant at soil salinity, these microorganisms can be used as biofertilizers to provide nutrients and increase plant resistance to salt stress.

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Conflict of interest
The authors declare no conflict of interest.

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