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Phoma betae endophytic fungi isolated from *Anabasis prostrata* roots confers barley salt stress tolerance through amelioration of ion homeostasis and water status .

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ABSTRACT

High salinity mitigates crop productivity and quality. Endophytic fungi have been shown to improve plants salinity tolerance. This study investigated efficiency of *Phoma betae*, isolated from *Anabasis prostrata* Pomel. roots collected from saline soil (EC = 8dS/m), under increasing salinity levels (EC = 2.5; 8 and 14dS/m) on emergence rate, biomass production, ion homeostasis (Na⁺ and K⁺) and leaf relative water content (RWC) of barley.

Results revealed a positive influence of *Ph. betae* on barley salinity tolerance. Barley emergence on heavily salted soil (14dS/m) was improved by *Ph. betae* (86.67%), compared to 60% recorded by control. Inoculated barley has a higher aerial dry matter (2.24g under EC = 8dS/m) as well as leaf water relative content (85.69% under EC = 14dS/m). *Ph. betae* improved K⁺ uptake (104.46ppm) and reduced Na⁺ accumulation (44.86ppm) under EC = 14dS/m. Taken together, results demonstrate the beneficial role of *Ph. betae* in improving plant growth and salt stress tolerance in barley.

1.Introduction

Salinity is an abiotic stress that affects crop production by inducing osmotic and/or ionic imbalance and germination by inducing toxicity, reduction in water availability, immobilization of stored reserves and modifying the structural organization of proteins (Ibrahim, 2016).

To combat salinity, tolerant varieties can be developed through traditional or molecular techniques, but the first is time consuming, while the second is highly expensive. For a rapid expansion of human population and demands for food, it is necessary to discover mechanisms that are cheap and quick. In this regard, the use of alternative methods like plant promoting endophytes can be effective in achieving normal plant growth under salt stress (Bilal *et al.*, 2018; Ikram *et al.*, 2018).

Plants are rich by endophytic fungi (Ismail *et al.*, 2018; Mehmood *et al.*, 2019). Endophytes are microbial communities that reside in the host tissues without affecting physiological plant functions and causing disease symptoms (Bacon and White, 2000). Rehman *et al.* (2017) have demonstrated the positive role of endophytic fungi in growth promotion of host under biotic and abiotic stress.

Endophytic fungi can stimulate plant growth, increase nutrient uptake, plant fitness, inhibit pathogen attack and reduce abiotic stress (Jan *et al.*, 2019). Endophytes can also regulate plant physiological activities against abiotic stresses, including salinity by producing plant hormones (gibberellins, auxin, cytokinins, abscisic acid) and secondary metabolites (Hussain *et al.*, 2018). Some of endophytes induce host plant salt tolerance by increasing antioxidants levels (Hamayun *et al.*, 2017) or controls osmo and stomatal regulation (Hardoim *et al.*, 2015).

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Among the endophytic fungi, *Piriformospora indica* maintains the Na^+ and K^+ homeostasis under salt stress in *Arabidopsis* (Arshad et al., 2017). In addition, the endophytes *Phoma glomerata* and *Penicillium sp.* significantly increased plant biomass, related growth parameters, assimilation of essential nutrients (potassium, calcium, magnesium,...) and reduced sodium toxicity in Cucumber plants under salinity (Waqas et al., 2012).

Keeping the potential benefits of endophytes in view, the present study has been designed to screen the role of endophytic fungus, *Phoma betae*, in alleviating salt stress in barley seedlings.

2. Materials and methods :

2-1. Isolation and identification of endophytic fungus:

The collection of *Anabasis prostrata* Pomel plant samples was performed in a saline area of Relizane (Lat. 35° 47' 46"N, Long. 0° 33' 11", Alt. 50m), Algeria. The collected plants were washed thoroughly in the laboratory under the tap water. Roots from the cleaned plants were detached, cut into small pieces. Sodium hypochlorite (NAOCL, 5%) treatment for 3 min, followed by sterile water thrice for 1min was used to sterilize the segments (Larran et al., 2007). Root pieces were placed on Petri dishes containing potato dextrose agar (PDA) supplemented after autoclaving with 15mL/L of amoxicillin. Petri dishes were put in an incubator at 27°C for one week to allow endophytic growth. The emerged fungal colonies were separated and cultured on potato-dextrose agar medium and incubated for another 7 days at 25 °C and the process was repeated till the collection of pure cultures or colonies.

Based on spore morphology, internal transcribed spacer (ITS) and 18S sequence analysis, strain 4 is *Phoma betae* (Kouadria et al., 2018a).

2-2. Screening of *Phoma betae* for barley salinity stress tolerance :

Soils used in the experiment are naturally salty soils collected from areas with different degrees of salinity (Plot1: <4 dS m⁻¹, Plot2: from 4 to 8 dS m⁻¹ and Plot3: from 8 to 16 dS m⁻¹) located in Algerian West (Lat. 35°47'046"N, Long. 0°33'011", Alt. 50 m), and their electrical conductivity was calculated by the National Institute of Soils, Irrigation and Drainage, El Matmar, Relizane, Algeria.

For the cylinders experiment, soil was sterilized and transferred to the cylinders. Healthy seeds of barley variety SAIDA 183 were surface sterilized with Sodium hypochlorite (5%) for 3 min. The seeds were rinsed thrice with ddH₂O to remove traces of Sodium hypochlorite. Seeds were inoculated by immersion in a total imbibition volume of distilled water (control) or *Phoma betae* inoculum containing 107 spores/mL for 24h, after which they were immediately placed into PVC cylinders (19 cm diameter and 50cm length). The experiment was carried out in triplicate and each replicate comprised of 1 cylinder with 10 seedlings (total = 10 × 1 × 3 = 30 seedlings per treatment). All the cylinders were kept in greenhouse. The experiment was conducted as a factorial design in randomized blocks with two factors. The first factor had two levels: seedlings inoculated with *Ph. betae*, and non-inoculated treatment (control). The second factor had three levels of soil salinity: unsalted soil with EC=2.5dS/m, moderate and severe salty soils with EC=8 and 14dS/m, respectively.

2-3. Measurements

2-3-1. Growth parameters: Emergence rate was determined 15 days after treatment, noting that it remained unchanged after 28 days of experimentation.

The harvested barley plants were washed with distilled water, thereafter; they were blotted dry gently on a paper towel and dried for 48 h at 80°C for determination of dry weight (DW).

2-3-2. Relative water content: Relative water content (RWC) was measured according to Scippa et al. (2004) and calculated as follows:

$$RWC (\%) = [(FW - DW)/(TW - DW)] \times 100.$$

Where FW = fresh weight; DW= dry weight; TW= turgid weight.

2-3-3. Mineral analysis: Dried leaf powder (50 mg) was digested by using 2 ml of nitric acid (35%) and 10 mL of 80% hydrochloric acid (0.1N) and the mixture was diluted with sterile H₂O to 50 mL. The K⁺ and Na⁺ contents were determined by flame photometry (Model Jenway PFP7, UK) following the methods previously reported by Chapman and Pratt (1961).

2-4. Statistical analysis

Analysis of variance (ANOVA) was carried out, using Statbox v6.4 statistical software. Data were represented as mean ± standard deviations. P < 0.05 shows a significant effect. The purpose of these tests was to identify statistically significant effects and interactions among various test and control treatments.

3. Results

3-1. Emergence rate and biomass

Result revealed a significant (P < 0.05) increase in emergence rate in *Ph. betae* inoculated barley plants under soil salinity 14dS/m (86.67%) as compared to the control (60%).

As shown in Fig. 1A a total emergence was recorded by inoculated and non-inoculated barley cultivated on unsalted soil (2.5ds/m) and moderate salinity (8dS/m).

Similarly, shoots biomass of inoculated plants have been significantly (P < 0.05) higher, whereas the control plants have lower shoots at all tested salt stress levels (Fig.1B).

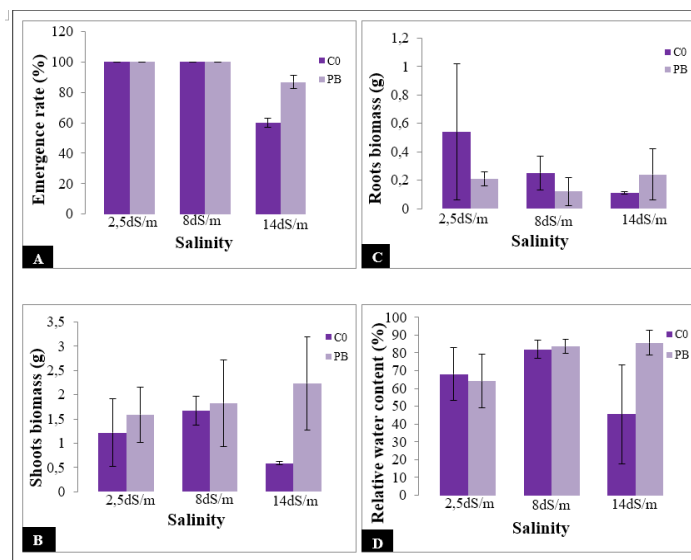


Fig. 1. Effect of salinity (CO) × *Phoma betae* (PB) interaction on barley (A) Emergence rate, (B) Shoots biomass, (C) Roots biomass and (D) Relative water content.

Moderate and high salinities negatively affected roots biomass. Moreover, under high salinity conditions, inoculated barley plants exhibited better roots biomass production ($0.24 \pm 0.1g$) as compared with non-inoculated barley plants ($0.11 \pm 0.01g$) (Fig.1C).

3-2. Relative water content

In the present study based on ANOVA result, control and *Ph. betae* associated barley plants differed significantly ($P < 0.05$) in relative water content (Fig.1D). *Ph. betae* inoculated barley plants retained higher relative water contents (RWC), and a maximum of $85.69 \pm 7.12\%$ was obtained when exposed to high salinity.

3-2. Ion content

Barley plants exhibited increased Na^+ contents and reduced K^+ levels under salinity stress (8 and 14 dS/m) as compared with control plants. However, under saline conditions, *Ph. betae* inoculation significantly mitigated the uptake of Na^+ (44.86 ± 4.67 ppm) and enhanced the accumulation of K^+ (104.64 ± 40 ppm) under high salinity (14 dS/m) inside barley cells, as compared with non-inoculated barley plants (Fig.2 A and B).

To examine the ionic burden of tissues, we examined the Na^+/K^+ ratio in plant tissues that were colonized versus those uncolonized by *Ph. betae*. The endophyte-colonized plants had a significantly lower Na^+/K^+ ratio ($0.43 \pm 0.6ppm$) than the uncolonized control plants (0.62 ± 0.5 ppm) under high salinity stress (14 dS/m).

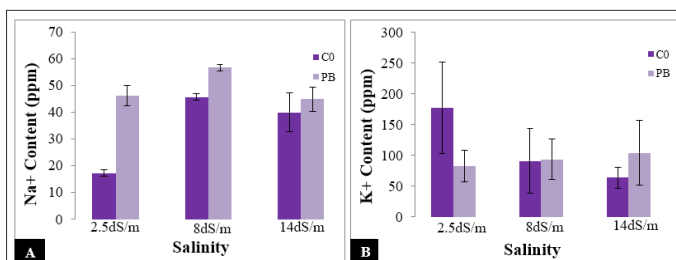


Fig. 2. Effect of salinity (CO) \times *Phoma betae* (PB) interaction on (A) Na^+ and (B) K^+ barley Leaves contents.

4. Discussion

Salinity is a critical factor that severely affects plant growth and metabolism (Deinlein et al., 2014). Plants are susceptible in their response to moderate salt stress, increases ionic imbalance inside organs, arresting plant growth, productivity and creates water deficiency (Mahmood et al., 2012). Those findings are consistent with our study which indicated that salt exposure declined growth rate relative to non-saline conditions. Current study supports the concept that beneficial endophytic association enhances plants growth and metabolism under salt stress. Strikingly, inoculation with *Ph. betae* significantly alleviated the damage induced by salt treatment for inoculated plants when compared to non-inoculated barley. Baltruschat et al. (2008) confirmed that Fungal symbiosis has shown to moderate some physiological processes and tolerance to salt stress.

These results suggested that *Ph. betae* play a pivotal role in barley salt stress tolerance. *Ph. betae* inoculation significantly improved plant growth and biomass yield under salt stress. Symbiotic relationship can enable the host plants to survive with stress, gain biomass and improve plant metabolism (Rubio et al., 2017; Kouadria et al., 2018b; Bouzouina et al., 2020). Endophytic fungal association via gibberellins and

indole acetic acid can improve plant growth under salt stress (Kumar et al., 2017) and mitigate salt stress toxic effects on plants (Zhang et al., 2016). Ghorbani et al. (2019) showed that NaCl treatments reduced biomass production non-inoculated tomato plants; however, *P. indica*-inoculated plants had higher biomass, which indicates the positive effect of *P. indica* inoculation on tolerance of tomato plants under salt stress.

Measurement of RWC reflects the water status of plants and helps to indicate plant responses to salt stress (González and González-Vilar, 2003). Plant growth and development depend on the leaves relative water contents, as salt stress initiate water deficit inside plant tissues (Munns and Tester, 2008). Current study revealed that salinity stress decreased the relative water content (RWC), causing water uptake reduction. The negative effect on water and nutrients uptake was induced by an increase in soluble salts causing osmotic effects and toxicity (Jiang et al., 2014).

On the other hand, The Current findings suggested that *Ph. betae* inoculated plants had higher water content, which is in close agreement with that of Zhang et al. (2016). Richardson et al. (2009) proposed that fungi associated plants fetch higher water contents from sources inaccessible to control plants. Symbiotic-interaction of *Trichoderma reesei* with wheat plants can improve its physiological processes and increase water content (Ikram et al., 2019).

Results showed an increase in Na^+ content accompanied with a significant decrease in K^+ content was observed in barley leaves with increasing salt concentration compared to the non-treated plants. Hu et al. (2012) have indicated that plants subjected to salt stress absorb Na^+ ions more than K^+ ions.

Excessive sodium levels can induce toxic influence on cell metabolism and decline photosynthesis (Mahajan and Tuteja, 2005). Therefore, maintaining ionic homeostasis and high K^+ concentration is the most important mechanisms for regulating plants osmotic potential under salt stress (Evelin et al., 2009).

The application of *Ph. betae* increased K^+ and significantly decreased Na^+ concentration, thereby maintaining a lower Na^+/K^+ ratio in *Ph. betae*-inoculated barley, compared to non-inoculated plants.

Li et al. (2017) exhibited that fungi can protect plants from the negative effects of excess salt ions by alleviating Na^+ plant uptake under saline condition which may be involved in enhancing plant salt tolerance by maintaining a low Na^+/K^+ ratio and ionic balance.

Piriformospora indica can improve tomato plants salt stress tolerance by increasing K^+ accumulation and maintaining Na^+/K^+ homeostasis (Ghorbani et al., 2019).

According to Zhu et al. (2016) *Piriformospora indica*, by reducing Na^+ absorption in leaves as photosynthetic parts, protects the photosynthetic apparatus and increases the carbon assimilation in plants under salinity stress.

5. Conclusion

In conclusion, results showed that *Ph. betae*, appears to confer barley salt tolerance through altering morphological and physiological indexes. In current study, *Ph. betae* was employed to accelerate plant growth and alleviate salt stress, which involved several mechanisms. *Ph. betae* mediated plant tolerance to salinity through: (i) *Ph. betae* have promoted plant growth and biomass production; (ii)

exhibited significant increases in RWC; (iii) mitigated Na⁺ uptake, enhanced K⁺ accumulation and maintained the appropriate Na⁺/K⁺ ratio, and re-established ion homeostasis. Since *Ph. betae* has no host specificity, the high potential of this fungus in permitting plants to stimulate stress response systems, by enhancing plant tolerance to salt stress provides an effective strategy for remediating the salinity soil.

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