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Extracts From Seaweeds and *Opuntia ficus-indica* Cladodes Enhance Diazotrophic-PGPR Halotolerance, Their Enzymatic Potential, and Their Impact on Wheat Germination Under Salt Stress

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ABSTRACT

Salinity affects more than 6% of the earth's land surface and more than 20% of its irrigated areas, being a major threat to agriculture. Diazotrophic bacteria are among the soil microbial functional groups threatened by this abiotic stress, since their activity is mostly inhibited by salt stress. Seventy soil bacterial strains were isolated from soils with distinct characteristics using the N-free Jensen's selective medium. Based on their ability to produce metabolites of agricultural interest, four strains were selected and molecularly identified as *Flavobacterium johnsoniae, Pseudomonas putida, Achromobacter xylosoxidans* and *Azotobacter chroococcum*. The selected strains were grown under distinct NaCl concentrations (0 to 600 mM in Nitrogen-Free broth and 0 to 2 M in Luria Bertani medium) in the absence and presence of Glycine Betaine (GB), aqueous and hydro-alcoholic extracts of *Ulva lactuca* (UL), *Enteromorpha intestinalis* (EI) and *Opuntia ficus-indica* (OFI) cladodes. The selected bacterial strains, glycine betaine (GB) and the aforementioned extracts were tested for their ability to promote germination of wheat seeds under 0 to 300 mM NaCl. In comparison to the results obtained with the synthetic osmoprotectant GB, extracts from *Opuntia ficus-indica*, *Ulva lactuca* and *Enteromorpha intestinalis* significantly promoted bacterial growth and seed germination under salt stress.

Key Words: Diazotrophic bacteria, Glycine betaine, *Opuntia ficus-indica*, plant growth-promoting rhizobacteria (PGPR), Salt stress, Seed germination.

INTRODUCTION

During the last century, rapid growth of the human population created a global scarcity of water resources, increased salinization of soils, loss of biodiversity, environmental degradation and decreased nutrient availability (Shahbaz and Ashraf, 2013). Of these problems, salt stress poses increasing challenges to agriculture, food security, and leads to increased exploitation of natural resources (Ashraf *et al.,* 2012). Six percent of the Earth's surface worldwide is affected by salinity, corresponding to about 20% of irrigated regions, especially in the arid and semi-arid regions where rainfall is insufficient to leach salts from the upper layers of the soil. It has been estimated that more than 50% of arable lands will be salinized by the year 2050 (Jamil *et al.,* 2011; Dikilitas and Karakas, 2012; Stanković, 2015).

A soil is considered saline if the electrical conductivity (EC) of the saturation extract in the area adjacent to the roots exceeds 4 dS m^{-1} at 25°C, and has an exchangeable sodium content of 15% (Shrivastava and Kumar, 2015). High concentrations of sodium and chloride, as well as other ions (potassium, calcium, carbonate, nitrate, and sulfate), decrease the acquisition of water by plants and negatively affect many physiological processes, such as photosynthesis, protein synthesis and lipid metabolism (Kosová *et al.,* 2011; Tapias *et al.,* 2012).