MINI REVIEW

Plant Growth Promoting Rhizobacteria Alleviating Salinity Stress in Spinach (*Spinacia oleracea L.*): A Mini Review

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DOI: 10.18811/ijpen.v9i04.10

Abstract

In the present era salinity stress becomes a huge obstacle for global agricultural productivity. It is reported that crop loss due to salinity alone is 20 to 50%. In the present review one denotes and preambles the significant role of plant growth promoting rhizobacteria (PGPR) as a green bioinoculant in mitigating salinity stress in spinach. Spinach is a salt-sensitive crop and salinity decreases spinach seedling germination, and root-elongation thereby lowering its productivity. The PGPR alleviates the detrimental effects of soil salinity in spinach by improving plant defense mechanisms. Such PGPR not only would increase the productivity of spinach but also of other crops as preamble here. This would lead to increased crop yield and hence meet the food demands of large population. The detrimental effects of soil salt stress in plants include nutrient uptake inhibition by interfering directly with ion transporters in the root plasma membrane (e.g. K^+ selective ion channels) and by inhibiting root growth.

However, work on alleviation of detrimental effects of salinity is scarce and needs to be explored more. This review is just and attempt to draw the attention of such agriculturists and scientists to acknowledge this aspect of spinach and PGPR. This is a healthy relation of spinach and PGPR and hence PGPR can be a futuristic, potential bioinoculant for spinach to cope with abiotic stress viz, soil salinity stress.

Keywords: Plant Growth Promoting Rhizobacteria, Soil Salinity Stress, Spinach

International Journal of Plant and Environment (2023); **ISSN:** 2454-1117 (Print), 2455-202X (Online)

Introduction

Agriculture productivity is greatly affected by abiotic stress. Soil salinity has been found to affect 20% of cultivated land globally and 33% of irrigated land (Machado and Serralheiro, 2017). Higher soil salt threshold (EC_t) ranging from 1 to 2.5 ds/m causes a decrease in glycophytic crop (spinach) productivity. To cope with such stress PGPR has been reported as a potent agent. It has been reported that area of 7 million hectares of India land is covered by saline soil. Soil salinity stress mostly occurs in Uttar Pradesh, Bihar, Madhya Pradesh, Punjab, Andhra Pradesh, Karnataka and Gujarat all major crop-producing states (Shrivastava and Kumar, 2015) (Fig. 1).

Spinach: The Wonder Leafy Vegetable

Spinach (*Spinacia oleracea* L.) originated in Persia is a green leafy vegetable belonging to family Chenopodiaceae. It was introduced by the Moors of North Africa to Spain (11th Century). It is consumed there in large amount and global production of spinach is expected to reach 1.24 billion in 2029.

Spinach: Nutritional Content

Spinach is rich in various nutrients and is a quite healthy vegetable. One cup of raw spinach contains the following nutrients (Table 1).

Spinach: A Glycophytic Plant

Spinach can be cultivated in various climates but with low salinity soil. Increasing soil or irrigation water salt content can lower the yield of spinach. Spinach is a salt-sensitive vegetable (Glycophytic plant) which if exposed to high concentrations of NaCl had salinity-induced nutritional disturbances (Grattan and Grieve, 1992). It was reported by Ferreira *et al.,* (2018) that irrigated water with EC_{iw} = 6.5 ds/m (salinity) lowered fresh and dry weights 34% and 27% of spinach, respectively.

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How to cite this article: Purnima., Dhawal, A., Singh, P. (2023). Plant Growth Promoting Rhizobacteria Alleviating Salinity Stress in Spinach (*Spinacia oleracea L.*): A Review. International Journal of Plant and Environment. 9(4), 369-372.

Submitted: 03/10/2023 **Accepted:** 19/11/2023 **Published:** 28/12/2023

Detrimental Effects of High Salinity in Spinach

A study showed that high salinity enhanced polyphenol content and decreased nitrate ion and oxalic acid concentration in spinach (Shimmachi *et al.,* 2008). Soil salinity also showed necrosis, stunting in growth and yellowing of leaves in spinach. The excessive salt content in spinach cultivated soil had death of plants as well. It was found that Spinach exhibited salt tolerance to lower concentrations only due to better osmotic adjustment. It was due to the accumulation of compatible solutes and total soluble sugars with higher antioxidant enzyme activity. But at higher salinity growth of spinach shoot was reduced and finally checked (Fig. 2).

PGPR: Mechanisms of Action of Lowering Soil Salinity

Volatile Organic Compounds production (VOCs)

Plants produce VOCs with the aid of PGPR. VOCs cause changes in the physiology of plant and enhance plant growth viz, escalate shoot biomass and provide defense against diseases. In the stress condition VOCs promote biosynthesis of osmoprotectants viz, glycine, betaine which protects Photosystem II. Such osmoprotectants also maintain the cell membrane integrity and enzymatic activity (Jagendorf and Takabe, 2001). It was reported by Zhang *et al.,* (2008) *Bacillus subtilis* (PGPR) alleviated salt stress with the aid of VOCs production. *Bacillus subtilis* facilitated the expression of HKT1/K^+ transporter at the rhizoplane region. It resulted in increased intake of nutrients and lower Na^+ influx to the root (Fig. 3).

Antioxidant enzyme production

Under salinity stress plants deal with oxidative stress (Reactive Oxygen Species (ROS), H2O2). PGPR protects plants against this stress by up-regulating the antioxidant enzyme mechanism. In such situations plant cells are protected from oxidative molecules by Superoxide Dismutase (SOD), Catalase (CAT), Peroxidase (POX) and Ascorbate peroxidase (APX). Plants are also protected via non-enzymatic antioxidants viz, ascorbic acid, glutathione, and tocopherols in saline stress (Gupta *et al.,* 2022). Gupta *et al.*, (2021) denoted *Bacillus amyloliquefaciens* NBRISN13 (SN13) enhanced chlorophyll content, plant biomass and upregulated proline and antioxidant enzyme expression.

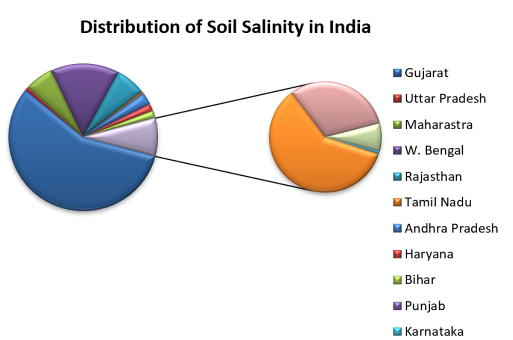

Fig. 1: Distribution of soil salinity in major crop producing states of India (Kumar and Sharma, 2020)

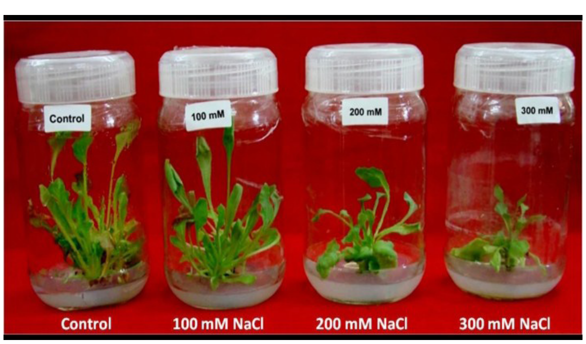

Fig. 2: Representation of detrimental effects of various level of soil salinity (Control (0), 100, 200 and 300 mM NaCl) applied to spinach and its growth effect on spinach shoot (Muchate *et al.*, 2019).

PGPR: Application for alleviation of salinity stress in Spinach

Spinach is a salt-sensitive plant. Salinity stress reduced root-elongation, spinach germination, chlorophyll content and increased permeability (Uchgaonkar *et al.,* 2018). Application of PGPR (*Pseudomonas fluorescens*) significantly increased fresh and dry weights as well as Fe, Zn, Cu and Mn concentrations in aerial parts of spinach under salinity-influenced soil (Bolhassani *et al.,* 2020). In a study of Nigam *et al.,* (2022) it was concluded that *Stenotrophomonas* sp. (PGPR) showed salinity tolerance in soil in case of spinach. It was more effective protectant than salicylic acid for reducing salinity-induced yield loss. The yield lowered due to low molecular weight, protein profiling and higher strength of ionic homeostasis (Table 2).

Co-application of two pre-isolated ACC deaminase-producing PGPR (*Bacillus amyloliquefaciens* and *Alcaligenes faecalis*) in spinach alleviated salt stress. They also enhanced growth of spinach i.e. improvement in chlorophyll a (93%), chlorophyll b (50%), total chlorophyll (76%), potassium concentration in leaf (70%) and root (60%) and reduction in leaf electrolyte (26%) leakage validated effectiveness of *Bacillus amyloliquefaciens* and *Alcaligenes faecalis* to mitigate salt stress Fig. 4.

In a study of Uchgaonkar *et al.*, (2018) *Pseudomonas aeruginosa* MGPB31 isolated from a marine environment alleviated salinity stress in spinach. It enhanced root length and shoot length as well.

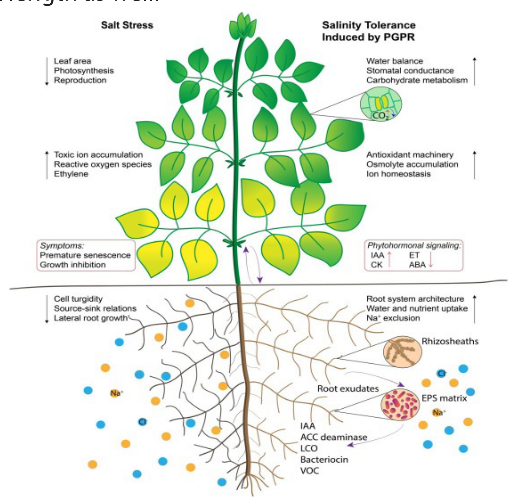

Fig. 3: Diagrammatic representation of different mechanisms of action opted by PGPR to develop tolerance against salinity stress in plant (Ilanggumaran and Smith, 2017)

Table 1: Representation of the nutritional value of Spinach (Lorraines and Ware, 2023)

Nutrient	*Amount*
Potassium	167 mg
Magnesium	24 mg
Iron	0.81 gram
Calcium	29.7 mg
Vitamin A	141 micrograms
Folate	58 micrograms
Protein	0.86 gram (Fresh weight)

Table 2: PGPR and their mechanisms of action alleviating salinity stress in different crops.

PGPR	*Saltconcentration (mM NaCl)*	*Plant/crop*	*Mechanisms opted and growth effects*	*References*
Pseudomonas putida	250	*Brassica napus* L.	ACC deaminase production. Increased shoot germination and higher chlorophyll content.	Chang *et al.,* 2012
Bacillus megaterium NRCB001, *Bacillus subtilis* NRCB002	130	*Medicago sativa* L.	Increased seed germination 32% and 42%	Zhu *et al.,* 2020
Pseudomonas simiae	100	*Phaseolus vulgaris* L.	Two VOCs production (4- Nitroguaiacol, quinoline). Enhanced seed germination.	Vaishnav *et al.,* 2016
Pseudomonas fluore scens	3000 ppm NaCl	*Vigna unguiculata* L.	SOD activity and proline synthesis. Increased plant growth.	Manaf and Zayed, 2015
Bacillusamyloliquefacien s SN13	200	*Oryza sativa* L.	Ethylene production. Increased plant salt-tolerance.	Nautiyal *et al.,* 2013
Pseudomonas putida 198	Salinity	*Gossypiumherbaceum* L.	Amino acid and Isoprenoid synthesis.	Yao *et al.,* 2010

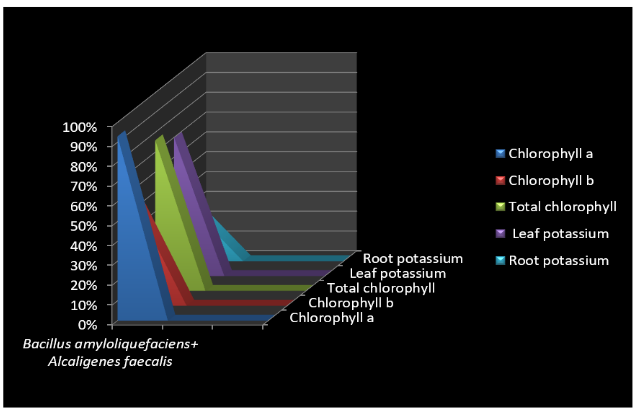

Fig. 4: Graph representing various growth effects of two PGPR (Bacillus amyloliquefaciens and Alcaligenes faecalis) in spinach under salinity stress (Hye *et al.,* 2020).

It is noteworthy that PGPR can work as an effective bioinoculum to alleviate salinity stress in salt-sensitive spinach plants and also enhance its yield and productivity.

Conclusions And Future Outlook

This review sheds light on the growth effects of PGPR on spinach under salinity stress. In addition, introducing certain PGPR provides salt tolerance in other crops as well. Biofertilizer and biopesticide aspects of PGPR have been studied earlier but their salinity tolerance mechanisms especially in case of spinach has been scarcely explored. Spinach is a salt-sensitive vegetable and detrimental effects of salinity on spinach have been reported. Hence use of PGPR as a bioinoculant for spinach growth enhancement is recorded in this work which is quiet significant.

The future outlook of this work is exploring certain PGPR to deal with salinity stress in spinach. Also, finding certain carrier material, fermentation process for large-scale field application of PGPR inoculum and increase its life span under abiotic stress as well.

Acknowledgements

The author would like to thanks Prof. Pooja Singh, Department of Botany, Deen Dayal Upadhyaya Gorakhpur University, Gorakhpur, for helping in the preparation of this manuscript.

Authors Contribution

Ms. Purnima collected data and managed references. Prof. Pooja Singh and Ms Purnima were involved in conception and design of review. Ms Purnima and Mr Ajay Dhawal organized and prepared the manuscript.

Conflict Of Interests

The authors declare that there are no conflicts of interest regarding publication of this paper.

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