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Evaluation of the salt-stress tolerance potential of indigenous *Stenotrophomonas rhizophila* and *Bacillus marisflavi* isolates

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ABSTRACT

Bacillus marisflavi and *Stenotrophomonas rhizophila* are considered important microorganisms in agriculture, largely due to their biocontrol potential and their ability to mitigate biotic and abiotic stresses in crop plants. Despite this, a limited number of studies have been conducted on rhizospheric interactions and stress tolerance between these microbes and crop plants. This study, therefore, aimed to evaluate the potential of the isolates *S. rhizophila* EU.2B33 and *B. marisflavi* EU.18 to improve salt stress tolerance in watermelon plants. Bacterial isolates were exposed to different concentrations of NaCl (5 mM, 10 mM, 20 mM, 40 mM, 60 mM, 100 mM, 500 mM, 1 M, and 2 M) in a salt-free nutrient broth medium. Isolates were incubated at 37°C for 48 h with continuous shaking of 150 rpm, and optical density taken thrice per every 24 h period using a microplate reader. After 4 and 6 hours of incubation, growth peaks were observed in both isolates, although *S. rhizophila* EU.2B33 exhibited a more efficient growth than *B. marisflavi* EU.18. Interestingly, a significant increase in growth was observed at salinity concentrations above 100 mM, although this level is regarded as the stress threshold. Protein analysis revealed an increase in band intensity with increasing dose and electrophoretically heterogeneous structure of the strains. According to SDS-PAGE results, similar bands were observed in both strains at approximately 35 and 25 kDa. At 60 mM salinity, *B. marisflavi* (214.8 ± 24.7 mg) and *S. rhizophila* (204.8 ± 25.0 mg) showed higher hypocotyl fresh weight values than the control (180.4 ±22.9 mg). At 200 mM, the control (54.9 ± 4.9 mg) treatment decreased significantly, while *S. rhizophila* (91.7 ± 8.5 mg) remained higher (P<0.05). These results indicate that *S. rhizophila* is, in particularl, more tolerant to salt stress. In addition, significant differences were observed in average germination time, germination index, and susceptibility index. This study demonstrates that these isolates have the potential to alleviate salinity stress in crop production and can help plants survive in environments generally considered stressful for crop plants.

1. Introduction

Plants are affected by various environmental stressors, generally classified as biotic and abiotic stresses. Plants experience biotic stressors from the activities of living organisms such as plants, animals, microorganisms, and other anthropogenic influences while abiotic stressors are brought on by negative impacts of environmental factors including temperature, radiation, drought, minerals, heavy metals etc. (Larcher 2003; Manghwar and Zaman 2024). In terms of negative impact on land use, mineral stress ranks second after drought (Blum and Jordan 1985).

Across the world, changes in the physicochemical properties of soils are generally associated with poor irrigation systems, substandard drainage systems, bedrock weathering, and agricultural practices. These changes can have adverse effects on the soils, including the development of soil salinity due to the accumulation of Na+ and Cl- ions. In addition, ionic fluctuations and osmotic stresses caused by soil salinity can lead to poor plant development. Proline accumulation, catalase, polyphenoloxidase, and peroxidase activities, membrane stabilization, and additional enzymatic activities have been reported to be influenced by salt stress (Ahmed and Bano 1992; Hualpa-Ramirez et al. 2024). In extreme cases of severe salinity stress, necrotic lesions have been observed on leaf margins, terminal regions, and roots (Larcher 2003) Several strategies have been explored to improve stress tolerance in crop plants. These include selective breeding, osmolyte regulation, phytohormone application, and transgenic plants as suitable methods for mitigating salt stress. These strategies have achieved limited success because they are time consuming, costly, and may affect indigenous beneficial species (Ashraf and Harris 2004; Li et al. 2025).

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Plant growth promoting rhizobacteria (PGPR) enhances growth and facilitate stress tolerance through the synthesis or degradation of various phytohormones. Recently, the use of PGPR have received significant attention in the scientific community as a cheap and environmentally-friendly alternative to chemical amendments. Beneficial rhizosphere dwelling bacteria can play an important role in enhancing stress tolerance and improving overall productivity in crop plants. Previous findings (Ryan et al. 2009; Berg et al. 2010), have reported improved salinity tolerance and enhanced root architecture when PGPR were deployed as biocontrol agents. Numerous studies have reported that *Stenotrophomonas* and *Bacillus* species support plant growth by providing tolerance to salt stress. In particular, *Stenotrophomonas rhizophila* (*S. rhizophila*) has been shown to increase stress tolerance and regulate Na^+ homeostasis by maintaining colonization in the rhizosphere under saline conditions (Liu et al. 2022). Similarly, *Stenotrophomonas* species have been reported to improve plant growth and physiological parameters under 100 mM NaCl conditions (Alexander et al. 2020). Furthermore, halotolerant *Bacillus marisflavi (B. marisflavi)*-like species are reported to be able to grow in the 150–800 mM NaCl range and increase plant biomass (Szymanska et al. 2020; Ayaz et al. 2022).

The aim of this study was to evaluate the effectiveness of PGPR isolates in enhancing watermelon seed germination under various NaCl-induced salinity stress conditions. Furthermore, the protein expression patterns of these isolates were also assessed. The findings will aid in the selection of promising salt-tolerant bacterial isolates to reduce stress and increase yield in watermelon plants.

2. Materials and Methods

2.1. Bacteria strains and growth conditions

Two bacterial strains, *S. rhizophila* EU.2B33 and *B. marisflavi* EU.18, previously characterized for their ACC deaminase activity were employed in this study (Ünlü et al. 2024). Pure cultures of these strains were grown in sterilized salt-free nutrient broth (NB) supplemented with NaCl at different concentrations of 5 mM, 10 mM, 20 mM, 40 mM, 60 mM, 100 mM, 200 mM, 1 M, and 2 M (Tort 1996; Turhan and Şeniz 2010; Kim et al. 2012). Treatments included nine salt doses and two controls, arranged in a randomized block design with three replicates. This was followed by incubation at 30°C with shaking at 120 rpm for 48 hours. Bacterial growth was monitored spectrophotometrically at 595 nm, with three readings obtained daily. As 100 mM NaCl is widely regarded as moderate salt stress (Bakhshandeh and Gholamhossieni 2018), growth responses were standardized to this threshold. Strains exhibiting tolerance were streaked onto salt-free nutrient agar plates (10 µL inoculum) and incubated at 35°C for 48 hours. Bacteria colony counting was performed as previously described (Madigan et al. 1997; Leboffe and Pierce 2021).

2.2. Protein isolation

Pellets of bacteria culture incubated for 48 hours were collected by centrifugation at 8000 x g for 10 minutes. Pellets were washed with 6 mL of 20 mM Tris-HCl and centrifuged at 6000 × g for 5 mins. Pellets were subsequently resuspended in 5 mL of 50 mM $CaCO_3$ buffer (pH 10.2) supplemented with 50 µL lysozyme (10 mg mL^{-1}), 1% β-mercaptoethanol, and 0.1% Triton X-100. The suspensions were incubated at 30°C for 15 minutes and subjected to brief sonication to facilitate cell lysis. Precipitated proteins were recovered by centrifugation at 14000 × g and resuspended in 1.5 mL 20 mM Tris-HCl. Protein preparations were stored at -20°C until further analysis.

2.3. Determination of protein concentration

Protein concentrations were quantified using the Bradford assay (Bradford 1976), with bovine serum albumin (BSA) as the standard.

2.4. SDS-polyacrylamide gel electrophoresis (SDS-PAGE)

SDS-PAGE was performed according to the protocol of (Laemmli 1970) with minor modifications. The protein samples were resuspended in equal volumes of 2× Laemmli sample buffer and heated at 95°C for 5 minutes prior to electrophoresis. Separation was carried out using a gel system consisting of a 5% stacking gel and a 12% resolving gel on a Protean II xi electrophoresis unit (Bio-Rad, Hercules, CA, USA), operated at a constant current of 25 mA for 6 hours. Following electrophoresis, gels were fixed in formaldehyde solution, rinsed with distilled water, and sequentially treated with sodium thiosulfate and silver nitrate solutions. Protein bands were visualized using a freshly prepared thiosulfate-based developer until distinct bands appeared, after which the reaction was terminated with citric acid (Yilmaz 2010). For molecular weight determination, a PageRuler™ Plus Prestained Protein Ladder (Thermo Scientific™, Cat No: 26620) was used as a reference marker.

2.5. Germination test

Commercially obtained watermelon seeds (Ersin F1, AgroPlanet Company) were used in this study. Seeds were randomly selected and placed in a sterile petri dish. Seeds in each petri dish were treated with 2 mL NaCl solutions with varying concentrations (control, 60 mM, 100 mM, 200 mM, 1 M, and 2 M). Sterile distilled water was used as the control solution. Germination assessments were performed according to the guidelines of the International Seed Testing Association (ISTA, 1996). Germination parameters such as germination percentage, germination index, mean germination time, sensitivity index, shoot length, and root length were recorded.

Calculations on germination percentage and germination rate were performed based on readings taken on day 7 and 14 as the ratio of germinated seeds to the total number of seeds in a petri dish (Akinci et al. 2004), by using the equations:

$$\text{Germination index } (GI) = \sum(\frac{G_t}{T_t})$$

where G_t= number of seeds germinated on day t, and T_t= the corresponding time in days.

The Mean Germination Time (MGT) was determined by the following method, Ellis and Roberts (1980):

$$MGT = \frac{\sum(f \cdot x)}{\sum f}$$

where f= number of seeds germinated on day x, and x= the day of germination.

The Sensitivity Index (SI) was calculated as described by Foolad et al. (2007):

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$$SI = \frac{MGT_{salt\ treatment}}{MGT_{control}}$$

2.6. Statistical analysis

The data obtained were analyzed using SPSS Statistics Programme version 17.0. A one-way analysis of variance (ANOVA) was performed to evaluate differences among treatments, and multiple comparisons among the control and the two isolates were determined using Tukey's HSD test.

3. Results

3.1. Bacterial growth

Bacterial strains *S. rhizophila* EU.2B33 and *B. marisflavi* EU.18, which exhibited growth on solid culture media in petri dishes, were considered as yielding positive results as displayed in Figure 1.

For *B. marisflavi* EU.18 (B1), after 30 hours the strain reached 1.24 nm at 1 M NaCl, 0.747 nm at 100 mM, and 0.73 nm at 2 M after 6 hours (Figure 2). The control remained at 0.3 nm after 30 hours. At the sixth hour, bacterial density continued to increase, reaching 0.92 nm at 1 M and 0.73 nm at 2 M. After 30 hours, growth increased sixfold at NaCl concentrations of 20 mM, 40 mM, 60 mM, 100 mM, 500 mM, and 1 M. Additionally, an increase in turbidity was observed, particularly at 500 mM (0.602 nm) and 1 M (1.24 nm), while growth in the control was not significant after 48 h.

For *S. rhizophila* EU.2B33 (B2), growth commenced under high salt concentrations as early as 2 hours after inoculation (Figure 3). Within the first 2–6 hours, bacterial growth in eight NaCl concentrations (5 mM, 10 mM, 20 mM, 40 mM, 60 mM, 100 mM, 500 mM, 1 M), were recorded as 0.059 nm, 0.058 nm, 0.521 nm, 0.165 nm, 0.159 nm, 0.172 nm, 1.661 nm, 1.022 nm, and 0.053 nm, respectively, with the highest increase observed at 100 mM (1.661 nm). The control treatment recorded 0.051 nm growth. At the concentrations mentioned above, the highest growth was observed after 26 h incubation and was recorded as 1.115 nm, 1.091 nm, 1.069 nm, 1.098 nm, 1.280 nm, 1.090 nm, 1.143 nm and 0.854 nm, respectively. After this period, a decrease in growth was observed with the control group maintaining growth ranges of 0.093-0.102 nm. For the B1 isolate, the maximum optical density (OD) was at 1 mM, representing a 243% growth rate when compared with the control group.

3.2. SDS-PAGE protein analysis

As displayed in Figure 4, it was observed that higher NaCl concentrations resulted in sharp band formations and the opposite was true for lower concentrations. For the B2 bacterial strain maximum growth was achieved at 500 mM salt concentration. OD calculations showed peaks at 100 mM (109×10^5 after 26 hours), 500 mM (166×10^5 after 6 hours), and 1 M (102×10^5 after 6 hours).

3.3. Germination assay

As shown in Table 1, Table 2, and Figure 5, both bacteria isolates demonstrated the ability to promote salinity tolerance in watermelon germination parameters. Compared with the control group, significant results were recorded for average germination period and germination percentage of seeds treated with both strains. At the same time, germination sensitivities were found to be lower in seeds treated with bacteria than the untreated control group, at the same salinity concentration (Table 2).

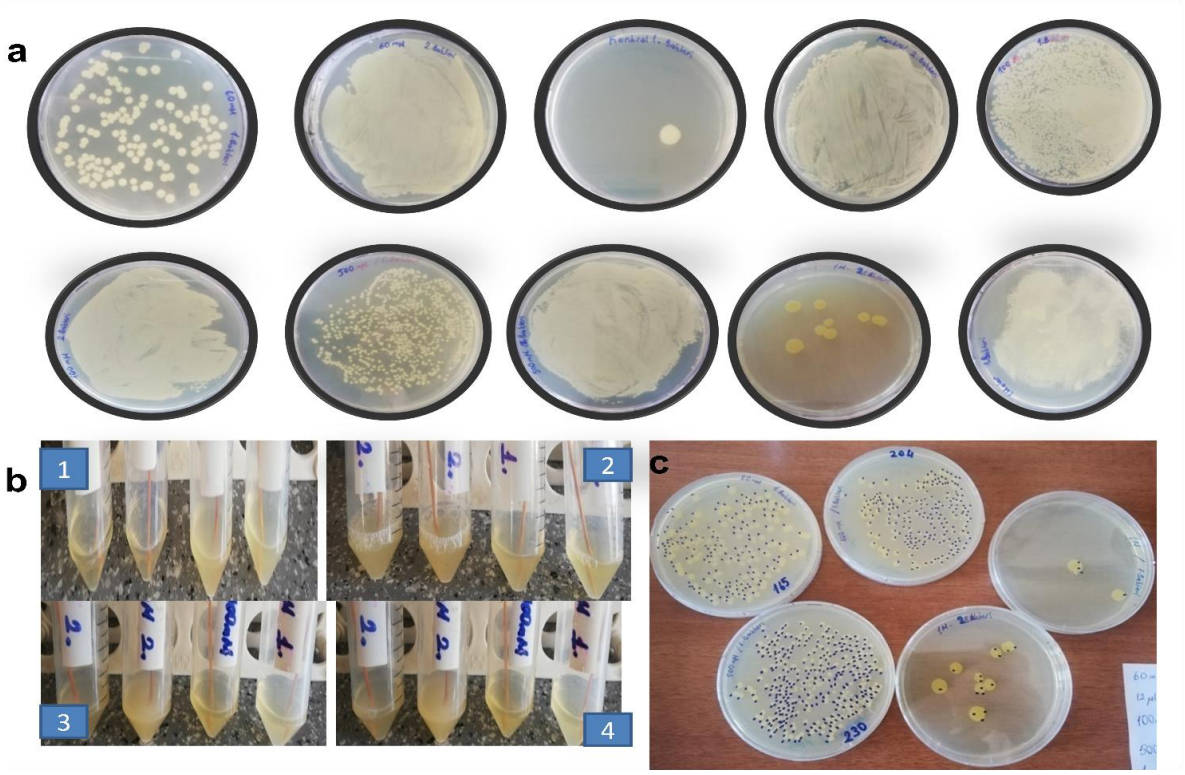


Figure 1. Growth of two bacterial strains a) in LB solid and b) liquid media under varying NaCl concentrations. c) Colony enumeration on solid petri medium.

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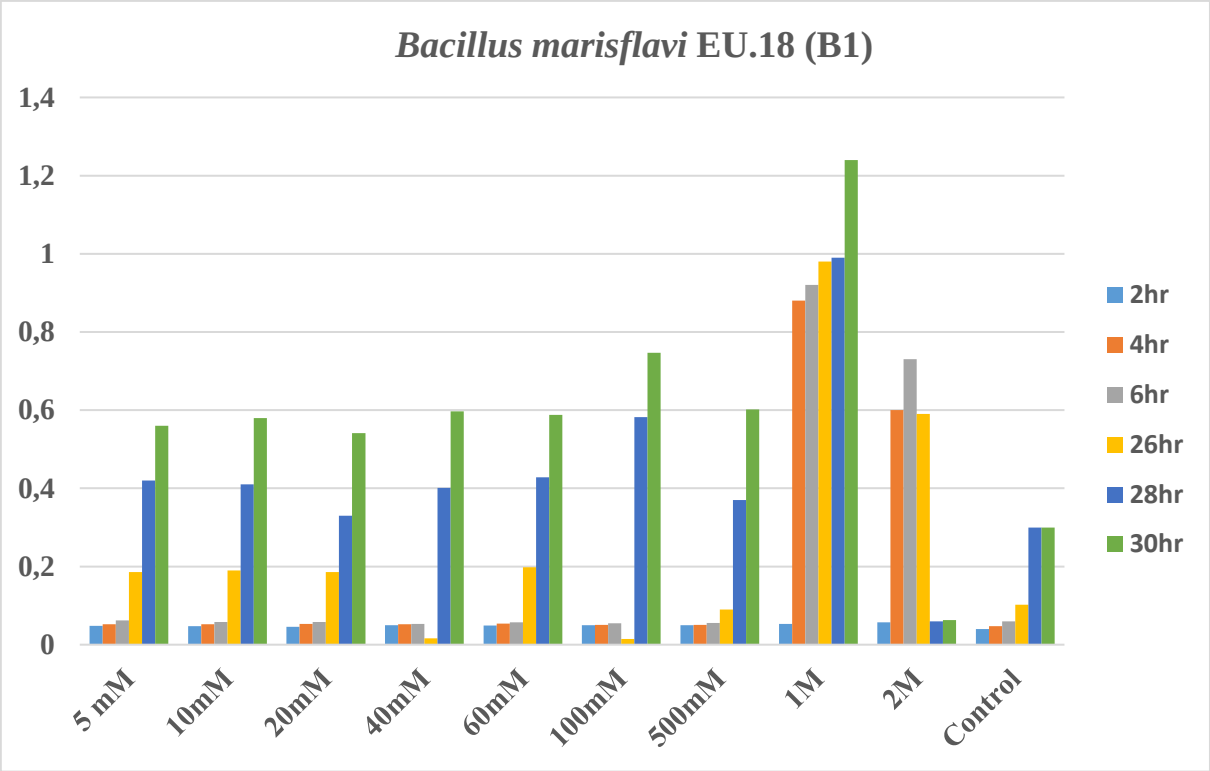


Figure 2. Optical densities of *B. marisflavi* EU.18 (B1) growth at different salinity levels and at different time periods.

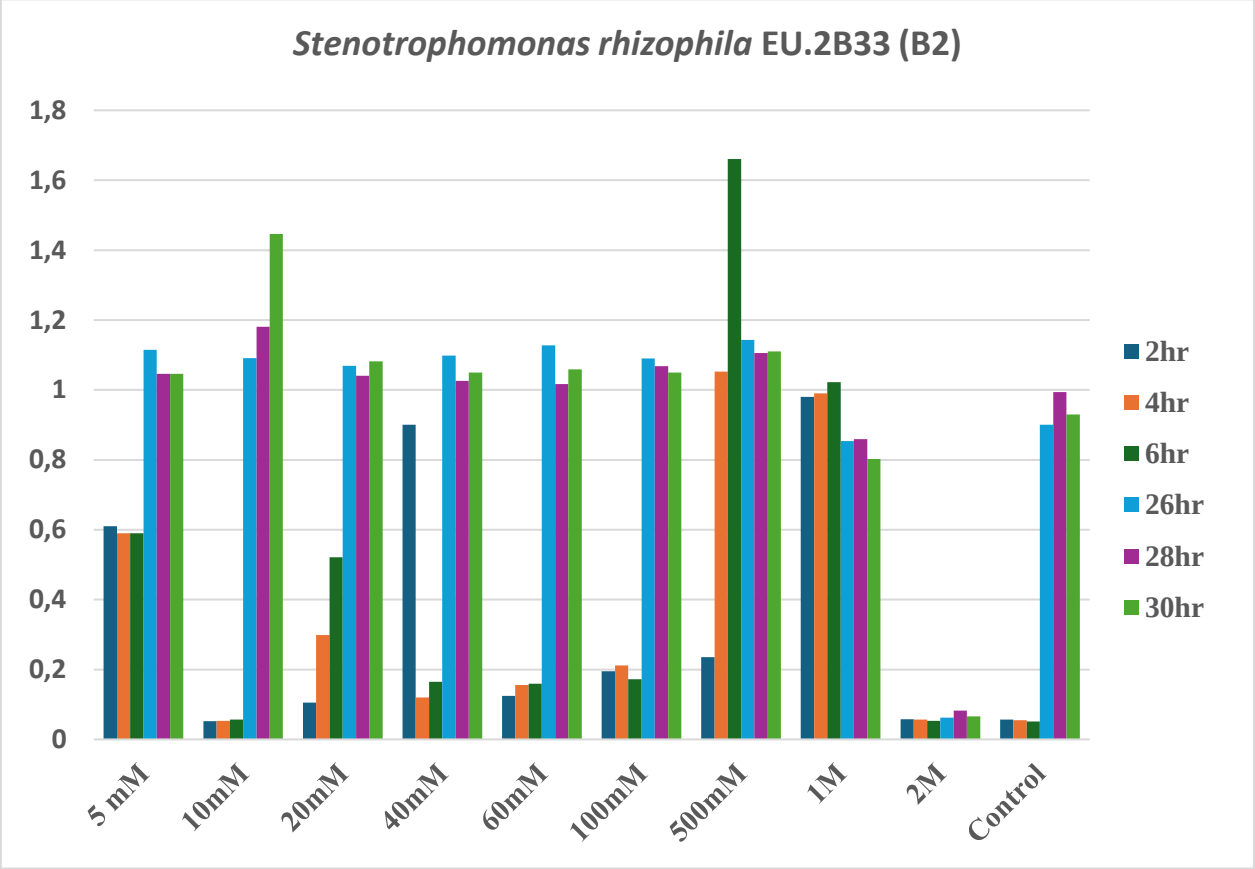


Figure 3. Optical densities of *S. rhizophila* EU.2B33 (B2) growth at different salinity levels and at different time periods.

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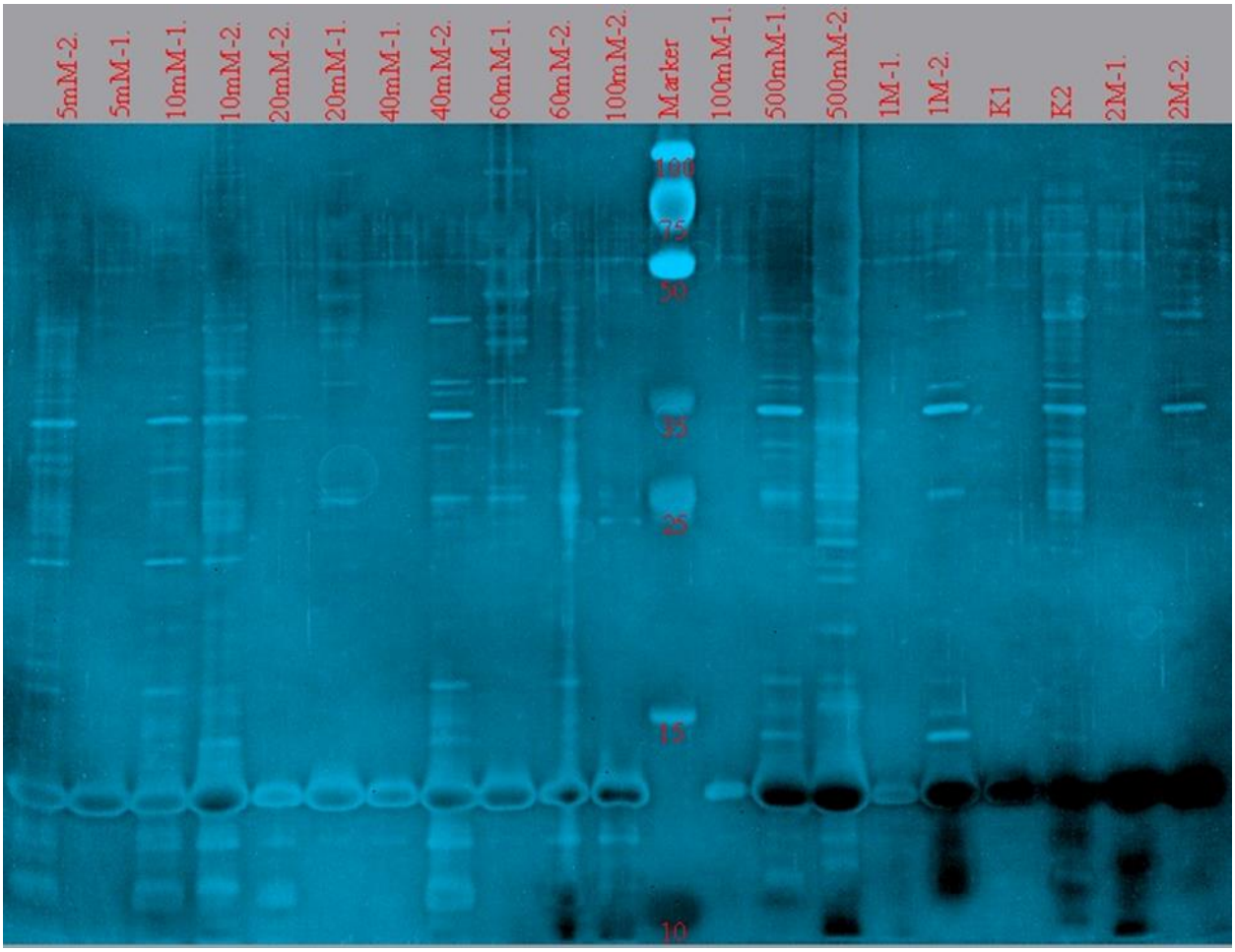


Figure 4. SDS-PAGE gel displaying protein banding patterns of bacteria isolates exposed to different concentrations NaCl-induced salinity. 1 and 2 represent *B. marisflavi*/ EU.18 and *Stenoptrophomonas rhizophia*/ EU.2B33 respectively.

Table 1. Germination test of watermelon seeds under different salinity stress and bacteria treatments

Treatments	Dose	Germination (day)	Sensitivity index (%)	Average germination period (day)	Germination percentage (%)
B. marisflavi EU.18	B1	9.8 ± 0.29^{Aa}	0.101 ± 0.00^{Ac}	2.00 ± 0.00^{Aa}	98.33 ± 2.88^{Aa}
	60 mM	9.3 ± 0.29^{Aa}	0.108 ± 0.00^{Ac}	2.33 ± 0.28^{Aa}	93.33 ± 2.88^{Aa}
	100 mM	4.5 ± 0.50^{Ab}	0.224 ± 0.25^{Ab}	2.57 ± 0.20^{Ab}	55.00 ± 5.00^{Ab}
	200 mM	2.2 ± 0.29^{Ac}	0.466 ± 0.06^{Aa}	5.63 ± 0.41^{Ac}	21.67 ± 2.88^{Ac}
S. rhizophila EU.2B33	B2	9.5 ± 0.50^{Aa}	0.105 ± 0.00^{Ab}	2.50 ± 0.00^{Ba}	95.00 ± 5.00^{Aa}
	60 mM	8.7 ± 1.04^{Aa}	0.116 ± 0.01^{Ab}	2.70 ± 0.34^{Aa}	88.33 ± 7.63^{Aa}
	100 mM	5.7 ± 0.76^{Bb}	0.178 ± 0.23^{Ab}	3.13 ± 0.15^{Bb}	66.67 ± 7.63^{Bb}
	200 mM	3.0 ± 0.50^{Ac}	0.339 ± 0.06^{Ba}	4.30 ± 0.26^{Ac}	30.00 ± 5.00^{Ac}
Control	60 mM	8.4 ± 0.33^{Aa}	0.100 ± 0.00^{Ac}	3.25 ± 0.25^{Bb}	65 ± 7.65^{Bb}
	100 mM	3.4 ± 0.50^{Ab}	0.104 ± 0.30^{Ac}	4.43 ± 0.33^{Ac}	30 ± 5.00^{Ac}
	200 mM	1.167 ± 0.42^{Ac}	0.624 ± 0.45^{Ab}	6.85 ± 0.15^{Cb}	15 ± 2.77^{Ac}

*Values are presented as mean ± standard deviation. Different lowercase letters indicate significant differences among salt treatments within the same bacterial application, while different uppercase letters indicate significant differences among bacterial treatments at the same salt concentration according to the post-hoc multiple comparison test ($P\leq0.05$).

According to the germination test results, in a total of 20 watermelon seeds in a petri dish, the stem and root fresh weight remained unchanged at a dose of 60 mM compared to the control, while at 100 mM, only a 5% loss was observed (Table 1). Germination continued in both bacterial species. Regarding germination time, at 60 mM, the bacteria were in the same group as the control with the same germination time, at 100 mM, the bacteria followed the control with a difference of 0.98 days, and at 200 mM, development continued without any seed damage (Table 2).

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Table 2. Statistical analysis of plant growth parameters upon exposure to different salt concentration treatments

Bacteria	Dose	Hypocotyl fresh weight (mg)	Root fresh weight (mg)	Hypocotyl dry weight (mg)	Root dry weight (mg)
B. marisflavi/ EU.18	B1	205.7±24.12^{Aa}	25.7±5.03^{Aa}	0.010±0.001^{Aa}	0.003±0.0006^{Aa}
	60 mM	214.8±7.92^{Aa}	24.7±3.23^{Aa}	0.086±0.005^{Ab}	0.008±0.0006^{Ab}
	100 mM	149.5±9.46^{Ab}	17.0±2.00^{Ab}	0.047±0.011^{Ac}	0.004±0.0004^{Aa}
	200 mM	74.0±12.16^{Ac}	8.5±0.85^{Ac}	0.024±0.004^{Aa}	0.004±0.0004^{Aa}
S. rhizophila EU.2B33	B2	204.2±12.57^{Aa}	26.2±3.70^{Aa}	0.009±0.001^{Aa}	0.003±0.0006^{Aa}
	60 mM	204.8±5.59^{Ba}	25.0±0.64^{Aa}	0.067±0.015^{Bb}	0.006±0.0007^{Bb}
	100 mM	196.5±0.50^{Ba}	13.2±0.20^{Ab}	0.030±0.000^{Bc}	0.004±0.0002^{Aa}
	200 mM	91.7±3.78^{Ab}	8.5±0.50^{Ab}	0.031±0.002^{Ac}	0.003±0.0004^{Aa}
Control	60 mM	180.4±0.50^{Ba}	22.9±2.25^{Aa}	0.010±0.001^{Aa}	0.008±0.0006^{Ab}
	100 mM	142.3±8.36^{Ab}	10.5±0.30^{Ab}	0.005±0.005^{Ab}	0.006±0.0007^{Bb}
	200 mM	54.9±11.14^{Ac}	4.9±1.45^{Ac}	0,005±0.005^{Ab}	0.004±0.0004^{Aa}

*Values are presented as mean ± standard deviation. Different lowercase letters indicate significant differences among salt treatments within the same bacterial application, while different uppercase letters indicate significant differences among bacterial treatments at the same salt concentration according to the post-hoc multiple comparison test ($P \leq 0.05$).

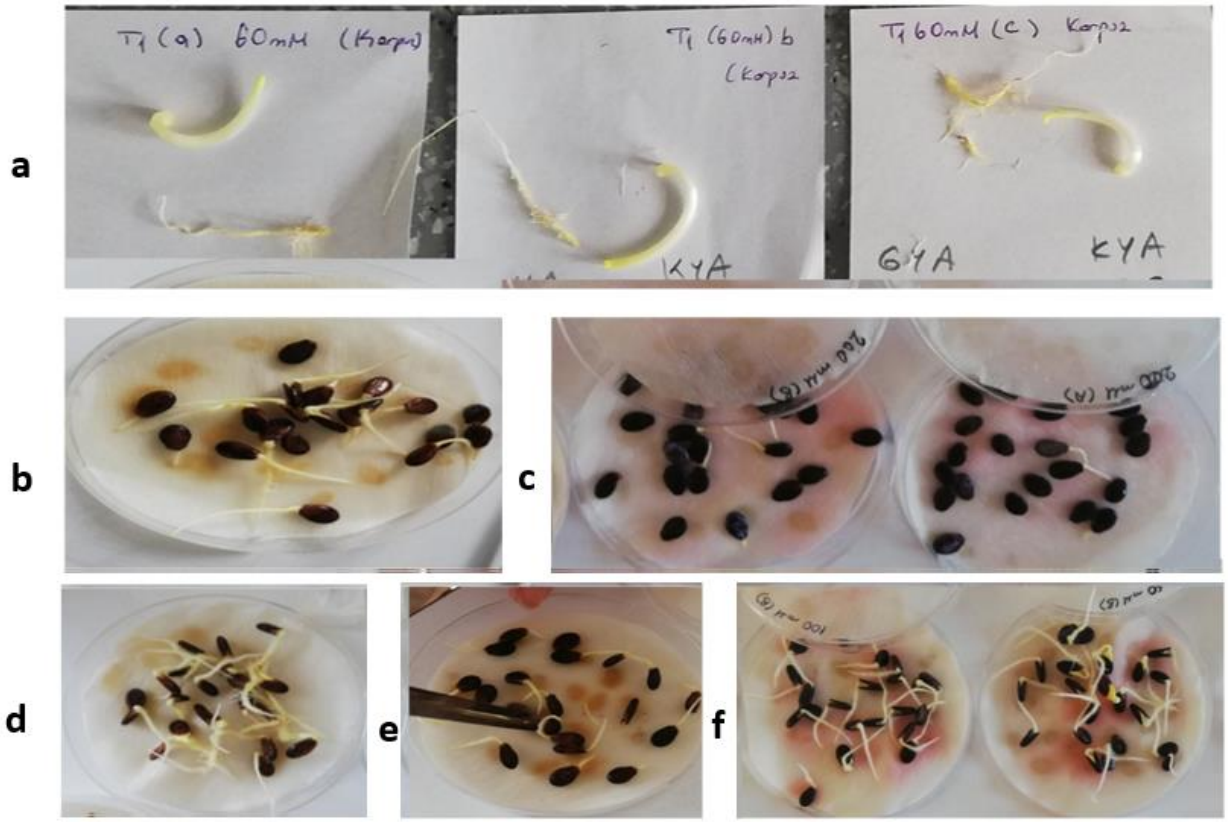


Figure 5. a) Hypocotyl and root fresh weight under 60 mM treatment, b) Growth response to B2 bacterial inoculation at 100 mM, c) Control treatment at 200 mM, d) Root development under B2 inoculation, e) B1 treatment at 200 mM, f) B2 treatment at 200 mM.

4. Discussion and Conclusion

Salt stress in agricultural soils poses a major challenge to crop productivity. PGPR has been documented to enhance growth and improve stress tolerance in crop plants, including salinity. As previous findings have shown, *B. marisflavi* and *S. rhizophila* have been found to facilitate plant growth and have positive effects on plants under salinity stress conditions (Yoon et al. 2003; Schmidt et al. 2012). The present study evaluated the potential of two PGPR isolate *B. marisflavi* EU.2B33 and *S. rhizophila* EU.18 in overcoming NaCl-induced salinity stress, their protein expression patterns under these conditions, and their ability to promote watermelon growth.

Bacillus marisflavi showcased significant increase in growth in the NaCl treated media than the control medium. Similar to our findings, Yang et al. (2023) showed the ability of *B. marisflavi* to alleviate salt stress in crops. On the other hand, the growth differences between the control medium and the saline medium were not significant for *S. rhizophila*. Even at a salinity concentration of 100 mM, which is generally considered to suppress growth (Mayak et al. 2004), the two isolates showed significant growth.

Furthermore, when compared to *S. rhizophila*, which showed constant growth in both control and saline conditions, *B. marisflavi* demonstrated increased growth in the saline media

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compared to the control medium. Significant bacterial growth was observed, particularly at salt concentrations of 100 mM, 500 mM, and 1 M. Previous studies have reported similar findings (Roder et al. 2005; Ribbeck-Busch et al. 2005), noting that the *B. mrisflavi* NIGAB-1 strain can grow at salinity concentrations up to 24% NaCl (Ahmad et al. 2020).

Similar band patterns were observed within the 25–35 kDa range in the SDS-PAGE protein profiles of *S. rhizophila* EU.2B33 and *B. marisflav*i EU.18. In both isolates, sharp protein bands were observed even at high NaCl concentrations such as 500 mM and 1 M. However, at a salinity concentration of 2 M, many bands disappeared for both strains; this may indicate that these isolates are intolerant to salinity at this concentration and salt stress may have suppressed their proteolytic activities. Liu et al. (2015) found that salt stress repressed the extracellular proteins in *Bacillus spp*. and can lead to a diminished band intensity in SDS-PAGE.

Thus, the tested bacteria isolates displayed an increase in protein synthesis in response to increased higher salt concentration.

In the germination trials, 55 % reduction in germination rate for *B. marisflavi* and a 67% increase in germination for *S. rhizophila* under 100 mM NaCl concentration were recorded (Table 1). Salt stress has been found to impede seed germination. For example, a study conducted by Kara et al. (2011) evaluated the germination rate of triticale seeds under different salinity concentrations and revealed salinity stress negatively impacted germination period of the seeds. Salinity stress may affect all aspects of germination, especially germination initiation, germination period, germination rate and sensitivity (Rahman et al. 2008). A study examining the effect of different salt levels on germination and seedling development in alfalfa found that the germination rate decreased as the salt level increased (Ercan 2020). Furthermore, Öztürk et al. (2018) evaluated seedling development under three different salt concentrations (100, 200, 300 mM) and found that seedling development was restricted and germination rates decreased compared to the control as the salt level increased.

Etesami and Beattie (2018) reported that beneficial bacterial may contribute to salt stress alleviation in crop plants by synthesizing stress tolerance hormones such as cytokinin, abscisic acid, indole-3-acetic acid, and ACC deaminase. Addition hormones including exopolysaccharides, trehalose, and volatile organic compounds have also been reported to contribute significantly to crop stress tolerance (Li and Jiang 2017). PGPR enhances a plant's ability to respond to salt stress by modulating gene expression, thereby conferring improved tolerance. This is achieved through the accumulation of metabolites such as betaine, proline, and trehalose, as well as the increased production of antioxidant enzymes like superoxide dismutase (SOD) and catalase (CAT), which scavenge reactive oxygen species (Kong and Glick 2017). Other beneficial plant growth-promoting (PGP) traits, such as phosphate solubilization and siderophore synthesis, not only contribute to stress tolerance but also improve nutrient uptake, thereby supporting overall plant health (Forni et al. 2016).

In conclusion, this study investigated the potential of indigenous *S. rhizophila* and *B. marisflavi* isolates in alleviating salt stress in crop plants. It was found that these isolates persisted and even demonstrated significant growth in highly concentrated saline conditions which are typically considered toxic for normal crop growth. Germination tests showed the isolates helped watermelon seeds in overcoming salinity stress by improving germination percentage, sensitivity index, and average germination time. Greenhouse and field experiments are recommended to monitor the performance of these isolates in improving stress tolerance in crop plants.

References

Ahmad N, Ali GM, Khan MR (2020) Molecular Identification and Characterization of *Bacillus sp.* NIGAB-1 for Phenol Degradation Under Saline Conditions. Iranian Journal of Biotechnoly 18(1): e2275. doi:10.30498/IJB.2020.133622.2275.

Ahmed J, Bano M (1992) The effect of sodium chloride on the physiology of cotyledons and mobilization of reserved food in *Cicer arietinum*. 40-48. doi:10.5555/19940707595.

Akinci IE, Akinci S, Yilmaz K, Dikici H (2004) Response of eggplant varieties (*Solanum melongena*) to salinity in germination and seedling stages. New Zealand Journal of Crop and Horticultural Science 32: 193-200. doi:10.1080/01140671.2004.9514296.

Alexander A, Singh VK, Mishra A (2020) Halotolerant PGPR Stenotrophomonas maltophilia BJ01 Induces Salt Tolerance by Modulating Physiology and Biochemical Activities of *Arachis hypogaea*. Frontiers in Microbiology 11: 568289. doi:10.3389/fmicb.2020.568289.

Ashraf M, Harris PJC (2004) Potential biochemical indicators of salinity tolerance in plants. Plant Science 166: 3-16. doi:10.1016/J.PLANTSCI.2003.10.024.

Ayaz M, Ali Q, Jiang Q, Wang R, Wang Z, Mu G, Khan SA, Khan AR, Manghwar H, Wu H, Gao X, Gu Q (2022) Salt Tolerant *Bacillus* Strains Improve Plant Growth Traits and Regulation of Phytohormones in Wheat under Salinity Stress. Plants 11: 2769. doi:10.3390/plants11202769.

Bakhshandeh E, Gholamhossieni M (2018) Quantification of soybean seed germination response to seed deterioration under PEG-induced water stress using hydrotime concept. Acta Physiologiae Plantarum 40(7): 126. doi:10.1007/S11738-018-2700-1.

Berg G, Egamberdieva D, Lugtenberg B, Hagemann M (2010) Symbiotic plant-microbe interactions: stress protection, plant growth promotion and biocontrol by Stenotrophomonas. In: Symbioses and stress: joint ventures in biology. Dordrecht: Springer Netherlands, pp. 445-460. doi:10.1007/978-90-481-9449-0_22.

Blum A, Jordan WR (1985) Breeding crop varieties for stress environments. Critical Reviews in Plant Sciences 2: 199-238. doi:10.1080/07352688509382196.

Bradford MM (1976) A Rapid and Sensitive Method for the Quantitation of Microgram Quantities of Protein Utilizing the Principle of Protein-Dye Binding. Analytical Biochemistry 72: 248-254.

Ellis RH, Roberts EH (1980) Improved Equations for the Prediction of Seed Longevity. Annals of Botany 45: 13-30. doi:10.1093/OXFORDJOURNALS.AOB.A085797.

Ercan MYI (2020) The effects of different chlorine salts and doses on germination and seedling development in alfalfa (*Medicago sativa L.*). Master's Thesis, Erciyes University, Kayseri.

Etesami H, Beattie GA (2018) Mining halophytes for plant growth-promoting halotolerant bacteria to enhance the salinity tolerance of non-halophytic crops. Frontiers in Microbiology 9: 317452. doi:10.3389/FMICB.2018.00148/FULL.

Foolad MR, Subbiah P, Zhang L (2007) Common QTL affect the rate of tomato seed germination under different stress and nonstress conditions. International Journal of Plant Genomics 2007(1): 097386. doi:10.1155/2007/97386.

Forni C, Duca D, Glick BR (2016) Mechanisms of plant response to salt and drought stress and their alteration by rhizobacteria. Plant and Soil 410(1): 335-356. doi:10.1007/S11104-016-3007-X.

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Hualpa-Ramirez E, Carrasco-Lozano EC, Madrid-Espinoza J, Tejos R, Ruiz-Lara S, Stange C, Norambuena L (2024) Stress salinity in plants: New strategies to cope with in the foreseeable scenario. Plant Physiology and Biochemistry 208: 108507. doi:10.1016/J.PLAPHY.2024.108507.

ISTA (1996) International Rules for seed testing 1996. In: International Seed Testing Congress. The International Seed Testing Association, Zurich.

Kara B, Akğün İ, Demet A (2011) Tritikale genotiplerinde çimlenme ve fide gelişimi üzerine tuzluluğun NaCl etkisi. Selçuk Tarım ve Gıda Bilimleri Dergisi 25.

Kim K, Hwang S, Sarava VS, Sa T (2012) Effect of Brevibacterium iodinum RS16 and Methylobacterium oryzae CBMB20 Inoculation on Seed Germination and Early Growth of Maize and Sorghum-sudangrass hybrid Seedling under Different Salinity Levels. Korean Society of Soil Sciences and Fertilizer 45: 51-58.

Kong Z, Glick BR (2017) The Role of Plant Growth-Promoting Bacteria in Metal Phytoremediation. Advances in Microbial Physiology 71: 97-132. doi:10.1016/bs.ampbs.2017.04.001.

Laemmli UK (1970) Cleavage of Structural Proteins during the Assembly of the Head of Bacteriophage T4. Nature 227(5259): 680-685. doi:10.1038/227680a0.

Larcher W. (2003) Physiological plant ecology: ecophysiology and stress physiology of functional groups. Springer Science and Business Media.

Leboffe MJ, Pierce BE (2021) A Photographic Atlas For The Microbiology Laboratory: Catalase Test. Morton Publishing Company, Englewood, Colorado.

Li HP, Ma H Bin, Zhang JL (2025) Halo-tolerant plant growth-promoting bacteria-mediated plant salt resistance and microbiome-based solutions for sustainable agriculture in saline soils. FEMS Microbiology Ecology 101: 37. doi:10.1093/FEMSEC/FIAF037.

Li HQ, Jiang XW (2017) Inoculation with plant growth-promoting bacteria (PGPB) improves salt tolerance of maize seedling. Russian Journal of Plant Physiology 64(2): 235-241. doi:10.1134/S1021443717020078.

Liu RF, Huang CL, Feng H (2015) Salt stress represses production of extracellular proteases in Bacillus pumilus. Genetics and Molecular Research 14: 4939-4948. doi:10.4238/2015.May.11.27.

Liu Y, Gao J, Wang N, Li X, Fang N, Zhuang X (2022) Diffusible signal factor enhances the saline-alkaline resistance and rhizosphere colonization of Stenotrophomonas rhizophila by coordinating optimal metabolism. Science of the Total Environment 834. doi:10.1016/j.scitotenv.2022.155403.

Madigan M, Martinko J, Parker J (1997) Brock biology of microorganisms. Upper Saddle River, NJ, Prentice hall.

Manghwar H, Zaman W (2024) Plant Biotic and Abiotic Stresses. Life 14(3): 372. doi:10.3390/LIFE14030372.

Mayak S, Tirosh T, Glick BR (2004) Plant growth-promoting bacteria that confer resistance to water stress in tomatoes and peppers. Plant Science 166: 525-530. doi:10.1016/J.PLANTSCI.2003.10.025.

Öztürk Y, Tatar N, Çarpıcı EB (2018) Tuz stresi koşullarında polietilen glikol ön uygulamalarının kamışsı yumak (*Festuca arundinacea* Schreb.) tohumlarının çimlenme özellikleri üzerine etkilerinin belirlenmesi. Uludağ Üniversitesi Ziraat Fakültesi Dergisi 32(1): 141-149. https://dergipark.org.tr/tr/pub/ziraatuludag/article/430302.

Rahman MM, Yamamoto M, Niimi M, Kawamura O (2008) Effect of nitrogen fertilization on oxalate content in rhodesgrass, guineagrass and sudangrass. Asian-Australasian Journal of Animal Sciences 21: 214-219. doi:10.5713/AJAS.2008.70350.

Ribbeck-Busch K, Roder A, Hasse D, De Boer W, Martínez JL, Hagemann M, Berg G (2005) A molecular biological protocol to distinguish potentially human-pathogenic strains of *Stenotrophomonas maltophilia* from non-pathogenic S. rhizophila strains. Environmental Microbiology 7: 1853-1858. doi:10.1111/J.1462-2920.2005.00928.X.

Roder A, Hoffmann E, Hagemann M, Berg G (2005) Synthesis of the compatible solutes glucosylglycerol and trehalose by salt-stressed cells of *Stenotrophomonas strains*. FEMS Microbiology Letters 243: 219-226. doi:10.1016/J.FEMSLE.2004.12.005.

Ryan RP, Monchy S, Cardinale M, Taghavi S, Crossman L, Avison MB, Berg G, van der Lelie D, Dow JM (2009) The versatility and adaptation of bacteria from the genus *Stenotrophomonas*. Nature Reviews Microbiology 7: 514-525. doi:10.1038/NRMICRO2163.

Schmidt CS, Alavi M, Cardinale M, Müller H, Berg G (2012) *Stenotrophomonas rhizophila* DSM14405 T promotes plant growth probably by altering fungal communities in the rhizosphere. Biology and Fertility of Soils 48: 947-960. doi:10.1007/S00374-012-0688-Z.

Szymanska S, Tyburski J, Piernik A, Sikora M, Mazur J, Katarzyna H (2020) Raising Beet Tolerance to Salinity through Bioaugmentation with Halotolerant Endophytes. Agronomy 10: 1571. doi:10.3390/agronomy10101571.

Tort N (1996) Effects of light, different growth media, temperature and salt concentrations on germination of cotton seeds (Gossypium hirsutum L. cv. Nazilli 87). Journal of Agronomy and Crop Science 176: 217-221. doi:10.1111/J.1439-037X.1996.TB00466.X.

Turhan A, Şeniz V (2010) Farklı tuz konsantrasyonlarının Türkiye'de yetiştirilen bazı domates genotiplerinin çimlenmesi üzerine etkileri. Uludağ Üniversitesi Ziraat Fakültesi Dergisi 24: 11-22.

Ünlü E, Semih Y, Halit Y, Abdul AK, Gün B, Abeer BI (2024) Characterization of multi-trait plant growth-promoting rhizobacteria isolated from alfalfa rhizosphere and evaluation of their efficacy on tomato and watermelon growth. Discover Agriculture 2(1): 117. doi:10.1007/S44279-024-00125-Z.

Yang X, Dai Z, Yuan R, Guo Z, Xi H, He Z, Wei M (2023) Effects of Salinity on Assembly Characteristics and Function of Microbial Communities in the Phyllosphere and Rhizosphere of Salt-Tolerant Avicennia marina Mangrove Species. Microbiology Spectrum 11. doi:10.1128/spectrum.03000-22.

Yilmaz S (2010) Molecular characterization of Bacillus thuringiensis strains isolated from different locations and their effectiveness on some pest insects. PhD Thesis, Erciyes University, Kayseri.

Yoon JH, Kim IG, Kang KH, Oh TK, Park YH (2003) Bacillus marisflavi sp. nov. and Bacillus aquimaris sp. nov., isolated from sea water of a tidal flat of the Yellow Sea in Korea. International Journal of Systematic and Evolutionary Microbiology 53: 1297-1303. doi:10.1099/IJS.0.02365-0.

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