



Advances in biology through agronomy, aquaculture, coastal and environmental sciences

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Editors

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**Advances in biology through
agronomy, aquaculture, coastal and
environmental sciences**
Volume II



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Advances in Biology through Agronomy, Aquaculture, Coastal and Environmental Sciences, Volume II, is an e-book that continues the work of the first version (<https://editorapantanal.com.br/ebooks/2023/advances-in-biology-through-agronomy-aquaculture-coastal-and-environmental-sciences/ebook.pdf>), published in 2023 by Leandris Argente!-Martínez and Ofelda Peñuelas-Rubio.

Our e-book compiles 25 manuscripts that present scientific results and reviews based on biological aspects. All of them contribute to explaining the responses of living organisms to agricultural, aquaculture, and coastal ecosystems, as well as those facing fragility or threat of climate change. This e-book was edited by Leandris Argente!-Martínez, Ofelda Peñuelas-Rubio, and Joe Luis Arias-Mosc!so, members of the Consolidated Academic Group ITVAYA-CA-3.

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The Editors

Prologue	4
Agronomy	
Chapter 1	9
The reduction in chemical fertilization combined with PGPM under a controlled deficit irrigation system for maize	
Chapter 2	22
Effects of sowing date and size on the physical and physiological quality of bread wheat seeds in southern Sonora, Mexico	
Chapter 3	35
Morphophysiological response and yield of tomato (<i>Solanum lycopersicum</i> L.) to growth regulators and glutamic acid	
Chapter 4	49
Influence of benzoxazinoid metabolites in maize roots interacting with diverse microbes	
Chapter 5	64
Comparison of RGB spectrum vegetation indices to estimate agronomic variables in wheat and oats	
Chapter 6	74
Alleviation of saline stress in maize and peanut plants induced by <i>Bacillus aryabhattai</i> strain CMAA 1363	
Chapter 7	92
Bacterial consortia as a sustainable strategy for disease management and productivity improvement in maize	
Chapter 8	109
Agronomic management for oat seed production in the Bajío region, Mexico	
Chapter 9	125
Risk factors in loading and unloading operations of agricultural products in land transport units at a company in Veracruz, Mexico	
Chapter 10	145
Physicochemical characterization of four varieties of durum wheat (<i>Triticum durum</i> Desf.) under full irrigation and reduced irrigation conditions	
Chapter 11	161
Antifungal activity of edible chitosan coatings and <i>Coriandrum sativum</i> L. essential oil against <i>Colletotrichum gloeosporioides</i> and their application on mango fruits	
Chapter 12	175
Agricultural gypsum with micronutrients in citrus cultivation	
Chapter 13	186

Initial Agronomic Adaptation of *Stevia rebaudiana* Bertoni in the High Mountain Region of Veracruz and Sustainable Management of *Planococcus citri* Using a Neem-Based Bioinsecticide

Chapter 14 197

Evaluation of yield components of two F1 maize hybrids under controlled deficit irrigation in a moderately saline vertisol soil in Yaqui Valley, Sonora, Mexico

Aquaculture

Chapter 15 207

Effects of partially replacing fish meal with mesquite pod meal (*Prosopis juliflora*) on the growth of Nile tilapia (*Oreochromis niloticus*)

Chapter 16 220

Consumer preferences and value-added opportunities in the commercialization of *Oreochromis niloticus* in Tenosique, Tabasco, México

Chapter 17 228

Partial substitution of pechita (*Prosopis glandulosa*) and alfalfa (*Medicago sativa*) flour with commercial flour in diets for tilapia (*Oreochromis niloticus*) farming

Chapter 18 239

Hydrolysate of the alga *Spirulina* influences the proliferation, growth, and development of *Spathiphyllum uxpanapense* *in vitro*

Chapter 19 251

Growth of the wild juvenile common snook *Centropomus undecimalis* in captivity

Coastal Sciences

Chapter 20 260

Notes on the recreational fishing of snook (*Centropomus* spp.) in the coastal zone of Centla, Tabasco, Mexico

Chapter 21 268

Linkage among climatic variation and artisanal fisheries behavior of common snook (*Centropomus undecimalis*) in tropical Atlantic coast

Environmental Sciences

Chapter 22 277

Fungal-based arsenic bioremediation: linking enzymatic detoxification mechanisms with bioreactor engineering

Chapter 23 292

Simplified dynamic modeling for scenario analysis of the anaerobic digestion of fruit and vegetable waste

Chapter 24 303

Impact of biofertilizers on wheat (*Triticum aestivum* L.) yield in different environments of the Bajío region of Guanajuato

Chapter 25 326

Genomic Reprogramming and Epigenetic Memory: Transforming Somaclonal Variation into a Tool for Climate Resilience

Chapter 26	351
Research on the use of rhizobacteria for the biodegradation of herbicides and insecticides in agriculture and their effects on environmental protection	
Index	360
About the editors	362

Alleviation of saline stress in maize and peanut plants induced by *Bacillus aryabhatai* strain CMAA 1363

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ABSTRACT

Salinity caused by the excess dissolved salts in the soil solution or irrigation water is among the abiotic stresses that most limit the development and yield of agricultural crops. This study was conducted with the objective of evaluating the effect of inoculation of the *Bacillus aryabhatai* strain CMAA 1363 on the induction of tolerance in maize (*Zea mays* L.) and peanut (*Arachis hypogaea* L.) plants grown under high-salinity conditions. Two bioassays were conducted to investigate the effects of *Bacillus aryabhatai* strain CMAA 1363 on the growth and vigor of maize (Bioassay 1) and peanut (Bioassay 2) plants grown under different salinity levels. The two bioassays were arranged in a completely randomized experimental design in a 2 × 4 factorial scheme with four replicates of 50 seeds. The studies consisted of two microbial treatments (noninoculated plants (control) and plants inoculated with *B. aryabhatai* strain CMAA 1363) and four levels of irrigation water salinity [0.0 MPa (control), −0.1 MPa (mild saline stress), −0.4 MPa (moderate saline stress) and −0.8 MPa (severe saline stress)]. The germination capacity (GC), germination speed index (GSI), mean germination time (MGT), mean germination rate (MGR) and early growth of the maize and peanut plants were measured. Inoculation with the *Bacillus aryabhatai* strain CMAA 1363 effectively mitigated the negative effects of salt stress on maize and peanut plants. These findings indicate that inoculation with *B. aryabhatai* in maize and peanut plants may be a sustainable alternative to enhance

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the development of maize and peanut crops under saline soil conditions or with the use of saline water for irrigation.

Keywords: Salinity; agricultural crops; *Zea mays* L.; *Arachis hypogea* L.

INTRODUÇÃO

Salinity caused by the excess dissolved salts in the soil solution or irrigation water is among the abiotic stresses that most limit the development and yield of agricultural crops (Zuffo et al., 2020; Atta et al., 2023; Khasanov et al., 2023). Currently, approximately 40% of the world's food is produced in irrigated areas, with Brazil being the sixth largest producer of food in irrigated areas in the world (i.e., 8.5 million hectares irrigated) (FAO, 2023). However, approximately 20–25% of the world's irrigated areas suffer from soil salinization (Hassan et al., 2021; Khasanov et al., 2023). Soil salinization has intensified in recent years because of the inappropriate and excessive use of mineral fertilizers, inadequate irrigation and drainage management, and irrigation with saline water (Stavi et al., 2021). In Brazil, soil salinity is more common in the arid and semiarid regions of the northeast and in the Pantanal region (Pessoa et al., 2022).

The effects of soil or irrigation water salinity on plants can occur directly and indirectly. Salinity stress directly affects plant growth through osmotic, ionic, and oxidative effects (Acosta-Motos et al., 2017; Taiz et al., 2017). The osmotic effect reduces the water potential of the soil solution, delaying the germination rate and plant growth because of limited water absorption by seeds and plants (Acosta-Motos et al., 2017; Zuffo et al., 2020). Ionic and oxidative effects result from the accumulation of specific phytotoxic ions that increase the production of reactive oxygen species (ROS), ionic imbalance of the cytosol, damage to the functions of cell membranes and walls, and interference in the physiological processes of plants (indirect effects) (Acosta-Motos et al., 2017; Zelm et al., 2020; Gong, 2021).

The response of plants to saline stress includes a series of biochemical, physiological, and morphological changes (Acosta-Motos et al., 2017; Kumar et al., 2020; Gao et al., 2022), which constitute the strategies and/or mechanisms of plant tolerance to salinity. The main tolerance strategies for mitigating saline stress are associated with increased water use efficiency, the production of plant hormones, osmotic adjustment, the production of antioxidant enzymes, and the activation of cellular signaling and messengers that improve plant metabolic reactions under saline conditions (Numan et al., 2018). These strategies aim to maintain plant growth and development under saline conditions. However, the plant response depends on the severity of the stress and the plant species or genotype (Taiz et al., 2017). Maize (*Zea mays* L.) and peanut (*Arachis hypogea* L.) plants are considered moderately salinity-tolerant crops, with soil salinity thresholds of 1.7 and 3.2 dS m⁻¹, respectively (Gheyi et al., 2016). However, relatively high salinity levels can drastically affect plant germination and growth.

Among the strategies used to mitigate the adverse effects induced by salinity, the application of biofertilizers based on plant growth-promoting rhizobacteria (PGPR) has been used to improve the germination uniformity and plant growth rate under saline stress conditions (Numan et al., 2018; Kumar et al., 2020; Mishra et al., 2021; Gao et al., 2022). Some PGPR possess specialized mechanisms that play key roles in salinity tolerance and plant growth stimulation. These bacteria improve hormonal and nutritional metabolism, osmotic regulation, signal transduction, and the synthesis of volatile organic compounds (acetoin and 2,3-butanediol), which can stimulate plant growth, especially in the root system, and improve the recovery capacity of seedlings when they are exposed to saline stress (Numan et al., 2018; Sarkar et al., 2018; Ayaz et al., 2022).

Among the PGPR with the potential to mitigate the adverse effects of salinity, species of the genus *Bacillus* have been extensively studied for the inoculation of some agricultural plants (Liu et al., 2017; Ferreira et al., 2018; Ansari et al., 2019; Ibarra-Villarreal et al., 2021; Ayaz et al., 2022). Upadhyay & Singh (2015) reported that the application of *Bacillus aquimaris* increased nutrient uptake by wheat plants, resulting in greater tolerance to saline conditions. Ansari et al. (2019) reported that inoculation with *B. pumilus* stimulated plant growth and alleviated saline stress in wheat plants. Similarly, Ferreira et al. (2018) reported that inoculation with *B. subtilis* improved plant growth and attenuated the biochemical damage induced by saline stress in maize plants. Other studies have also proven the effectiveness of using *B. pumilus* in rice plants (Khan et al., 2016), *B. paralicheniformis* in wheat plants (Ibarra-Villarreal et al., 2021), and *B. amyloliquefaciens* in *Arabidopsis thaliana* plants (Liu et al., 2017) and rice (Nautiyal et al., 2013) in improving plant tolerance to salinity. However, the effects of *Bacillus aryabhattai* inoculation on the induction of plant tolerance to salinity are still unclear.

This study was conducted with the objective of evaluating the effect of inoculation of the *Bacillus aryabhattai* strain CMAA 1363 on the induction of tolerance in maize (*Zea mays* L.) and peanut (*Arachis hypogaea* L.) plants grown under high-salinity conditions.

MATERIAL E MÉTODOS

Plant material and treatments

Two bioassays were conducted at the Laboratory of Plant Ecophysiology and Sustainable Agriculture (L-PESA), State University of Mato Grosso do Sul, Cassilândia, Mato Grosso do Sul, Brazil, to investigate the effects of *Bacillus aryabhattai* strain CMAA 1363 on the growth and vigor of maize (Bioassay 1) and peanut (Bioassay 2) plants grown under different salinity levels. Seeds from commercial maize and peanut genotypes were purchased from agricultural retailers in the municipality of Chapadão do Sul, Mato Grosso do Sul, Brazil. These genotypes were chosen because they are widely recommended for cultivation in the Brazilian Cerrado region. The main characteristics of the maize and peanut seeds are shown in Table 1.

Table 1. Water content, thousand-seed mass and germination rate of the maize and peanut seeds used in this study

Crop	Cultivar	Water content (%)	Thousand seed mass (g)	Germination (%)
Maize	DKB 360 PRO3	11.58	242	100
Peanut	IAC 503	6.30	778	94

Microorganisms

The *B. aryabhattai* strain CMAA 1363 used in this study originated from the commercial inoculant Auras[®], a product licensed by Embrapa and marketed by NOOA Ciência e Tecnologia Agrícola and registered in the Ministry of Agriculture, Livestock and Food Supply—MAPA under N° 0007579000003. This bacterial strain was initially isolated from the mandacaru root in the Brazilian caatinga biome and belongs to the microorganism collection of Embrapa Meio Ambiente (Kavamura et al., 2017). For inoculum development, the commercial strain CMAA 1363 was grown in Petri dishes (9.0 × 1.5 cm) with solid Luria Bertani (LB) culture medium (10 g L⁻¹ peptone, 5 g L⁻¹ yeast extract, 5 g L⁻¹ NaCl, 15 g L⁻¹ agar; pH 7.0) for 72 h at 28 ± 2 °C, 60% relative humidity and a 12 h photoperiod. After the incubation period, the concentration of the strain CMAA 1363 was evaluated using the serial dilution method and standardized to 1.0 × 10⁹ colony forming units per milliliter (CFU mL⁻¹).

Experimental Design and Treatments

The two bioassays were arranged in a completely randomized experimental design in a 2 × 4 factorial scheme with four replicates of 50 seeds. The studies consisted of two microbial treatments (noninoculated plants (control) and plants inoculated with *B. aryabhattai* strain CMAA 1363) and four levels of irrigation water salinity [0.0 MPa (control), -0.1 MPa (mild saline stress), -0.4 MPa (moderate saline stress) and -0.8 MPa (severe saline stress)].

The strains of *B. aryabhattai* CMAA 1363 were applied to the sowing furrow at a dosage of 2.0 L ha⁻¹ of the suspension containing the microbial inoculum (100 µL of microbial solution per meter of sowing furrow) at a concentration of 1.0 × 10⁹ CFU mL⁻¹. The solution containing the microbial inoculum was applied to the seeding furrow using a micropipette and adjusted to apply 6.0 mL of solution per meter of furrow (equivalent to 120 L ha⁻¹ of spray volume).

The plants were irrigated daily with iso-osmotic solutions of 0.0, -0.10, -0.40 and -0.80 MPa prepared with sodium chloride (NaCl). The amount of NaCl added to obtain saline solutions with distinct levels of osmotic pressure was calculated by the van't Hoff equation (Hillel, 1971): $\Psi_s = -RTC_i$, where Ψ_s is the osmotic pressure (MPa), R is the universal constant of noble gas (0.008314 MPa mol⁻¹ K⁻¹), T is the absolute temperature (273.15 + °C), C is the molar concentration of the solute (mol L⁻¹) and i is

the van't Hoff factor, that is, the number of ions released when the solute is dissolved in water [i.e., for NaCl, this value is 2.0 (Na^+ and Cl^-)].

Plant Growth Conditions

The seeds were sown in plastic containers ($44 \times 30 \times 7.5$ cm) filled with sterilized quartz sand at a depth of 2.0 cm. The sand was sieved through a mesh with a diameter of 0.05 to 0.8 mm and then moistened with different solutions at 70% of the substrate's water retention capacity (BRASIL, 2009), which was equivalent to 150 mL kg^{-1} aqueous solution. The plastic containers were kept under laboratory conditions using artificial light supplemented with red (620–630 nm) and blue (455–475 nm) wavelengths at ratios of 85% (red) and 15% (blue) from light-emitting diodes (LEDs) at a $180 \pm 50 \mu\text{mol m}^{-2} \text{ s}^{-1}$ light intensity, a 12/12 h photoperiod (light/darkness), and a temperature of $25.4 \text{ }^\circ\text{C}$ ($\pm 2.1 \text{ }^\circ\text{C}$) for 18 days. The substrate moisture content was monitored daily at 3:00 p.m. using the gravimetric method by weighing the plastic containers. The moisture content of the substrate was maintained at 70% of the water retention capacity of the sand through daily irrigation.

Measurements of Germination and Seedling Growth

The germination capacity (GC), germination speed index (GSI), mean germination time (MGT), mean germination rate (MGR) and early growth of the maize and peanut plants were measured. Equations 1–5 and the parameters therein were employed to express the seed germination and plant vigor index.

$$\text{GC (\%)} = S_{\text{NG}}/S_{\text{N0}} \times 100 \quad [\text{Eq. 1}]$$

where GC is the germination capacity, S_{NG} is the number of germinated seeds, and S_{N0} is the number of viable experimental seeds (50 seeds).

$$\text{GSI} = \Sigma(n_i/t_i) \quad [\text{Eq. 2}]$$

where GSI is the germination speed index (seed day^{-1}), n_i is the number of germinated seeds on a given day, and t_i is the time in days from the sowing day (Maguire, 1962).

$$\text{MGT} = (\Sigma n_i t_i) / \Sigma n_i \quad [\text{Eq. 3}]$$

where MGT is the mean germination time (day), n_i is the number of germinated seeds on a given day, and t_i is the time in days from the sowing day (Laboriau, 1983).

$$\text{LVI} = [\text{TL(m)} \times \text{GC (\%)}] \quad [\text{Eq. 4}]$$

where LVI is the plant length vigor index, TL is the total plant length and GC is the seed germination capacity (Abdul-Baki and Anderson, 1973).

$$\text{WVI} = \text{TDM(g)} \times \text{GC (\%)} \quad [\text{Eq. 5}]$$

where WVI is the plant weight vigor index, RDM is the total dry matter and GC is the seed germination capacity (Abdul-Baki and Anderson, 1973).

After 18 days of exposure to salinity stress, ten seedlings per replicate were randomly chosen to measure the length and dry matter of the shoot and roots. The shoot length (SL), root length (RL), and total plant length (TL) were measured using a meter scale. The shoot dry matter (SDM), root dry matter (RDM), and total plant dry matter (TDM) were recorded on an analytical balance (± 0.0001 g) after oven drying at 85 °C for 48 h.

Statistical analysis

The data were previously tested for homoscedasticity of variances (Levene test; $p > 0.05$) and normality of residues (Kolmogorov–Smirnov test; $p > 0.05$) and then subjected to analysis of variance (ANOVA). The means of the treatments were compared by the Tukey test at the 0.05 level of confidence. The analyses were performed using Rbio[®] software version 140 for Windows (Rbio Software, UFV, Viçosa, MG, BRA).

RESULTADOS E DISCUSSÃO

In bioassay 1, analysis of variance revealed significant effects ($p < 0.05$) of *Bacillus aryabhattai* inoculation and salinity level on most germination, initial growth, and vigor traits of the maize plants, except for germination capacity. The interaction effect between *B. aryabhattai* inoculation and salinity level was significant ($p < 0.05$) for most of the evaluated characteristics, except for germination capacity (Table 2).

Table 2. Summary of the analysis of variance for the effects of microbial inoculation with *Bacillus aryabhattai* and salinity levels on the germination traits, initial growth, and vigor of maize and peanut plants.

Causes of variation	Probability > F										
	GC	GSI	MGT	SL	RL	TL	SDM	RDM	TDM	LVI	WVI
Bioassay 1 (Maize)											
Microbial inoculation (I)	0.25	0.08	0.04	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.01
Salinity level (S)	0.12	0.01	0.02	0.01	0.01	0.01	0.01	0.03	0.01	0.01	0.02
I × S	0.32	0.04	0.01	0.04	0.01	0.01	0.01	0.02	0.01	0.02	0.01
CV (%)	4.78	5.34	4.78	8.95	7.56	6.92	8.39	7.64	9.21	6.71	7.47
Bioassay 2 (Peanuts)											
Microbial inoculation (I)	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Salinity level (S)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
I × S	0.02	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.04	0.03	0.04
CV (%)	7.53	9.03	8.57	4.35	5.59	4.02	9.14	8.17	6.48	8.85	9.86

GC: germination capacity; GSI: germination speed index; MGT: mean germination time; SL: shoot length; RL: root length; TL: total plant length; SDM: shoot dry matter; RDM: root dry matter; TDM: total plant dry matter; LVI: plant length vigor index; WVI: plant weight vigor index.

In bioassay 2, the results of the analysis of variance revealed that the effects of isolation and interactions between *B. aryabhatai* inoculation and salinity level were significant ($p < 0.05$) for all the traits of germination, initial growth, and vigor of the peanut plants (Table 2).

The coefficient of variation (CV) values obtained in the two experimental trials were less than 10% for all the dependent variables measured in the maize and peanut seedlings, a value considered low for the agricultural experiments (Table 2). According to Gomes (2000), the CV is a measure of dispersion used to estimate the precision of the experiment, and when the values are less than 10%, it indicates that the results of the experimental trial have excellent precision.

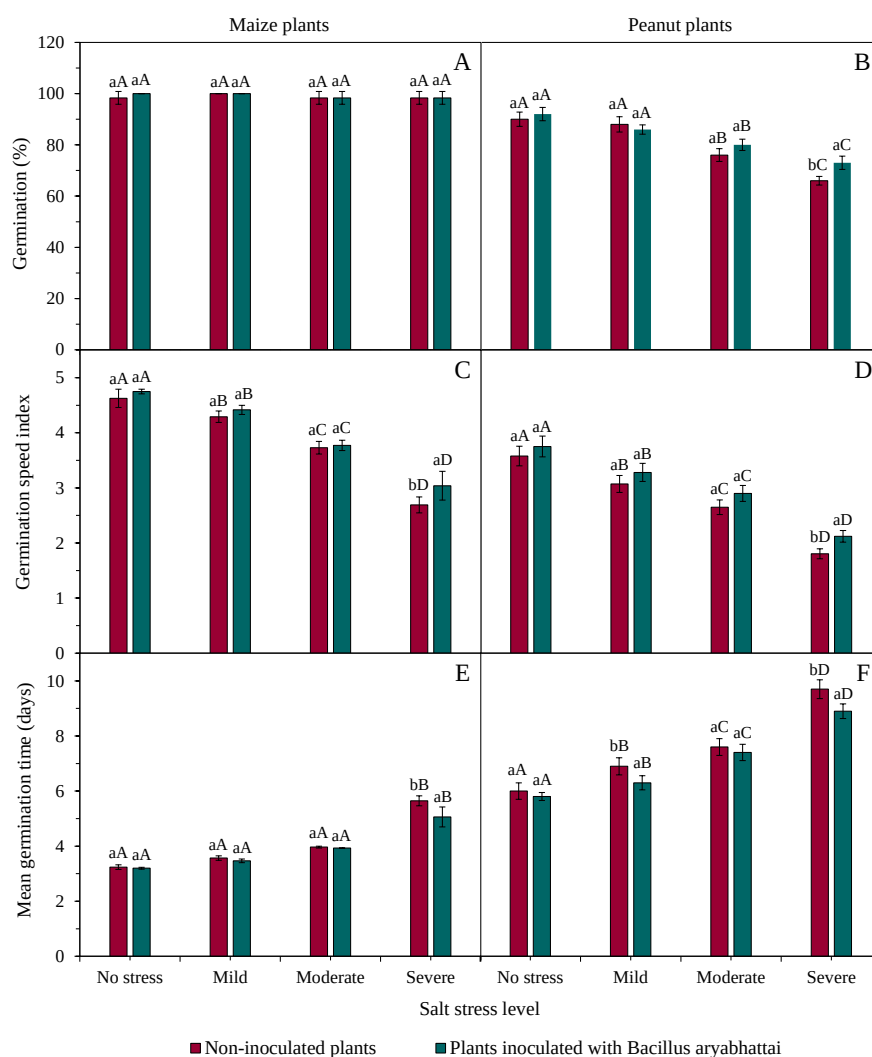


Figure 1. Effects of salinity on the germination capacity (A and B), germination speed index (C and D), and mean germination time (E and F) of maize (A, C, E) and peanut (B, D, F) plants not inoculated or inoculated with *Bacillus aryabhatai* strain CMAA 1363. Bars followed by distinct letters, lowercase for *B. aryabhatai* inoculation or uppercase for salinity levels, show significant differences according to Tukey's test at 5% probability. Data refer to mean values ($n = 40$) $\pm$ standard error of the mean.

Inoculation with *B. aryabhatai* and irrigation water did not affect the germination capacity of maize seeds (Figure 1A). However, when peanut seeds were subjected to moderate and severe salinity stress,

the seed germination capacity was significantly lower than that in the no-stress and mild-stress treatments. Nevertheless, under severe salinity stress conditions, the germination capacity of peanut seeds increased with increasing *B. aryabhatai* inoculation (Figure 1B). These results showed that *B. aryabhatai* inoculation was effective at improving peanut seed germination capacity under severe salinity conditions, confirming the results reported by Lessa et al. (2022).

The increased salinity resulted in a reduction in the germination speed index of maize (Figure 1C) and peanut (Figure 1D) seeds. Oliveira et al. (2022) reported a significant reduction in the germination speed index and germination capacity of tomato seeds with increasing salinity levels in irrigation water. Under saline conditions, the soil water potential decreases, resulting in a lower capacity for water absorption by the seeds, affecting the imbibition process, germination speed, and seed germination capacity (Taiz et al., 2017). However, under severe salinity stress, compared with noninoculated plants, plants inoculated with *B. aryabhatai* presented a greater germination speed index. Similar results were reported by Abdallah et al. (2016) and Jasim et al. (2015), who reported that inoculation with *Bacillus* sp. was able to stimulate both germination and initial plant growth. This increase in seed germination speed may be associated with the ability of bacteria of the genus *Bacillus* to produce plant hormones (Kang et al., 2014), which stimulate the seed germination process.

Inoculation with *B. aryabhatai* and irrigation water did not affect the mean germination time of maize seeds up to moderate salinity levels (Figure 1E). However, compared with that under other salinity levels, the mean germination time under severe salinity stress was significantly longer. Nevertheless, inoculation with *B. aryabhatai* mitigated the delay in the germination process of maize seeds. Increased salinity levels resulted in increased mean emergence time of the peanut plants (Figure 1F). However, under mild and severe salinity stress, inoculation with *B. aryabhatai* reduced the average emergence time of peanut plants. These findings indicate that inoculation with *B. aryabhatai* has a beneficial effect against saline stress, mitigating the adverse effects of salinity and promoting the germination process.

Mild saline stress resulted in greater shoot length in maize plants (Figure 2A), with no differences between inoculated and noninoculated plants. However, *B. aryabhatai* inoculation had a positive effect on the shoot length of maize plants exposed to moderate stress. With respect to peanut plants, *B. aryabhatai* inoculation resulted in greater shoot length under mild saline stress conditions (Figure 2B). Similarly, Kavamura et al. (2013) reported that compared with noninoculated plants, plants inoculated with *Bacillus* sp. were 27% taller.

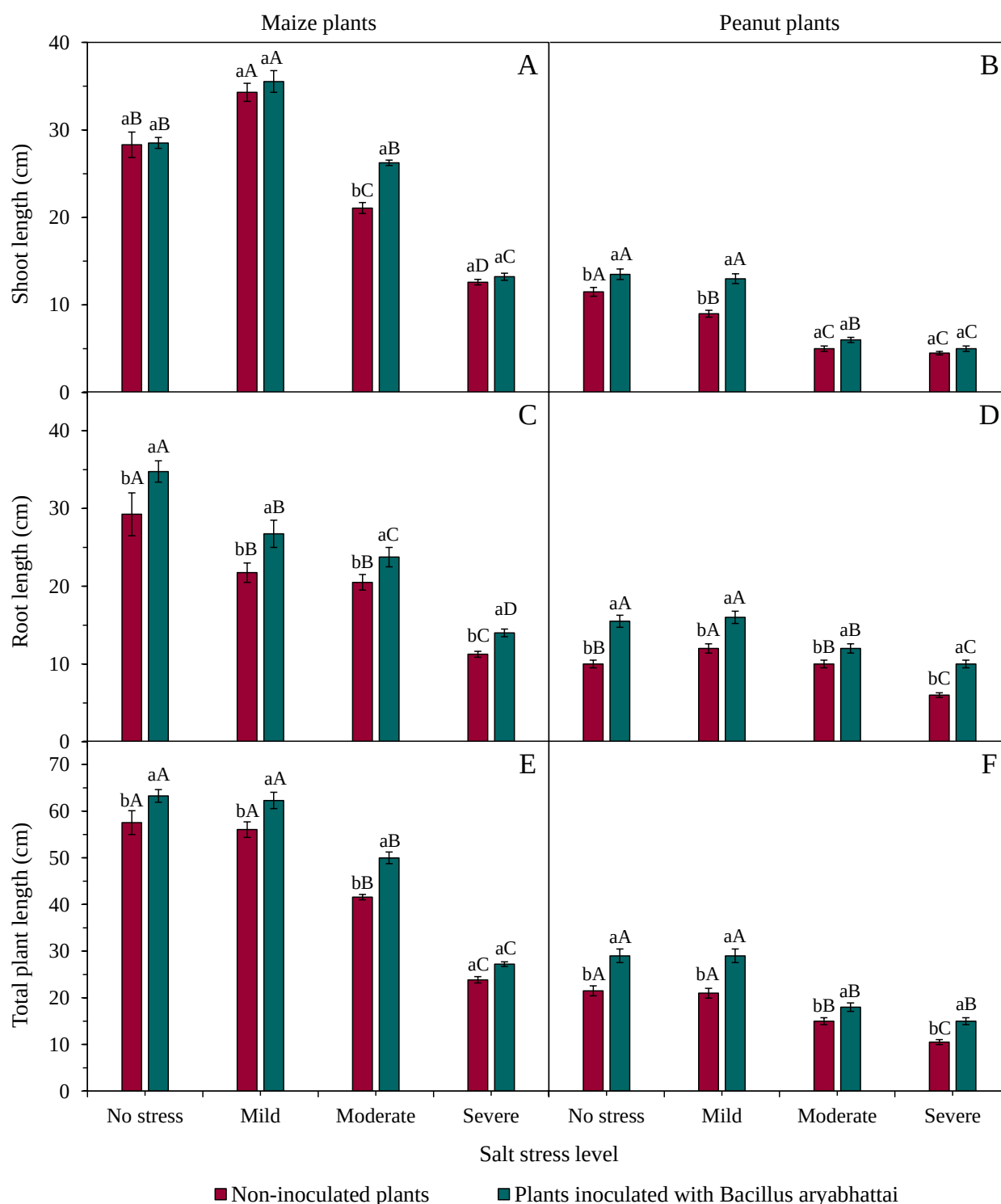


Figure 2. Effects of different levels of irrigation water on shoot length (A and B), root length (C and D) and total plant length (E and F) of maize plants (A, C, and E) and peanut plants (B, D, and F) uninoculated and inoculated with *Bacillus aryabhatai* CMAA 1363. Bars followed by distinct lowercase letters for the inoculation of *B. aryabhatai* or uppercase letters for the salinity levels are significantly different (Tukey test; $p \leq 0.05$). Data refer to mean values ($n = 40$) $\pm$ standard error.

The use of plant growth-promoting bacteria has contributed to combating the negative effects of abiotic factors (Alor et al., 2017). Tolerance to saline stress in various crops can be increased by bacteria

of the genus *Bacillus* (Paul; Harshad, 2024). Researchers report that the use of bacteria of the genus *Bacillus* acts on multiple mechanisms in plants, such as biological nitrogen fixation (Teixeira-Filho; Galindo., 2019; Galindo et al., 2020), increasing iron availability (Sivasakth et al., 2014), and solubilizing and transporting phosphorus and zinc (Jalal et al., 2022; Rosa et al., 2022). In addition, they improve plant growth and development through the production of plant hormones such as gibberellins, cytokinins, auxins, and salicylic acid (Zaheer et al., 2019). Tiwari et al. (2017) reported that compared with noninoculated rice plants, plants inoculated with *Bacillus amyloliquefaciens* presented increased total soluble sugar levels. In this study, inoculation with *B. aryabhattai* also improved the growth of maize (Figure 3) and peanut (Figure 4) plants, indicating the high potential for using this bacterium in the development of modern and sustainable agriculture.

The greatest root length was observed in maize and peanut plants inoculated with *B. aryabhattai* at all salinity levels (Figures 3 and 4). However, increasing the salinity level of the irrigation water limited root growth (Figures 2C and 2D). Lee et al. (2017) reported that the *B. aryabhattai* strain SR02 improved the growth of soybean and rice plants. These researchers reported that the SR02 strain can synthesize plant hormones (gibberellin and abscisic acid), which are responsible for the significant increase in the number of soybean roots. Yuan et al. (2015) reported that the NJN-6 strain of *B. amyloliquefaciens* was able to synthesize organic acids in banana roots, which improved root growth in these plants.

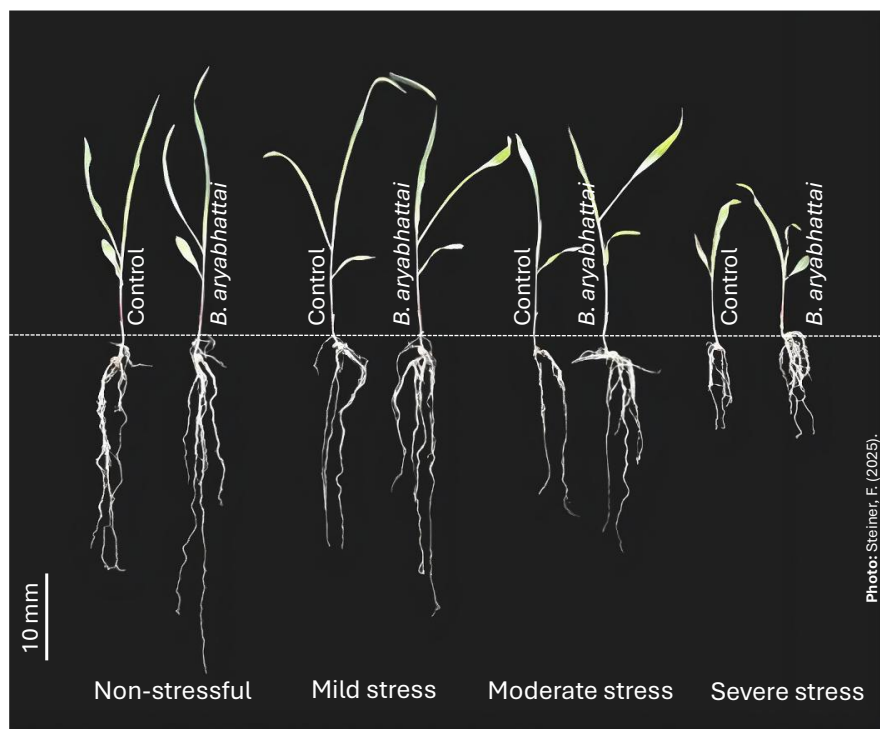


Figure 3. Maize plants (*Zea mays* L.) were irrigated for 18 days with different levels of irrigation water salinity and inoculated with *Bacillus aryabhattai* strain CMAA 1363.

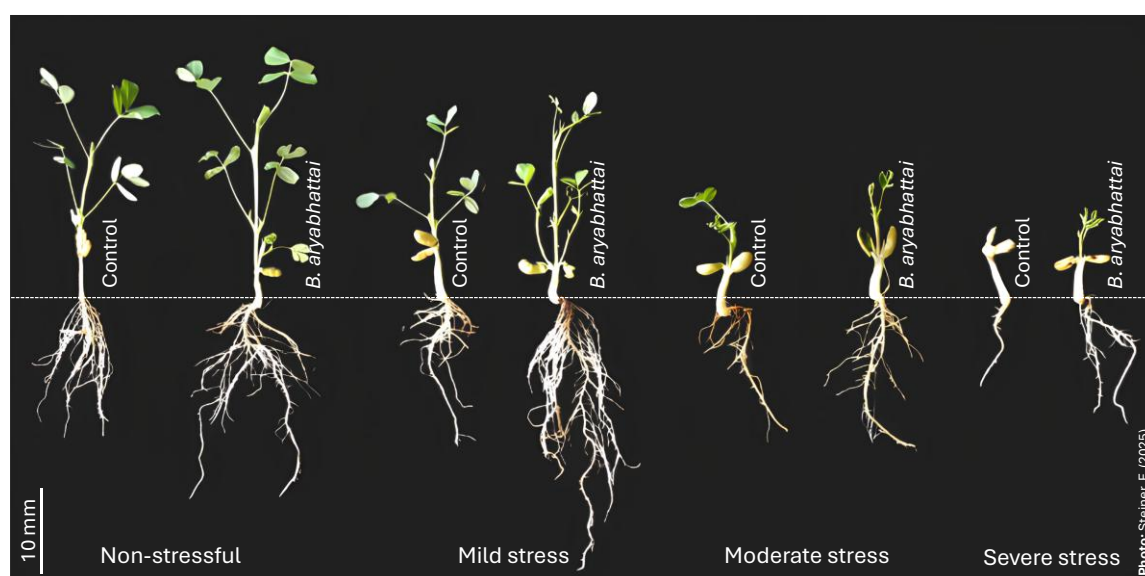


Figure 4. Peanut plants (*Arachis hypogaea* L.) were irrigated for 18 days with different levels of irrigation water salinity and inoculated with *Bacillus aryabhatai* strain CMAA 1363.

Similar results were reported by Maio et al. (2021), who reported that *B. aryabhatai* was able to stimulate root growth and promote greater soil water use efficiency. Metoui et al. (2020) reported that inoculation with *B. mojavensis* and *B. pumilus* promoted root growth and water and nutrient uptake in barley plants under saline stress. Islam et al. (2022) reported that saline stress, when induced by irrigation, limits water uptake by plants because of osmotic and physiological effects, in addition to causing biochemical changes that reduce water use efficiency.

The greatest accumulation of dry matter in maize roots occurred under control conditions and under moderate salinity stress. Regardless of the salinity level, compared with noninoculated plants, plants inoculated with *B. aryabhatai* had greater root dry matter (Figure 5C). With respect to the peanut plants, there was a reduction in root dry matter accumulation with increasing irrigation water salinity (Figure 7D). In turn, inoculation with *B. aryabhatai* did not result in a significant effect on peanut root accumulation under moderate and severe stress conditions.

Inoculation with *B. aryabhatai* had a significant effect on the total dry matter production of maize plants under severe saline stress conditions. However, there were no significant differences up to the moderate salinity level (Figure 5E). Conversely, the total dry matter production of peanut plants significantly decreased with increasing salinity levels in the irrigation water. However, inoculation with *B. aryabhatai* resulted in higher total dry matter production at all salinity levels (Figure 5F). These results demonstrate that bacteria of the genus *B. aryabhatai* can mitigate the effects of saline stress, in addition to promoting plant growth.

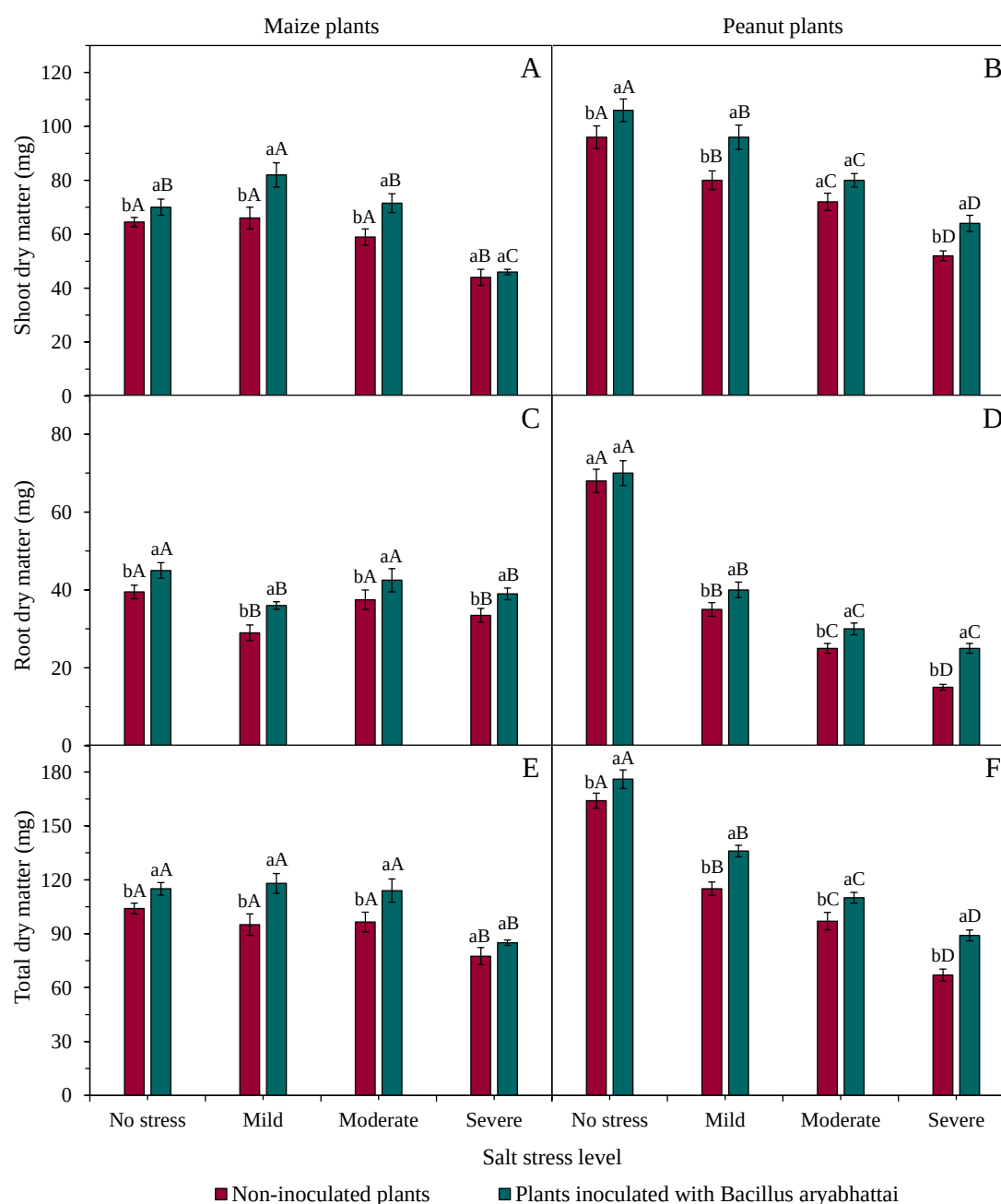


Figure 5. Effects of different levels of irrigation water on shoot dry matter (A and B), root dry matter (C and D) and total dry matter (E and F) in maize plants (A, C, and E) and peanut plants (B, D, and F) uninoculated and inoculated with *Bacillus aryabhattai* CMAA 1363. Bars followed by distinct lowercase letters for the inoculation of *B. aryabhattai* or uppercase letters for the salinity levels are significantly different (Tukey test; $p \leq 0.05$). Data refer to mean values ($n = 40$) $\pm$ standard error.

Xu et al. (2022) reported that *B. aryabhattai* isolated from wild plant species promoted the growth of *Arabidopsis*, *N. tabacum*, and other plant species. The isolate increased the size and dry matter of the plants evaluated, indicating that *B. aryabhattai* can stimulate the growth of a wide range of plant species. In addition to promoting plant growth through the activity of plant hormones and metabolites (Radhakrishnan; Lee, 2016), *Bacillus* species may assist in the induction of endogenous proteins, amino acids, and minerals that can promote plant growth (Radhakrishnan; Lee, 2016; Kang et al., 2014).

Mild saline stress levels did not significantly affect the plant length vigor index of maize or peanuts; however, from the moderate salinity level onward, there was a significant reduction in the plant length vigor index (Figures 6A and 6B). Nevertheless, at all the salinity stress levels tested, inoculation with *B. aryabhatai* was effective, with a greater length vigor index for both the maize and the peanut plants (Figures 6A and 6B).

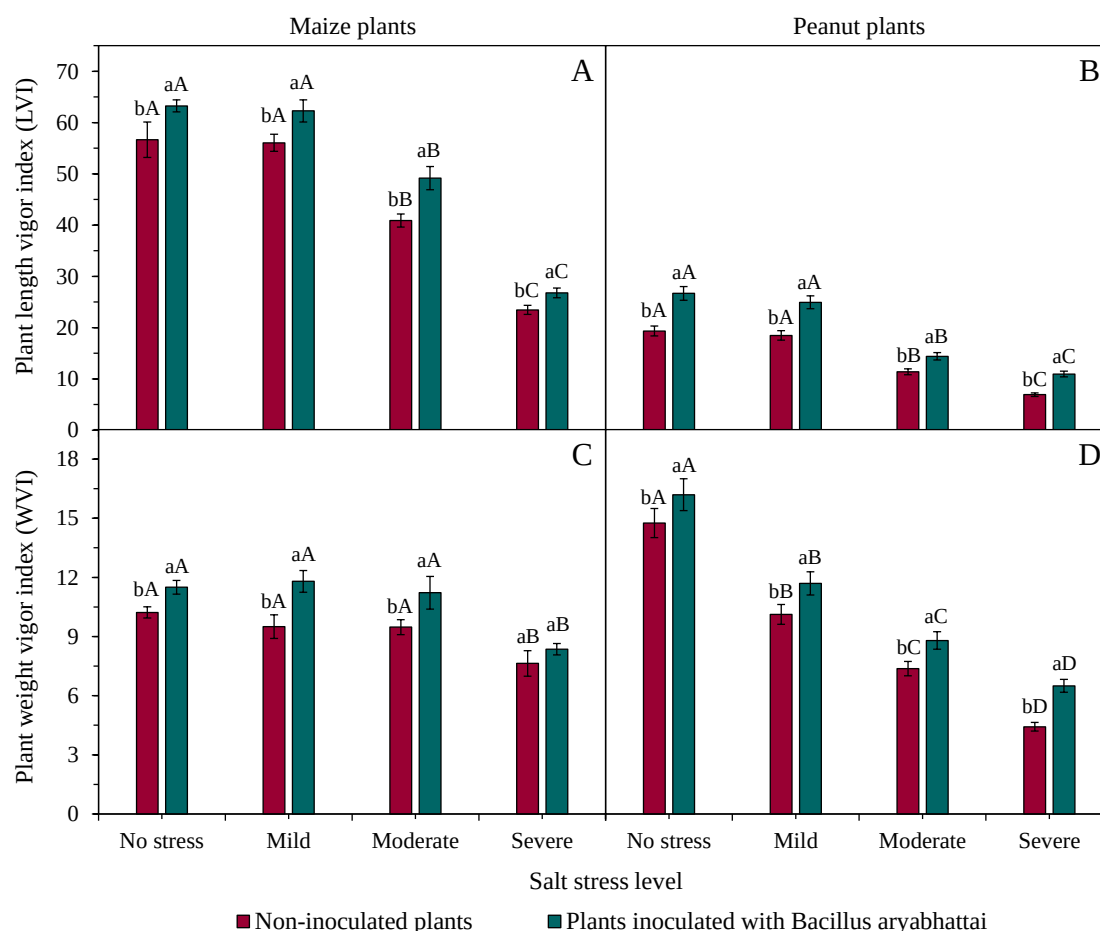


Figure 6. Effects of different levels of irrigation water on the plant length vigor index (A and B) and plant weight vigor index (C and D) of maize (A, C) and peanut plants (B and D) uninoculated and inoculated with *Bacillus aryabhatai* CMAA 1363. Bars followed by distinct lowercase letters for the inoculation of *B. aryabhatai* or uppercase letters for the salinity levels are significantly different (Tukey test; $p \leq 0.05$). Data refer to mean values ($n = 40$) $\pm$ standard error.

By studying the effects of *B. aryabhatai* inoculation under saline stress, reported that salinity affects water and nutrient absorption, resulting in a reduction in the stem diameter of maize plants. However, these effects were attenuated by the use of *B. aryabhatai*. Inoculation of *B. aryabhatai* in the early stages of plants can mitigate the adverse effects of abiotic stresses through biochemical changes in the plant, facilitating water and nutrient absorption (Maio et al., 2021; Qiu et al., 2021).

Sousa et al. (2021) reported that this decrease can be attributed to irrigation with saline water, since the salts present in irrigation water can inhibit the translocation and synthesis of the hormones

essential for plant growth, resulting in reduced dry matter production. In this study, at all the stress levels tested, the length vigor index increased in the *B. aryabhattai*-inoculated plants. Furthermore, at the other levels, the inoculated plants presented a greater weight vigor index.

Among the salinity levels, severe stress resulted in a reduction in the weight vigor index (WVI) of the maize plants, which did not significantly differ between the plants inoculated with *B. aryabhattai* and those not inoculated with *B. aryabhattai* (Figure 6C). On the other hand, the WVI of peanut plants decreased with increasing salinity. However, compared with noninoculated plants, plants inoculated with *B. aryabhattai* presented a greater WVI at all levels of salinity stress (Figure 6D).

Morais (2018) reported that inoculation with *B. aryabhattai* mitigated the negative effects of abiotic stress on soybean plants by activating the antioxidant defense system. Liu et al. (2017) reported that inoculation of *Arabidopsis thaliana* plants with the *Bacillus amyloliquefaciens* strain FZB42 could stimulate plant growth under both saline and nonsaline stress conditions.

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CONCLUSIONS

Inoculation with the *Bacillus aryabhattai* strain CMAA 1363 effectively mitigated the negative effects of salt stress on maize and peanut plants. These findings indicate that inoculation with *B. aryabhattai* in maize and peanut plants may be a sustainable alternative to enhance the development of maize and peanut crops under saline soil conditions or with the use of saline water for irrigation.

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A

Alfalfa, 256, 258, 261
 anaerobic digestion, 324, 325, 326, 330, 331
 Anthracnose, 184, 189
 Aquaculture, 280, 281
Arachis hypogea, 76
 Arsenic, 307, 309, 311, 316

B

Benzoxazinoids, 58
 Biomass yield, 9, 16, 17
 Bioreactor, 310, 316
 bioremediation., 394
 Borlaug, 25, 27, 28, 29, 30

C

calcium prohexadione, 36, 38, 41, 42, 43, 44
 Centla, 289, 290, 291, 292, 293, 294
Centropomus undecimalis, 297, 298, 299, 303, 304

Ch

Chitosan, 184, 185, 191
 Chlorophyll content, 15, 16

C

consortia, 94, 95, 97, 99, 100, 101, 103, 104
Coriandrum sativum L., 184, 185, 186, 190, 191, 194
 CPUE, 289, 291, 292, 294
 cytokinins, 36, 38, 40, 41, 42, 43, 44, 46

D

Dates, 116, 122, 133, 139, 146
 Degradation, 392
 Detoxification, 310, 311

E

ENSO, 297, 298, 300

F

Fertilization, 339
 fish, 232, 233, 234, 237, 239, 240, 242
 fruit and vegetable waste, 324, 325, 331

G

Gluten, 172, 175
 Grain quality, 174
 Growth, 260

H

hybrids, 222, 223, 224, 225, 226, 227, 228
 Hydrolyzed extract, 273
 Hypopótamo, 13, 18

I

In vitro culture, 269
 irrigation, 222, 223, 225, 226, 227, 228

L

Locations, 344

M

maize, 50, 51, 53, 54, 55, 56, 57, 222, 223, 225, 227, 228
 Maize, 94, 95, 97, 98, 99
 Mango, 188
 mesquite, 232, 233, 234, 238, 240, 241, 242
 Mesquite, 256, 258, 261, 262
 Microbial, 99, 101, 104
 Morphometric analysis, 289, 293
 morphophysiological, 36, 37, 38, 45, 46

N

NDVI, 9, 10, 12, 14, 15, 18
 nile tilapia, 232
 NOM-017-PESC-1994, 289, 290, 291, 293, 294

O

Oat, 67

Oreochromis niloticus, 232, 233, 234, 241, 242, 246, 247

P

paclobutrazol, 36, 38, 40, 41, 42, 43, 44, 45, 46, 47

Pantanos de Centla, 290

Particle size, 324

physiological quality, 22, 23, 24, 29, 31

Planting, 115, 116, 119, 122, 123, 131, 133, 135, 139, 140

Prosopis juliflora, 232, 233, 234, 238, 240

Protein content, 171

R

Recreational fishing, 289

Reduced irrigation, 167, 178, 179

RGB, 65, 66, 68, 69, 70

Rheological properties, 175

S

S/I ratios, 324, 328, 329, 330, 331

saline, 222, 223

SDS sedimentation, 171, 176

size, 22, 23, 24, 25, 26, 27, 28, 29, 31

Spirulina sp, 267, 269, 270, 276

substrate-to-inoculum, 324, 325, 329, 331

T

Tabasco, 289, 290, 291, 292, 294, 297, 298, 299, 300, 301, 302, 303, 304

Tilapia, 260

tomato, 36, 37, 38, 40, 42, 43, 44, 45

Treatments, 339, 341, 343, 344, 349, 351, 352

V

Varieties, 119, 122, 123, 136, 139, 141

Vegetation indices, 65, 69

VFAs, 325, 326, 328, 331

volatile fatty acids, 325, 326

W

Water stress, 173

Weight, 116, 118, 119, 122, 123, 133, 135, 136, 139, 140, 141

wheat, 22, 23, 24, 25, 26, 27, 28, 29, 31

Wheat, 67

Wild juveniles, 283

Y

yield, 22, 24, 25, 27, 28, 29, 31

Yield, 116, 118, 119, 120, 122, 123, 125, 133, 135, 136, 137, 139, 140, 141, 143, 343, 345, 351, 352

Z

Zea mays, 75, 76, 77, 85, 222

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