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Editorial

Abiotic Stress Responses and Microbe-Mediated Mitigation in Plants

Ying Ma

Centre for Functional Ecology, Department of Life Sciences, University of Coimbra, Calçada Martim de Freitas, 3000-456 Coimbra, Portugal; cathymaying@gmail.com; Tel.: +351-239240752

Agriculture bears the brunt of degraded ecosystems, as climate change, soil degradation, and biodiversity imbalances impede both productivity and quality. Among microbial biotechnologies, the utilization of plant-beneficial microbes (PBM) is promising as a novel and effective solution for sustainable agriculture, mitigating the adverse effects of climate change (e.g., biotic stresses in plants) and maximizing the ecological potential for agricultural production. PBMs, associated with plant ecosystems, play a crucial role in plant growth, development, and soil health through diverse plant growth-promoting (PGP) mechanisms, either directly or indirectly. While the application of PBM and their products show potential for enhancing plant production and protection and has garnered significant attention in agricultural practice, there remains a need to develop innovative approaches to investigate microbial environment ecology and enhance our understanding of the role of plant–microbe interactions in alleviating various climatic stresses. Thus, this research topic aims to advance our comprehensive understanding of plant–microbe–soil interactions, promote plant growth under climatic stresses, and review recent breakthroughs in the correlation between microbial biodiversity, crop yield, and health. Ultimately, this contributes to the transformation of agricultural production systems through PBM-related biotechnologies.

The Special Issue "Abiotic stress responses and microbe-mediated mitigation in plants" comprises seven articles addressing diverse climatic and abiotic stresses (such as drought, salinity, extreme temperatures, and heavy metals), the response of plants to these stresses, and the potential of PBM as a means to mitigate stress in different crop species.

Seema et al. [1] isolated endophytes from *Rhazya stricta* roots and assessed their potential to enhance the growth of drought-stressed sunflower seedlings. The isolated endophytic fungus, identified as *Fusarium proliferatum*, exhibited significant PGP attributes in sunflowers compared to control plants. The symbiotic association between *F. proliferatum* and sunflowers improved host growth and conferred greater tolerance to high drought stress. This improvement was attributed to the release of drought-related metabolites and phytohormones by *F. proliferatum*, which potentially helped reprogram the host antioxidant system to better cope with drought. The findings suggest that *F. proliferatum* has the potential to be used as a plant biostimulant and drought-stress reliever in areas facing severe drought conditions.

Arévalo-Hernández et al. [2] evaluated cacao germplasm for early growth, nutrient concentration, and potential tolerance to soil acidity. Sixty cacao genotypes from diverse geographic origins were grown in acid and limed soil conditions. Growth parameters, nutrient concentrations, and physiological responses varied significantly among the genotypes. Limed conditions resulted in better growth than acid conditions. The study identified ten cacao genotypes that exhibited potential tolerance to soil acidity, suggesting their suitability for breeding programs or use as rootstock. The number of leaves and root area were identified as the best early growth predictors of acid soil tolerance. Additionally, N, Ca, Mg, and K uptake showed potential roles in cacao's ability to tolerate soil acidity. The findings provide valuable insights for selecting cacao genotypes that can thrive in acidic

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soil conditions, offering an alternative approach to address the challenges posed by soil acidity in tropical regions where access to amendments is limited.

In a study by Ravi et al. [3], a potent rhizobacterial strain *B. flexus* M2 was characterized for its ability to reduce Cr(VI) under various environmental stressors. The strain exhibited tolerance to high temperatures, alkaline pH, NaCl, and drought conditions. Instrumentation analysis confirmed the strain's ability to intra- and extracellularly reduce Cr(VI). The PGP activities of strain M2 were unaffected by chromium-induced toxicity and positively influenced the growth and Cr accumulation in *V. radiata*. These results suggest that applying *B. flexus* M2 could be a promising phytostabilization agent to control Cr entry into the food chain. It will also serve as a potential biofertilizer for crop production in harsh environmental conditions. The study provides insights into the potential use of rhizobacteria for soil restoration and crop productivity in heavy metal-contaminated regions.

Moreover, Narayanan et al. [4] identified potential plant growth-promoting rhizobacteria (PGPR) from the rhizosphere of *Arachis hypogaea* L. Among the isolates obtained, strain Ah4 demonstrated superior PGP activities. Phylogenetic analysis confirmed its identity as a nitrogen (N)-fixing *Kosakonia* species. *Kosakonia* sp. MGR1 (Ah4) exhibited high indole-3-acetic acid (IAA) production and phosphate-solubilizing efficiency. Optimal growth conditions were determined to be 35 °C, pH 7.5, and 48 h of incubation with glucose as a carbon source. Under these conditions, *Kosakonia* sp. MGR1 produced significant amounts of IAA, N, and soluble phosphate. When applied to *A. hypogaea*, *Kosakonia* sp. MGR1 enhanced growth and biomolecule contents, including carbohydrates and total proteins. This study suggests that *Kosakonia* sp. MGR1 has notable PGP activities and could be beneficial for improving the growth of *A. hypogaea*, warranting further investigation into its interaction with the plant.

Acuña-Rodríguez et al. [5] focused on enhancing the tolerance of highbush blueberry plants to cold temperatures and drought by inoculating them with Antarctic fungal endophytes (AFE) that were originally isolated from Antarctic plants. The results showed that AFE inoculation positively affected plant performance in both environmental conditions. The inoculated plants exhibited higher gene expression related to stress tolerance, improved photochemical efficiency, and reduced oxidative stress compared to the uninoculated plants. Additionally, the presence of AFE improved plant survival and increased fruit size and weight, particularly under well-watered conditions. These findings suggest that inoculating plants with fungal endophytes from extreme environments could be a promising and cost-effective approach to enhance crop resilience in the face of challenging production scenarios, especially in regions experiencing worsening conditions due to climate change.

Another study investigated the effects of seed coating with *Achromobacter xylosoxidans* BOA4 and/or irrigation with an extract of *Enteromorpha intestinalis* (EI) algae on salt-stressed tomato plants [6]. The treatments of BOA4 and/or EI resulted in increased plant shoot dry weight by 33% on average but decreased the root-to-shoot biomass ratio by 44% on average. Anthocyanin content increased significantly with EI and BOA4 plus EI treatments. The study examined protein tyrosine nitration (PTN) as a response to salt stress and found that it was reduced by an average of 30% in stressed roots or shoots with BOA4, EI, or both treatments. This response was inversely correlated with cytokinin contents, particularly cis-zeatin-type and isopentenyladenine (iP), which increased significantly following the treatments. The production of iP by *Achromobacter xylosoxidans* BOA4 and the role of cis-zeatin-type cytokinins in stress relief were confirmed. These findings suggest that seed coating with BOA4, EI extract, or both can improve tomato growth under high-salt conditions by reducing PTN and increasing cytokinins. The study highlights the potential of cytokinin-producing biostimulants for enhancing plant stress tolerance and opens new avenues for further research in this field.

Liu et al. [7] examined the effects of rhizobia inoculation on drought tolerance and physiological mechanisms in Chinese milk vetch. It was found that active nodulation in the roots improved drought tolerance compared to plants with inactive or no nodules. The activity of enzymes involved in N assimilation, such as GS, GOGAT, and GDH, was higher in actively nodulated plants. These plants also exhibited higher levels of proline, arginine, alanine, and glutamate compared to plants with inactive or no nodules. Additionally, drought-induced increases in putrescine, spermidine, and spermine were more pronounced in actively nodulated plants. The findings suggest that active nodulation enhances drought tolerance in milk vetch by promoting N fixation, ammonium assimilation, and the synthesis of free amino acids and polyamines.

Collectively, these manuscripts provide valuable insights into the various climatic and abiotic stresses that impact crop productivity and quality. They elucidate the consequences and responses of plants to these stresses and highlight how the judicious application of PBM can contribute to sustaining agricultural productivity and ensuring high-quality outputs amidst changing climate conditions. Nevertheless, to unravel the precise mechanisms of stress mitigation in crop plants, it is imperative to prioritize the generation of research data that are more focused on omics-based approaches, including genomic, metagenomic, proteomic, and metabolomic studies, particularly targeting plant–microbe interactions within abiotic stress systems.

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References

1. Seema, N.; Hamayun, M.; Hussain, A.; Shah, M.; Irshad, M.; Qadir, M.; Iqbal, A.; Alrefaei, A.F.; Ali, S. Endophytic *Fusarium proliferatum* Reprogrammed Phytohormone Production and Antioxidant System of *Oryza sativa* under Drought Stress. *Agronomy* **2023**, *13*, 873. [CrossRef]
2. Arévalo-Hernández, C.O.; Arévalo-Gardini, E.; Farfan, A.; Amaringo-Gomez, M.; Daymond, A.; Zhang, D.; Baligar, V.C. Growth and Nutritional Responses of Juvenile Wild and Domesticated Cacao Genotypes to Soil Acidity. *Agronomy* **2022**, *12*, 3124. [CrossRef]
3. Srinivas Ravi, M.; Karthik, C.; Padikasan, I.A.; Ma, Y. Alleviation of Cr(VI) Toxicity and Improve Phytostabilization Potential of *Vigna radiata* Using a Novel Cr(VI) Reducing Multi-Stress-Tolerant Plant Growth Promoting Rhizobacterial Strain *Bacillus flexus* M2. *Agronomy* **2022**, *12*, 3079. [CrossRef]
4. Narayanan, M.; Pugazhendhi, A.; David, S.; Chi, N.T.L.; Nasif, O.; Alharbi, S.A.; Ma, Y. Influence of *Kosakonia* sp. on the Growth of *Arachis hypogaea* L. on Arid Soil. *Agronomy* **2022**, *12*, 1801. [CrossRef]
5. Acuña-Rodríguez, I.S.; Ballesteros, G.I.; Atala, C.; Gundel, P.E.; Molina-Montenegro, M.A. Hardening Blueberry Plants to Face Drought and Cold Events by the Application of Fungal Endophytes. *Agronomy* **2022**, *12*, 1000. [CrossRef]
6. Santana, M.M.; Rosa, A.P.; Zamarreño, A.M.; García-Mina, J.M.; Rai, A.; Cruz, C. *Achromobacter xylosoxidans* and *Enteromorpha intestinalis* Extract Improve Tomato Growth under Salt Stress. *Agronomy* **2022**, *12*, 934. [CrossRef]
7. Liu, Y.; Guo, Z.; Shi, H. Rhizobium Symbiosis Leads to Increased Drought Tolerance in Chinese Milk Vetch (*Astragalus sinicus* L.). *Agronomy* **2022**, *12*, 725. [CrossRef]