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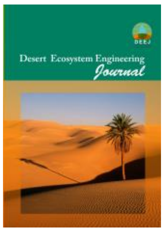

Effects of Plant Growth-Promoting Bacteria on Physiological Traits, Ion Homeostasis, and Yield of Camelina sativa Under Combined Drought and Dust Stress

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Extended Abstract

Introduction: Environmental stresses, particularly drought and dust, pose significant constraints to agricultural productivity, especially in arid and semi-arid regions. Camelina sativa, an oilseed crop valued for its nutritional and industrial applications, exhibits sensitivity to these abiotic stressors, which can adversely affect its physiological, biochemical, and morphological processes. This study aimed to evaluate the effects of inoculating C. sativa with plant growth-promoting bacteria (PGPB)—Bacillus amyloliquefaciens and Bacillus halotolerans, applied individually and as a 1:1 consortium—on the plant's physiological and biochemical responses, as well as its overall growth performance, under combined drought and dust stress conditions.**Materials and Methods:** The bacterial strains were procured from the Regional Collection Center for Industrial Fungi and Bacteria of Iran. Four inoculation treatments were prepared at a final concentration of 3×10^8 CFU mL^{-1}: a non-inoculated control, **B. amyloliquefaciens** alone, **B. halotolerans** alone, and a 1:1 mixture of both strains. Healthy **Camelina** seeds were bacterized via immersion in the respective suspensions for two hours prior to sowing. Seeds were planted at a density of 40 seeds per square meter in plots arranged in a completely randomized design. Plants were subjected to three irrigation regimes: 4-day intervals (well-watered control), 6-day intervals (moderate drought), and 8-day intervals (severe drought). Simultaneously, dust stress was applied using particulates (<10 µm) collected from identified critical emission sources in Aran and Bidgol, Isfahan Province, simulating natural deposition rates ranging from 0.57 to 1.13 g m^{-2} day^{-1}. Leaf samples were collected prior to seed maturity for biochemical analyses, including the quantification of chlorophyll *a*, *b*, and total chlorophyll; carotenoids; ascorbic acid; total phenolic content; proline; soluble sugars; and essential nutrients (N, P, K, Ca). Growth and yield parameters, such as dry biomass, seed yield, and root dry weight, were also measured. All data were subjected to analysis of variance (ANOVA) using SPSS software, and means were compared using Duncan's multiple range test at a 5% probability level ($\alpha = 0.05$).

Results: Drought and dust stress significantly altered nutrient content and biochemical parameters in **C. sativa**. Nitrogen content declined under both stresses, indicating impaired uptake likely due to reduced transpiration, disrupted membrane integrity, and suppressed nitrate reductase activity under dust exposure. Inoculation with plant growth-promoting bacteria (PGPB) significantly increased nitrogen content under stress, attributable to biological nitrogen fixation and enhanced protein synthesis, consistent with prior studies on PGPR-mediated stress alleviation. Calcium concentration decreased under drought but was elevated by bacterial inoculation, suggesting a role in reinforcing cell wall stability and stress-signaling pathways. Phosphorus content was also reduced under drought and dust stress; however, PGPB inoculation—particularly with **B. amyloliquefaciens** and **B. halotolerans**—increased phosphorus availability through phosphate solubilization, organic acid production, and enzymatic mineralization. Potassium levels were primarily reduced by dust stress, and bacterial inoculation, especially with **B. amyloliquefaciens**, enhanced potassium uptake, likely through improved ion homeostasis and exopolysaccharide-mediated sodium sequestration. Proline and phenolic compounds accumulated significantly under drought and dust stress, functioning as osmoprotectants and antioxidants. Bacterial inoculation reduced stress-induced proline accumulation, indicating improved water status, hormonal modulation (IAA, cytokinins, gibberellins), and enhanced root development. Soluble

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sugars decreased under stress, particularly under combined drought and dust conditions, due to stomatal closure and reduced photosynthetic efficiency. However, PGPB inoculation—notably with **B. halotolerans**—increased soluble sugar content, reflecting better osmotic adjustment and sustained metabolic activity. Chlorophyll *b* and carotenoids were sensitive to stress, showing marked reductions under drought and dust. Bacterial treatments increased chlorophyll content while lowering carotenoid accumulation, suggesting reduced oxidative stress through improved nutrient uptake and induced antioxidant activity.
Morphological traits, including shoot dry weight, root dry weight, and seed yield, were adversely affected by drought and dust stress. Inoculation with **B. halotolerans** significantly improved seed weight and shoot biomass, whereas **B. amyloliquefaciens** primarily enhanced root dry weight. These improvements can be linked to better nutrient acquisition, phytohormonal stimulation, and maintenance of photosynthetic pigments under stress. The combined bacterial inoculation demonstrated synergistic effects, promoting overall plant resilience and yield stability under adverse conditions.

Discussion and Conclusion: This study demonstrates that concurrent drought and dust stress disrupt key physiological and biochemical processes in **C. sativa**, leading to reduced soluble sugars, nitrogen, phosphorus, and chlorophyll *b*, alongside increased proline, phenolics, calcium, potassium, and carotenoids. Dust stress was observed to intensify the effects of drought on several measured parameters.

Inoculation with **B. amyloliquefaciens** and **B. halotolerans**—both individually and in combination—effectively mitigated these adverse effects. The bacterial treatments enhanced nutrient uptake, regulated osmolyte accumulation, boosted antioxidant capacity, and stimulated growth-promoting hormonal activity, collectively improving physiological performance and seed yield under stress conditions.

These findings underscore the potential of plant growth-promoting bacteria (PGPB) as a sustainable and eco-friendly strategy for enhancing crop resilience in arid and semi-arid regions. The results further emphasize the importance of selecting specific bacterial strains based on prevailing environmental conditions and stress types to optimize plant productivity and stress adaptation.

Keywords: Plant Growth-Promoting Bacteria, Drought, Dust, Ascorbic Acid, Camelina.