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Enriched with Biofertilizer and Soil Amendments**
Rakyan Haikal Sabili, Prof. Dr. Laurentius Hartanto Nugroho, M.Agr.
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Growth and Physiological Responses of Tomato (*Solanum lycopersicum* L.) in Red Mud-Contaminated Soil Enriched with Biofertilizer and Soil Amendments

By

Rakyan Haikal Sabili
22/492361/BI/10912

Supervisor: Prof. Dr. Laurentius Hartanto Nugroho, M.Agr.

ABSTRACT

Red mud, a highly alkaline by-product of alumina production, contains elevated concentrations of heavy metals that pose risks to soil quality and plant growth. Biofertilizers have emerged as a sustainable approach for improving plant performance in contaminated soils. This study evaluated the effects of biofertilizer, applied alone or in combination with humic acid (HA) and nanosilica (NS), on the growth, physiological, biochemical, and volatile organic compound (VOC) profiles of tomato (Solanum lycopersicum) grown in red mud-contaminated soil. Six treatments were evaluated: positive control, negative control, biofertilizer (B), B + HA, B + NS, and B + HA + NS. Growth parameters were monitored over seven weeks, while physiological responses were assessed through nitrate reductase activity (NRA) and superoxide dismutase (SOD) activity. Biochemical responses were evaluated using chlorophyll content (SPAD) and headspace gas chromatography–mass spectrometry (HS-GC-MS) analysis of leaf VOCs. Plant height and leaf count did not differ significantly among treatments ($p > 0.05$), indicating that biofertilizer, alone or combined with humic acid and nanosilica, did not measurably improve tomato growth under red mud stress. Similarly, NRA and SOD activities showed no significant differences across treatments ($p > 0.05$). However, chlorophyll content was significantly higher ($p < 0.05$) in the B + HA + NS treatment compared to the positive control, and VOC profiling revealed greater metabolite diversity in plants receiving biofertilizer-based amendments, particularly B + HA. Overall, while biofertilizer application did not enhance tomato growth, the combined application of biofertilizer, humic acid, and nanosilica improved chlorophyll retention and biochemical stress responses, indicating potential as a supportive strategy for mitigating physiological stress in red mud-contaminated environments.

KEY WORDS: biofertilizer, abiotic stress, enzymatic activity, red mud, *Solanum lycopersicum*

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Pertumbuhan dan Respons Fisiologis Tomat (*Solanum lycopersicum* L.) pada Tanah Terkontaminasi Red Mud dengan Penambahan Biofertilizer dan Pengayaan Media

By

Rakyan Haikal Sabili
22/492361/BI/10912

Supervisor: Prof. Dr. Laurentius Hartanto Nugroho, M.Agr.

ABSTRAK

Red mud merupakan limbah samping produksi alumina yang bersifat sangat basa dan mengandung logam berat sehingga berpotensi menurunkan kualitas tanah serta menghambat pertumbuhan tanaman. Penelitian ini bertujuan untuk mengevaluasi pengaruh biofertilizer, baik secara tunggal maupun dikombinasikan dengan asam humat (HA) dan nanosilika (NS), terhadap pertumbuhan, respons fisiologis, biokimia, dan profil senyawa organik volatil (volatile organic compounds/VOC) tanaman tomat (Solanum lycopersicum) yang ditanam pada tanah tercemar red mud. Penelitian menggunakan enam perlakuan, yaitu kontrol positif, kontrol negatif, biofertilizer (B), B + HA, B + NS, dan B + HA + NS. Parameter yang diamati meliputi pertumbuhan tanaman selama tujuh minggu, aktivitas nitrat reduktase (NRA), aktivitas superoksida dismutase (SOD), kandungan klorofil (SPAD), serta profil VOC menggunakan Headspace Gas Chromatography–Mass Spectrometry (HS-GC-MS). Hasil penelitian menunjukkan bahwa tinggi tanaman dan jumlah daun tidak berbeda nyata antar perlakuan ($p > 0,05$), yang mengindikasikan bahwa aplikasi biofertilizer, baik tunggal maupun dikombinasikan dengan asam humat dan nanosilika, belum mampu meningkatkan pertumbuhan tomat secara nyata pada kondisi tercemar red mud. Aktivitas NRA dan SOD juga tidak menunjukkan perbedaan yang signifikan antar perlakuan ($p > 0,05$). Namun demikian, kandungan klorofil pada perlakuan B + HA + NS secara signifikan lebih tinggi ($p < 0,05$) dibandingkan kontrol positif, dan analisis VOC menunjukkan keragaman metabolit yang lebih tinggi pada tanaman yang diberi biofertilizer, khususnya pada kombinasi B + HA. Secara keseluruhan, meskipun aplikasi biofertilizer belum meningkatkan pertumbuhan tomat, kombinasi biofertilizer, asam humat, dan nanosilika terbukti mampu meningkatkan retensi klorofil dan respons biokimia terhadap cekaman, sehingga berpotensi sebagai strategi pendukung dalam mitigasi stres fisiologis pada lingkungan yang tercemar red mud.

KATA KUNCI: aktivitas enzim, biofertilizer, cekaman abiotik, red mud, *Solanum lycopersicum*.