Examining the Synergistic Effects of Hydrotropism, Magnetotropism, and Simulated Microgravity on Allium fistulosum Morphology Using a Novel 3D Clinostat

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As humanity ventures into extraterrestrial agriculture and advances controlled-environment farming, understanding how plants integrate directional growth cues under altered abiotic conditions is essential. This study examined Allium fistulosum growth responses to hydrotropism, magnetotropism, and gravitropism under combinations of normal gravity, simulated microgravity (via a 3D clinostat; 0.02 g, 0.10 g, 0.25 g), homogeneous and heterogeneous water distribution, and moderate magnetic fields (pull forces of 0.10 kg, 0.20 kg, 0.50 kg, 1.00 kg). ANOVA revealed significant treatment effects on shoot and root architecture, biomass, and chlorophyll content. Shoot length increased under microgravity, with elongation amplified in static magnetic fields (SMFs), likely due to disrupted directional signaling and accelerated cell cycles. Shoot biomass declined under microgravity, with further reductions observed in moisture gradients, potentially linked to abscisic acid (ABA) biosynthesis reallocating resources to root development. Root biomass and count increased in SMFs, hypothesized to result from enhanced ion fluxes, reactive oxygen species (ROS) signaling, and upregulation of cell division genes in meristems. Microgravity caused random root growth and reduced secondary root formation, likely due to impaired auxin redistribution from disrupted statolith sedimentation. Hydropatterning was observed in heterogeneous water distributions, evidenced by lateral branching and elongation toward high-moisture zones. Chlorophyll a and b content decreased under microgravity, likely due to impaired plastid differentiation, while SMFs were associated with increased pigment levels. Chlorophyll content was reduced in moisture gradients, potentially from ABA-induced suppression.

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