Title: Enhancing Light Utilization Efficiency of Dragon Fruit Canopies Using Bi-Directional Adjustable-Focusing LED Lighting System

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Abstract: Commercial light-emitting diodes (LEDs) offer fixed lighting patterns with limited canopy coverage, creating a mismatch with dragon fruit's dynamic photosynthetic and phenological needs. To mitigate the inherent limitations of conventional unidirectional irradiance distributions, a bi-directional emission LED system incorporating adjustable focusing mechanisms is engineered. Monte Carlo ray-tracing and numerical integration are employed to quantitatively analyze the influence of plant architectural complexity, LED positioning strategies, and angular emission profiles on canopy light distribution. Concurrently, three optimization algorithms—Simulated Annealing (SA), Genetic Algorithm (GA), and Ant Colony Optimization (ACO)—are comparatively evaluated for their efficacy in maximizing radiation efficiency (RE) and utilization efficiency (UE). The proposed method (1) achieves targeted photon delivery while minimizing light spillage between canopies, resulting in 39.39% and 206.67% higher UE compared with the other two schemes under the same static fixture at a height of 1.7 m and an emission angle of 50°, and (2) achieves high prediction accuracy, with RE and UE determination coefficients (R^2) of 96% and 97%, respectively.

Keywords: Photonics , Lighting , Optimization , Genetic algorithms , Light emitting diodes , Fixtures , Vectors , Energy efficiency , Crops , Bidirectional control

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