Protected Cultivation as a Pathway to Nutrient-Rich Vegetables

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Abstract

Protected cultivation has become a cornerstone of sustainable agricultural intensification, enabling stable production of nutrient-rich vegetables despite climate variability and resource constraints. Greenhouse-grown vegetables already account for more than 60% of the global market value, offering improved productivity, quality, and a year-round supply.

Here, we analyze how agrotechnological innovations and cultural practices can enhance the nutritional profiles of vegetables within protected environments. Our bibliometric analysis revealed a surge in research over the last decade. Although each category began with a similar number of publications in 2014 (around eight), their trajectories diverged markedly over the following decade. Articles published between 2014 and 2024 revealed striking growth trends: studies on environmental conditions increased by about 8.8-fold. However, those on agrotechnological innovations increased by more than 32-fold, and on cultural practices by nearly 9.5-fold, presenting a high potential for improving nutritional quality.

Practices such as biofortification, controlled eustress, deficit irrigation, grafting, biostimulant use, and precision nutrient management have demonstrated strong correlations (R^2 = 0.97–0.98) with improved levels of vitamins, minerals, and bioactive compounds. These techniques influence plant metabolism by regulating stress-responsive pathways, enhancing nutrient uptake, and stimulating the biosynthesis of secondary metabolites. Additionally, optimized harvest timing and crop-specific adaptation further stabilize nutrient density and quality. These approaches redefine protected cultivation as an integrated, knowledge-based production system that combines productivity, sustainability, and nutritional security.

Coordinated innovation in agronomy and technology transforms protected cultivation from yield-oriented systems into nutrition-centered ones. By aligning physiological mechanisms with sustainable management practices, producers can achieve nutrient-dense crops without compromising yield or environmental efficiency. Future progress will depend on integrating digital monitoring, AI-assisted decision-making tools, and genotype-specific models to fine-tune cultivation strategies that enhance both nutritional value and resource-use efficiency.

Practical recommendation: Researchers, growers, and policymakers should strengthen interdisciplinary collaboration to advance nutrition-oriented protected cultivation. Promoting scalable solutions such as eustress management, biofortification, and sustainable agrotechnologies will support global efforts to combat hidden hunger and ensure resilient food systems.

Keywords: protected cultivation, nutritional quality, biofortification, eustress, sustainable innovation

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