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Editorial: Vertical farming: new trends, products, and production approaches

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Editorial on the Research Topic

Vertical farming: new trends, products, and production approaches

Introduction

As global urbanization accelerates and conventional agriculture faces mounting pressures from climate change, land degradation, and resource scarcity, vertical farming (VF) and controlled environment agriculture (CEA) have emerged as disruptive solutions (Erekath et al., 2024). This Research Topic brings together 11 innovative articles, including empirical studies, comprehensive reviews, and technological assessments that reflect the breadth and maturity of current research in this field. Organized around four interconnected axes, namely urban integration and environmental performance, light optimization and crop enhancement, production systems and postharvest innovation, and socioeconomic and systemic perspectives (Figure 1), these contributions collectively shed light on critical pathways toward more resilient, efficient, and equitable plant food systems.

Rethinking the built environment: VF urban integration and environmental synergies

At the intersection of agriculture, architecture, and sustainability, Blom et al. explored the synergistic integration of VF into various building typologies in the Netherlands. By modeling scenarios in apartments, offices, restaurants, swimming pools, and supermarkets, the study quantified how residual resources such as heat, greywater, and nutrient-rich waste can be leveraged to reduce external inputs required by VF. Apartments demonstrated strong potential for thermal energy recovery and full provision of vegetables using resident-generated waste streams, while restaurants and pools offered viable opportunities for water reuse. Offices and supermarkets showed limited resource synergies due to insufficient greywater and nutrient outputs. The study highlighted the need for context-specific strategies and the potential of integrated systems to reduce environmental footprints in urban areas.

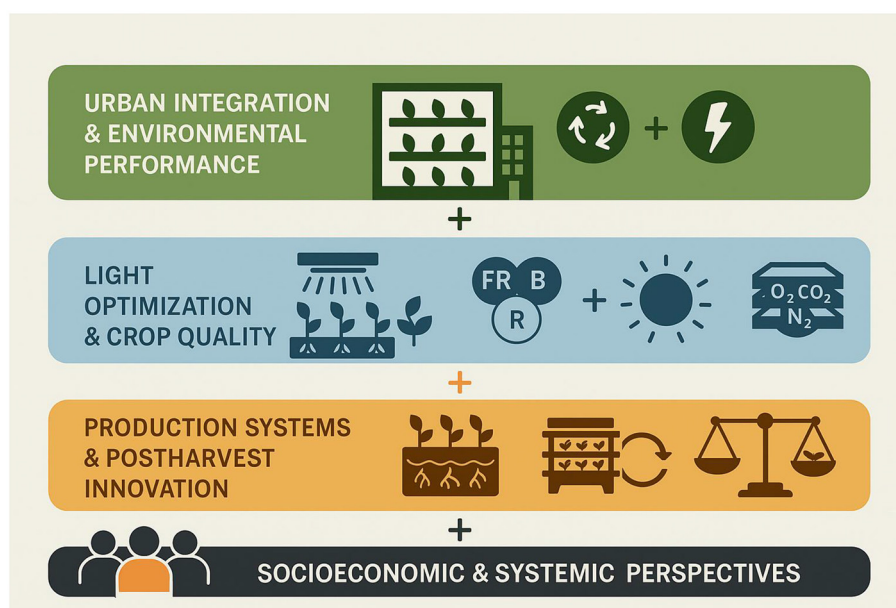


FIGURE 1
Illustrative overview of the four main themes discussed in this Research Topic on vertical farming.

Complementing this architectural perspective, [Martin et al.](#) presented a life cycle assessment of modular cabinet vertical farms situated near consumption points, such as office cafeterias, in Stockholm. Their analysis confirmed that the proximity to end-users, combined with renewable energy use and shared infrastructure, can result in greenhouse gas (GHG) emissions that are lower or comparable to those of traditional supply chains. The study also emphasized that environmental performance is highly sensitive to local factors such as the electricity mix and methodological choices, underscoring the importance of regional context and careful system design.

Broadening the scope, [Sowmya et al.](#) provided a conceptual review of VF as a strategy to address food insecurity and environmental degradation in rapidly urbanizing areas. The authors highlighted the ability of VF to enable year-round production of crops, such as fruit and horticultural products, through soilless techniques like hydroponics and aeroponics, particularly in regions with limited arable land and water resources. They outlined VF's ecological, nutritional, and socioeconomic benefits, while also noting that it remains costly and technologically complex, with adoption challenges especially pronounced in low-income and developing urban contexts. A key contribution of the paper is its call for increased scientific research, standardization, and collaboration between academia and industry to overcome current reliance on commercial data and to enhance the scalability, affordability, and sustainability of VF systems.

Light as a strategic tool for crop quality and productivity

As plant growth in indoor VF systems is decoupled from natural sunlight, artificial lighting becomes a powerful agronomic

lever. Five studies in this Research Topic investigated how spectral composition and intensity affect biomass production, plant physiology, and phytochemical content across various species. [Thoma et al.](#) examined lovage (*Levisticum officinale*), focusing on rutin content, a health-promoting flavonoid. Their experiment revealed that a short-duration, high-irradiance UV-B treatment (1 W m^{-2}) notably increased rutin content in leaves, particularly 2 days after exposure. In parallel, green light, especially under high photosynthetic photon flux density (PPFD), stimulated total biomass accumulation. These results suggest that targeted light treatments can optimize both functional quality and yield in medicinal and aromatic plants. In a complementary study, [Flores et al.](#) explored how PPFD intensity affects the morphology, pigmentation, and antioxidant activity of Brassicaceae microgreens (green and red cultivars of cabbage, kale, mizuna, and mustard). They found that high polychromatic light intensities ($210 \mu\text{mol m}^{-2} \text{ s}^{-2}$) increased plant dry weight and leaf phenolic content, while low and medium intensities (120 and $160 \mu\text{mol m}^{-2} \text{ s}^{-1}$, respectively) promoted hypocotyl elongation and pigmentation in certain cultivars. The study, conducted in a growth chamber, highlighted the importance of balancing productivity, energy input, and phytochemical outcomes in indoor VF systems.

Taking a volumetric optimization approach, [Liu et al.](#) evaluated space usage efficiency (SUE) in edamame cultivation within plant factories with artificial lighting (PFALs). Nine lighting combinations, varying PPFD and color temperature, were tested. The most efficient treatment ($700 \mu\text{mol m}^{-2} \text{ s}^{-2}$ with 5,000 K LED) maximized biomass production while minimizing plant height, thus improving vertical space utilization. The study also highlighted the influence of light quality, particularly the red/blue (R:B) light ratio, on plant morphology and SUE. This work provides a valuable framework for optimizing productivity and infrastructure efficiency in high-density farming setups. [Akter et al.](#) further

explored light spectral tuning in cilantro (*Coriandrum sativum* L.) production. The inclusion of far-red light (FR) in the R:B ratio (specifically R3:B1:FR1) led to significantly increased plant height, leaf expansion, and yield. Interestingly, the quality and mineral content remained stable across treatments, indicating the feasibility of enhancing plant yield without trade-offs in nutritional value. In another study, Anum et al. assessed how different R:B ratios (PPFD = 250 $\mu\text{mol m}^{-2} \text{s}^{-1}$) affected two pakchoi (*Brassica chinensis* L.) cultivars. The results revealed cultivar-specific responses: red pakchoi showed increased pigment accumulation and efficient gas exchange under R2:B1, while green pakchoi benefited nutritionally from R4:B1. The study also found that glucosinolate content, linked to health benefits, was highest under full-spectrum white light. These nuanced responses reinforce the importance of tailoring lighting strategies to species, cultivar, and market goals.

Integrated strategies for agronomic sustainability and postharvest quality

Prabhadharshini et al. investigated the cultivation of palak (Indian spinach) in an A-frame vertical hydroponic system, focusing on optimizing growing media and nutrient formulations. The combination of coir pith and vermiculite, along with a balanced nutrient solution (NPK 60:50:60 ppm), yielded the best production results. Furthermore, the study addressed postharvest preservation by demonstrating that refrigerated storage combined with modified atmosphere (6% O₂, 5% CO₂, 89% N₂) packaging significantly extended the shelf life of palak leaves. This integrated approach, encompassing both yield maximization and postharvest quality maintenance, contributes to advancing more circular and waste-resilient urban plant food chains.

Economic viability and broader societal lens

The economic sustainability of VF was examined by Amici et al., who studied two Italian commercial microgreen farms. Both operations were found to be profitable, with energy costs kept low thanks to digital optimization and efficient lighting strategies. Nonetheless, high start-up costs and the need for skilled labor remain significant barriers, prompting the authors to recommend targeted policy interventions, particularly renewable energy incentives and certification frameworks, to reduce entry barriers and accelerate VF scalability. Regarding social challenges, the review by Sowmya et al. highlighted the potential of VF to address food insecurity in rapidly growing cities, while cautioning that high costs and technological complexity could exacerbate inequalities if adoption remains limited to high-income contexts. From a scientific perspective, Zhang et al. conducted a bibliometric analysis on *Pennisetum* research from 1970 to 2023. Although not directly focused on VF, their work underscores the growing interest in underutilized species for forage, ecological, and industrial uses. The analysis identified emerging trends in molecular breeding and international cooperation, suggesting potential contributions

of lesser-known species to sustainable agriculture, including applications in CEA.

Conclusion

Collectively, the studies in this Research Topic highlight the dynamic, interdisciplinary progress in VF and CEA. They demonstrate clear advances in technical optimization, from light engineering to urban integration, while raising critical questions about equity, accessibility, and long-term sustainability. These 12 contributions consolidate robust empirical assessments, methodological innovations, and systems-thinking approaches, reaffirming VF's potential to supplement traditional agriculture. As cities expand and the climate crisis intensifies, reimagining plant food systems through the lens of VF offers a compelling vision. However, its success will depend not only on technological innovation but also on governance, design, and social priorities, particularly in addressing key research gaps such as standardized impact assessments, improved energy integration, crop diversification, and inclusive socio-economic models. This Research Topic aims to advance that dialogue, grounded in science, and drive systemic transformations toward more resilient plant food systems.

Author contributions

JP: Conceptualization, Writing – original draft. MD: Conceptualization, Writing – review & editing. CC: Conceptualization, Writing – review & editing. MM: Conceptualization, Writing – review & editing.

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Conflict of interest

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