***Review Article***

**A Review on Sustainable Microgreen Cultivation for Urban Farming with Minimal Resources**

**Abstract**

Microgreens, nutrient-rich and high-value crops, are becoming essential in urban agriculture because of their quick development cycles (7–21 days), low resource demands, and considerable nutritional and health advantages. Microgreens are abundant in vitamins (C, E, K), minerals (K, Ca, Fe, Zn, Mg), antioxidants (polyphenols, carotenoids, glucosinolates) and bioactive compounds, providing antioxidant, anti-inflammatory, anticancer, antidiabetic, antimicrobial, and neuroprotective effects, thereby mitigating malnutrition and chronic disease risks. Their cultivation is resource-efficient, utilizing 158–236 times less water than mature crops, requiring minimum space, and eliminating the need for pesticides, rendering them optimal for sustainable urban agriculture. Diverse cultivation techniques, such as cocopeat, soil-based systems, vermiculite/perlite, hydroponic/soilless approaches, and alternative substrates (e.g., compost, coconut coir, rice straw), improve production, nutrient composition, and sustainability. Cocopeat facilitates accelerated development and enhances carotenoid and chlorophyll concentrations, whereas soil-based substrates with organic additions augment micronutrient availability. Hydroponic techniques, including aeroponics and nutrient film technology, diminish nitrate concentrations and increase yields, while local substrates such as sugarcane bagasse and composted waste improve cost-efficiency and environmental sustainability. Critical determinants affecting microgreen cultivation encompass light (blue/red LEDs, 12–24-hour photoperiods), temperature (24–28°C), humidity (45–65%), seed density, and nutrient solutions (e.g., calcium fertigation, Hoagland’s solution). Optimized conditions improve biomass, bioactive chemicals, and shelf life. Microgreens, such as cabbage, amaranth, and basil, are versatile in various growing media and environmental conditions, rendering them a scalable and sustainable solution for urban food security and nutritional improvement with low ecological impact.

**Keyword:** microgreen, nutrient-rich, urban agriculture, review

**Introduction**

Microgreens are high-value crops, gaining popularity due to their unique flavor, color, texture, and acceptance in culinary applications and nutraceuticals, particularly in urban and peri-urban markets [1]-[5]. Moreover, they offer significant health benefits and nutritional superiority. For instant, nutrient-dense microgreens contain higher levels of vitamins C, E, and K; minerals like K, Ca, Fe, Zn, and Mg; antioxidants (polyphenols, carotenoids, and glucosinolates); and phytochemicals compared to mature vegetables, thus making them valuable functional foods for addressing malnutrition and promoting health [6]-[15]. Additionally microgreens are rich in bioactive compounds, which offering antioxidant, anti-inflammatory, anticancer, antidiabetic, anti-obesity, antimicrobial, and neuroprotective properties, thereby reducing risks of cardiovascular diseases, chronic diseases, and oxidative stress [6], [9], [10], [16]-[18]. Furthermore, biofortification through fertilization, e.g., Ca and Zn, and seed nutropriming significantly increases mineral content like Ca, Zn, and Fe in microgreens, consequently addressing global micronutrient deficiencies [19]-[21]. In additions they require 7–12 days for harvesting, and optimizing cultivation practices, including modular fertigation and lighting (e.g., waveband, intensity, and photoperiod) along with controlled environment factors such as temperature, CO₂, and VPD, enhances yields, bioactive content, quality, and shelf-life of microgreens [22]-[31]. Most importantly, microgreens are sustainable and resource-efficient, since they require 158–236 times less water than mature crops, minimal space, and no pesticides, while their shortened growth cycles of 7–21 days, reducing environmental impact thus supporting sustainable urban farming [7], [8], [21], [26], [32].

**Cultivation Methods**

**Cocopeat-Based Media:** Cocopeat, owing to its excellent water retention and aeration, is highly effective, as it encourages quicker growth and shorter harvest periods [33]. Moreover, it improves morphological characteristics of mustard, radish, and flaxseed (e.g., shoot height and yield) and raises carotenoid and chlorophyll content [34]. For example, in red amaranthus, fenugreek, and spinach, vermicompost combined with cocopeat increases plant height, fresh weight, and dry weight [35]. Additionally, additives like humic acid and calcium oxide (CaO) make cocopeat as productive as imported peat while lowering disease risk in Brassica microgreens [36]. In contrast, in onion seedlings, cocopeat outperforms farmyard manure, vermicompost, perlite, vermiculite, and sand in growth parameters [37].

**Soil-Based Media:** Soil-based media, often supplemented with organic matter like peat moss or compost and inorganic components like perlite or vermiculite, enhance radish and amaranthus productivity and quality when amended with organic materials such as vermicompost and poultry manure [38], [39]. Furthermore, soil-based media can deliver higher micronutrient concentrations (e.g., potassium, magnesium, copper, iron, zinc) compared to other media [33]. For instance, a mixed media of soil, husk charcoal, and perlite in a TAP121 ratio supports balanced growth and high vitamin A, C, and antioxidant levels in bok choy and water spinach [40]. However, when combined with sand or coco coir, there is a risk of soil-borne illnesses, which requires careful management [36].

**Vermiculite and Perlite-Based Media:** Vermiculite and perlite improve soil structure and drainage but differ in water retention and aeration properties. Their combination in potting mixtures achieves balanced drainage and moisture retention, thus producing high biomass and nutrient content (e.g., phenols, flavonoids) in crops like broccoli, red beet, and black radish [41]. Moreover, perlite with cocopeat promotes longer roots and higher fresh weight in cauliflower microgreens [42]. Similarly, vermiculite enhances germination and shoot development in hydroponic systems, especially with calcium fertilization [43]. Notably, nutrient quality varies among species, with antioxidants (e.g., in red basil) higher in vermiculite media [44].

**Hydroponic and Soilless-Based Media:** Hydroponic and soilless cultivation use nutrient-rich water solutions or substrates. For example, systems like aeroponics, DWC, NFT, and ebb and flow reduce nitrate levels and improve yields in basil, Swiss chard, and rocket lettuce [45], [46]. Additionally, soilless media like burlap and jute fabric enhance sustainability by reducing post-harvest cleaning costs while maintaining phenols and chlorophyll in mustard and basil microgreens [44], [47]. Furthermore, prawn wastewater in aquaponic systems significantly increases yields of amaranthus and beet microgreens compared to plain water [48]. Similarly, vertical farming multilayer systems without substrates are effective for radish with high nutritional quality [49]. Moreover, hydroponic microgreen growth and nutrient content are optimized with adequate Ca fertigation [20].

**Local Substrates (Alternative):** Alternative substrates like composted green manure, coconut coir, wood fiber, rice straw, mustard stalk, siliqua, sugarcane bagasse, water hyacinth, banana pseudostem, and sawdust are used as substitutes or in mixtures with traditional substrates [50], [51]. For instance, compost-based cultivation in urban settings enhances access to nutrient-dense foods with minimal environmental impact [7]. Additionally, local substrates like coir dust, sugarcane filter cake, and NaOH-treated rice straw are cost-effective, thus supporting high yields and low microbial contamination in vine spinach and kangkong [51], [52]. Similarly, compost and vermiculite mixtures enhance chlorophyll and carotenoid content in sunflower and water spinach [53]. Moreover, rice husk charcoal increases chlorophyll and carotenoid content in pakchoi microgreens [54]. Furthermore, sterilized coconut coir (boiled for 15 minutes) reduces disease incidence and maintains quality in Chinese kale [55]. In addition, using locally available organic waste compost mixed with peat and perlite reduces reliance on peat while improving sustainability [21]. For example, a 50% soil + 50% compost mixture yields the highest fresh weight in mustard microgreens, whereas 100% soil inhibits growth [56]. Finally, cabbage microgreens grown on compost have significant nutrient content compared to hydroponics [57].

**Factors for Microgreen Cultivation**

Several factors influence successful microgreen cultivation, including light (intensity, quality, duration), temperature, humidity, seed density, watering, air circulation, variety selection, fertilization, and growing medium. Optimizing these enhances yields and nutritional content.

**Light:** Microgreens require adequate light for photosynthesis, which impacts growth rates and nutritional values. Natural sunlight is ideal, but artificial lighting is necessary for indoor cultivation. For instance, blue, red, and white LED lighting enhances yields, plant height, and bioactive compounds like carotenoids and flavonoids in *Brassica carinata* and amaranthus [58], [59]. Moreover, a 24-hour photoperiod increases yields and nutritional values (e.g., anthocyanin, flavonoids) while reducing nitrate in Brassicaceae microgreens [60]. Additionally, light intensity (120–160 µmol m⁻² s⁻¹) and a 12-hour photoperiod optimize yield and resource efficiency in beet microgreens [61]. Furthermore, algae treatment enhances chlorophyll and carotenoid content in pea microgreens under low light intensity [62].

**Temperature and Humidity:**Microgreens thrive at 24–28°C and 45–65% humidity, thereby improving growth in mung bean, lentils, red radish, pearl millet, mustard, and red cabbage, with harvest times ranging from 6–13 days [63]. However, high temperatures (28°C) may reduce vitamin C and sugar content in hemp microgreens, while macro elements remain stable [64]. For example, red cabbage microgreens show high vitamin C and phenol content at optimal temperatures [63]. Moreover, humidity influences post-harvest quality, as mustard microgreens stored at 5°C ± 1°C (refrigerated, controlled humidity) exhibit lower weight loss compared to room temperature [65].

**Seed Density and Sowing Techniques:** Seed density (8–12 seeds/cell or 150–200 g/m²) increases fresh shoot yield but may reduce individual shoot size in arugula, radish, and mustard [66], [67], [68]. Additionally, seed inoculation with endophytic bacteria Herbaspirillum sp. improves buckwheat microgreen growth at 10–20% inoculum concentration [69].

**Nutrient Solution and Fertilization:** In soilless cultivation, nutrient solutions and fertigation are crucial. For instance, calcium solutions (5–10 mM) improve germination, hypocotyl length, and biomass in radish microgreens, with toxicity above 20 mM [43]. Similarly, Hoagland’s nutrient solution (50%) optimizes yield, while 125% enhances secondary metabolites in basil microgreens [70]. Moreover, coconut water boosts growth and yield in broccoli and mustard when combined with cocopeat or compost [71], [72]. Furthermore, post-emergent fertilization increases shoot height, fresh/dry weights, and macronutrients in Brassica and radish microgreens [73].

**Microgreen Cultivation**

**Cabbage:** Cabbage microgreens thrive at 24–28°C, thus supporting maximum yields and nutrient accumulation [63]. Additionally, a 16-hour light/8-hour dark cycle promotes photosynthesis and biomass production [27], [74]. Moreover, relative humidity of 79 ± 2% supports healthy growth without microbial issues [27]. For example, cocopeat is highly effective for growth, yield, chlorophyll, and ascorbic acid content [34], [75]. Furthermore, vermicompost increases mineral content (Fe, Zn, Mn) compared to hydroponic systems [57]. Similarly, NaOH-pretreated rice straw supports high plant length and fresh weight, comparable to cocopeat [51]. In addition, peat-based substrates boost ascorbic acid by 30% and anthocyanins by 12% without nutrient supplementation [19]. Moreover, aquaponic systems with prawn wastewater yield 2180.69 g/m² compared to 1127.69 g/m² with dechlorinated water [48]. Finally, optimal seed density is 10–12 seeds per cell for yield or 4 seeds for nutrition-focused cultivation [48], [76].

**Amaranth:** Amaranth microgreens grow optimally at 24 ± 2°C [59]. For instance, continuous 24-hour white light at 14–21 mol m⁻² d⁻¹ increases fresh biomass by up to 42% and improves energy-use efficiency, while a 16-hour light/8-hour dark cycle is also effective [25], [59]. Moreover, blue LED maximizes fresh weight, chlorophyll a, and polyphenol content, whereas red light increases nitrate but depresses polyphenols [59]. Additionally, maintaining 50–60% relative humidity minimizes microbial risks [59]. Furthermore, a cocopeat + vermicompost (60:40) mixture enhances plant height, fresh weight, dry weight, nutrient availability, and sensory acceptability [35]. Similarly, poultry manure + soil (60:40) yields the highest growth and quality [38]. In addition, cocopeat alone is effective for morphological traits and biochemical composition [34]. Finally, integration with prawn cultivation supports sustainable, high-yield production [48].

**Basil:** Basil microgreens grow best at 21–24°C during the day and 17–19°C at night [70], [77]. For example, continuous 24-hour white light at 14–21 mol m⁻² d⁻¹ increases fresh biomass by 10–42% and energy-use efficiency, while a 16-hour light/8-hour dark cycle is also effective [25], [70]. Moreover, maintaining 50–60% relative humidity is essential [44]. Additionally, vermiculite enhances yield and antioxidants, particularly in red basil [44], [78]. Similarly, cocopeat supports high germination, plant height, and leaf number [78]. Furthermore, jute fabric promotes high antioxidant content with lower nitrate levels [44]. In addition, peat-based substrates are effective for organic production, with control treatments yielding the highest shoot biomass [79]. Moreover, a seed density of 41.0 g m⁻² optimizes yields in hydroponic systems, with higher yields in full sun and warmer seasons [46]. Finally, storing at high humidity and moderate temperatures preserves freshness [80].

**Radish Microgreens (Raphanus sativus L.)**

**Overview:**
Radish microgreens are fast-growing (ready in 5–7 days), pungent, and rich in vitamin C, antioxidants, and minerals such as calcium and potassium.
**Sustainability Aspects:**Require minimal substrate; can grow on cocopeat, jute mats, or even tissue paper.Thrive in ambient temperatures (18–24°C), eliminating the need for heating/cooling.Require only light misting; can be grown in reused trays.

**Urban Farming Potential:**
Radish microgreens’ rapid growth and adaptability to vertical stacking make them ideal for small balconies or windowsills.

**Broccoli Microgreens (Brassica oleracea var. italica)**

**Overview:**
*Broccoli microgreens are a nutritional powerhouse, especially rich in sulforaphane, a compound known for its cancer-preventing properties.****Sustainability Aspects:****Grow within 7–10 days, with high yields on organic media like coconut husk fiber.Require limited water—1–2 light sprayings per day.Can grow in low-light areas with supplemental LED lighting.*

**Urban Farming Potential:**
Perfect for health-conscious urbanites. They can be grown year-round with simple setups like hydroponic trays or recycled containers.

**Mustard Microgreens (Brassica juncea L.)**

**Overview:**
Mustard microgreens are flavorful with a spicy kick and contain glucosinolates, known for their antioxidant properties.
**Sustainability Aspects:**Germinate quickly (3–5 days), reducing energy inputs.Require low nutrient input; can thrive on spent compost or hydroponically.Very water-efficient.

**Urban Farming Potential:**
Their bold flavor and fast growth make them excellent for small-scale kitchen gardens.

 **Fenugreek Microgreens (Trigonellafoenum-graecum L.)**

**Overview:**
Fenugreek microgreens are rich in iron, fiber, and protein, with a slightly bitter taste ideal for detox diets.
**Sustainability Aspects:**Grow well on moist kitchen towels or trays with compost.Do not require fertilization during the microgreen stage.Minimal space and light requirements.

**Urban Farming Potential:**
Ideal for sunny windows or terraces. Extremely cost-effective and suitable for daily home use.

**Spinach Microgreens (Spinacia oleracea L.)**

**Overview:**
Spinach microgreens are mild in flavor, rich in iron, folate, and vitamin A.
**Sustainability Aspects:**Slightly slower to grow (10–14 days) but high in biomass.Prefer cooler temperatures (15–20°C), suitable for indoor shaded setups.Minimal pest issues and water requirements.

**Urban Farming Potential:**
Grow well in recycled shallow containers or under LED grow lights in indoor environments.

 **Pea Microgreens (Pisum sativum L.)**

**Overview:**
Pea microgreens are sweet, crunchy, and rich in vitamin C, protein, and dietary fiber.
**Sustainability Aspects:**Require presoaking but germinate reliably.Tolerant of low light, though better with indirect sunlight or LEDs.Grow well on low-cost substrates like soil-less media or cotton fabric.

**Urban Farming Potential:**
Due to their height and high yield, they are excellent for vertical trays or rack systems in urban rooftops or corridors.

**Kale Microgreens (Brassica oleracea var. acephala)**

**Overview:**
Kale microgreens are nutrient-dense with high levels of vitamin K, calcium, and antioxidants.
**Sustainability Aspects:**Germinate in 3–4 days and are ready to harvest in 7–10 days.Grow well in organic, compost-based media with minimal fertilizer.Suitable for reuse of waste water from kitchens (after filtration**).(CHANGE THE ALIGNMENT)**

**Urban Farming Potential:**
Their high value and easy cultivation make them popular in both home gardens and commercial microgreen startups.

**Conclusion**

Microgreens’ high concentrations of vitamins, minerals, antioxidants, and bioactive compounds make them a promising option for nutrient-dense, sustainable food with significant health benefits. Their adaptability in culinary and nutraceutical applications, combined with resource-efficient cultivation techniques like cocopeat, soil-based, hydroponic, and alternative substrates, makes them ideal for urban farming. Optimizing environmental factors like light, temperature, humidity, and fertilizer management improves yield, quality, and shelf-life. Microgreens address global micronutrient deficiencies and promote environmentally friendly agriculture through diverse, sustainable production techniques.Microgreens such as radish, broccoli, mustard, fenugreek, spinach, pea, and kale offer an excellent opportunity for sustainable, space-efficient, and resource-light urban farming. Utilizing low-cost substrates, recycled containers, minimal water, and organic inputs, urban growers can integrate microgreen cultivation into their lifestyle. These crops not only contribute to personal health and food security but also align with environmental sustainability goals.

**References:**

[1] Kyriacou, M. C., Rouphael, Y., Di Gioia, F., Kyratzis, A., Serio, F., Renna, M., ... & Santamaria, P. (2016). Micro-scale vegetable production and the rise of microgreens. *Trends in Food Science & Technology*, 57, 103-115.

[2] Mir, S. A., Shah, M. A., & Mir, M. M. (2017). Microgreens: Production, shelf life, and bioactive components. *Critical Reviews in Food Science and Nutrition*, 57(12), 2730-2736.

[3] Ebert, A. W. (2013). Sprouts, microgreens, and edible flowers: the potential for high value specialty produce in Asia. SEAVEG 2012: High Value Vegetables in Southeast Asia: Production, Supply and Demand, 216-227.

[4] Rebolledo, P., Carrasco, G., Moggia, C., Gajardo, P., Sant’Ana, G. R., Fuentes-Peñailillo, F., ... &Vendruscolo, E. P. (2024). Assessment of Vegetable Species for Microgreen Production in Unheated Greenhouses: Yield, Nutritional Composition, and Sensory Perception. Plants, 13(19), 2787.

[5] Tallei, T. E., Kepel, B. J., Wungouw, H. I. S., Nurkolis, F., Adam, A. A., &Fatimawali. (2024). A comprehensive review on the antioxidant activities and health benefits of microgreens: current insights and future perspectives. International Journal of Food Science and Technology, 59(1), 58-71.

[6] Tallei, T. E., Kepel, B. J., Wungouw, H. I. S., Nurkolis, F., Adam, A. A., &Fatimawali. (2024). A comprehensive review on the antioxidant activities and health benefits of microgreens: current insights and future perspectives. International Journal of Food Science and Technology, 59(1), 58-71.

[7] Weber, C. F. (2017). Broccoli microgreens: A mineral-rich crop that can diversify food systems. Frontiers in Nutrition, 4, 7.

[8] Ebert, A. W. (2022). Sprouts and microgreens—novel food sources for healthy eating. Trends in Food Science & Technology, 128, 108-117.

[9] Mishra, G. P., Priti, Dikshit, H. K., Aski, M., Sangwan, S., Stobdan, T., ... & Praveen, S. (2022). Microgreens: a novel food for nutritional security. In Conceptualizing Plant-Based Nutrition: Bioresources, Nutrients Repertoire and Bioavailability (pp. 123-156). Singapore: Springer Nature Singapore.

[10] Bhaswant, M., Shanmugam, D. K., Miyazawa, T., Abe, C., & Miyazawa, T. (2023). Microgreens—a comprehensive review of bioactive molecules and health benefits. Molecules, 28(2), 867.

[11] Ayeni, A. (2021). Nutrient Content of Micro/Baby-Green and Field-Grown Mature Foliage of Tropical Spinach (Amaranthus sp.) and Roselle (Hibiscus sabdariffa L.). Foods, 10, 2546.

[12] Butkutė, B., Taujenis, L., &Norkevičienė, E. (2018). Small-seeded legumes as a novel food source. Variation of nutritional, mineral and phytochemical profiles in the chain: raw seeds-sprouted seeds-microgreens. Molecules, 24(1), 133.

[13] Lenzi, A., Orlandini, A., Bulgari, R., Ferrante, A., &Bruschi, P. (2019). Antioxidant and mineral composition of three wild leafy species: A comparison between microgreens and baby greens. Foods, 8(10), 487.

[14] El-Nakhel, C., Pannico, A., Graziani, G., Kyriacou, M. C., Gaspari, A., Ritieni, A., ... &Rouphael, Y. (2021). Mineral and antioxidant attributes of Petroselinum crispum at different stages of ontogeny: Microgreens vs. baby greens. Agronomy, 11(5), 857.

[15] Martínez-Ispizua, E., Calatayud, Á., Marsal, J. I., Cannata, C., Basile, F., Abdelkhalik, A., ... & Martínez-Cuenca, M. R. (2022). The nutritional quality potential of microgreens, baby leaves, and adult lettuce: an underexploited nutraceutical source. Foods, 11(3), 423.

[16] Le, T. N., Chiu, C. H., & Hsieh, P. C. (2020). Bioactive compounds and bioactivities of Brassica oleracea L. var. italica sprouts and microgreens: An updated overview from a nutraceutical perspective. Plants, 9(8), 946.

[17] Wojdyło, A., Nowicka, P., Tkacz, K., &Turkiewicz, I. P. (2020). Sprouts vs. microgreens as novel functional foods: Variation of nutritional and phytochemical profiles and their in vitro bioactive properties. Molecules, 25(20), 4648.

[18] Rizvi, A., Sharma, M., & Saxena, S. (2023). Microgreens: a next generation nutraceutical for multiple disease management and health promotion. Genetic Resources and Crop Evolution, 70(2), 311-332.

[19] Di Gioia, F., Hong, J. C., Pisani, C., Petropoulos, S. A., Bai, J., &Rosskopf, E. N. (2023). Yield performance, mineral profile, and nitrate content in a selection of seventeen microgreen species. Frontiers in Plant Science, 14, 1220691.

[20] Reichmuth, C. M. (2025). The Effects of Calcium Availability on Growth and Calcium Content of Hydroponic Daikon Radish Microgreens. [No journal specified; likely a thesis or dissertation].

[21] Poudel, P., Di Gioia, F., Lambert, J. D., & Connolly, E. L. (2023). Zinc biofortification through seed nutri-priming using alternative zinc sources and concentration levels in pea and sunflower microgreens. Frontiers in Plant Science, 14, 1177844.

[22] Kyriacou, M. C., Rouphael, Y., Di Gioia, F., Kyratzis, A., Serio, F., Renna, M., ... & Santamaria, P. (2016). Micro-scale vegetable production and the rise of microgreens. Trends in Food Science & Technology, 57, 103-115.

[23] Allred, J. A. (2017). Environmental and cultural practices to optimize the growth and development of three microgreen species. [No journal specified; likely a thesis or dissertation].

[24] Amitrano, C., Paglialunga, G., Battistelli, A., De Micco, V., Del Bianco, M., Liuzzi, G., ... & De Pascale, S. (2023). Defining growth requirements of microgreens in space cultivation via biomass production, morpho-anatomical and nutritional traits analysis. Frontiers in Plant Science, 14, 1190945.

[25] Lanoue, J., St. Louis, S., Little, сестра, & Hao, X. (2022). Continuous lighting can improve yield and reduce energy costs while increasing or maintaining nutritional contents of microgreens. Frontiers in Plant Science, 13, 983222.

[26] Tavan, M., Wee, B., Brodie, G., Fuentes, S., Pang, A., & Gupta, D. (2021). Optimizing sensor-based irrigation management in a soilless vertical farm for growing microgreens. Frontiers in Sustainable Food Systems, 4, 622720.

[27] Flores, M., Hernández-Adasme, C., Guevara, M. J., &Escalona, V. H. (2024). Effect of different light intensities on agronomic characteristics and antioxidant compounds of Brassicaceae microgreens in a vertical farm system. Frontiers in Sustainable Food Systems, 8, 1349423.

[28] Fayezizadeh, M. R., Ansari, N. A., Sourestani, M. M., &Hasanuzzaman, M. (2024). Variations in photoperiods and their impact on yield, photosynthesis and secondary metabolite production in basil microgreens. BMC Plant Biology, 24(1), 712.

[29] Ali, V., Mandal, J., & Vyas, D. (2025). Insights into light-driven dynamics of phytochemicals in sprouts and microgreens. Plant Growth Regulation, 105(1), 129-152.

[30] Meng, Q., & Severin, S. N. (2024). Continuous light can promote growth of baby greens over diurnal light under a high daily light integral. Environmental and Experimental Botany, 220, 105695.

[31] Sheibani, F., Gómez, C., Morrow, R., Bourget, M., & Mitchell, C. A. (2025). Interactive Effects of Photon Flux Density and Carbon Dioxide Concentration on Energy-use Efficiency for Indoor Baby-greens Production. HortScience, 60(7), 1092-1098.

[32] Parkes, M. G., Cubillos Tovar, J. P., Dourado, F., Domingos, T., & Teixeira, R. F. (2022). Life cycle assessment of a prospective technology for building-integrated production of broccoli microgreens. Atmosphere, 13(8), 1317.

[33] Dubey, S., Harbourne, N., Harty, M., Hurley, D., & Elliott-Kingston, C. (2024). Microgreens production: exploiting environmental and cultural factors for enhanced agronomical benefits. Plants, 13(18), 2631.

[34] Gunjal, M., Singh, J., Kaur, S., Nanda, V., Ullah, R., Iqbal, Z., ... &Rasane, P. (2024). Assessment of bioactive compounds, antioxidant properties and morphological parameters in selected microgreens cultivated in soilless media. Scientific Reports, 14(1), 23605.

[35] Revanna, M. L., Manjunatha Swamy, T. S., &Vijayalaxmi, K. G. (2024). Optimizing Soilless Media for Superior Microgreen Production and Sensory Acceptance. Journal of Scientific Research and Reports, 30(12), 640-647.

[36] Hoang, G. M., & Vu, T. T. (2022). Selection of suitable growing substrates and quality assessment of Brassica microgreens cultivated in greenhouse. Academia Journal of Biology, 44(2), 133-142.

[37] Priyadarshini, V. M., & Kumari, P. M. (2021). Influence of growing media on herbage yield of onion (Allium cepa L.) microgreens. International Journal of Botany Studies, 6(5), 1376-1378.

[38] Pradeepa, P. P., Maurya, D., Bhati, D., Harendra, Jatav, V., & Kumar, P. (2023). Impact of different growing media on growth, productivity and storability of red amaranthus microgreens.

[39] Khatoon, S., & Singh, M. (2022). Impact of various substrates on the physicochemical properties of radish microgreens. Annals Phytomedicine, 11, 591-596.

[40] Sukewijaya, I. M., Dwiyani, R., &Bimantara, P. O. (2025). Optimization of Growing Media to Support Microgreens Growth and Nutritional Profile. Agro Bali: Agricultural Journal, 8(1), 102-113.

[41] Balik, S., Dasgan, H. Y., Ikiz, B., &Gruda, N. S. (2024). The Performance of Growing-Media-Shaped Microgreens: The Growth, Yield, and Nutrient Profiles of Broccoli, Red Beet, and Black Radish. Horticulturae, 10(12), 1289.

[42] Rabago, A. H., Rosales, R. J., Gregorio-Balbas, M. B., &Pungtilan, A. L. (2024). Utilization of Locally Available Substrates And Their Effect on the Growth And Yield of Cauliflower (Brassica oleracea botrytis group) Microgreens. Basrah Journal of Agricultural Sciences, 37(2), 276-287.

[43] Goble, C. C. (2018). Effects of Calcium Fertilization on Growth, Yield, and Nutrient Content of Hydroponically Grown Radish Microgreens.

[44] Bulgari, R., Negri, M., Santoro, P., & Ferrante, A. (2021). Quality evaluation of indoor-grown microgreens cultivated on three different substrates. Horticulturae, 7(5), 96.

[45] Bulgari, R., Baldi, A., Ferrante, A., &Lenzi, A. (2017). Yield and quality of basil, Swiss chard, and rocket microgreens grown in a hydroponic system. New Zealand Journal of Crop and Horticultural Science, 45(2), 119-129.

[46] Nolan, D. A. (2019). Effects of seed density and other factors on the yield of microgreens grown hydroponically on Burlap.

[47] Min Allah, S., Dimita, R., Negro, C., Luvisi, A., Gadaleta, A., Mininni, C., & De Bellis, L. (2023). Quality evaluation of mustard microgreens grown on peat and jute substrate. Horticulturae, 9(5), 598.

[48] Guerreiro, S. L., Cabral Júnior, J. F. G., Eiras, B. J., Miranda, B. D. S., Lopes, P. C. A., Melo, N. F. A. C. D., ... &Palheta, G. D. A. (2024). Integrating Aquaponics with Macrobrachiumamazonicum (Palaemonidae: Decapoda) Cultivation for the Production of Microgreens: A Sustainable Approach. AgriEngineering, 6(3), 2718-2731.

[49] Tilahun, S., Baek, M. W., An, K. S., Choi, H. R., Lee, J. H., Hong, J. S., &Jeong, C. S. (2023). Radish microgreens produced without substrate in a vertical multi-layered growing unit are rich in nutritional metabolites. Frontiers in Plant Science, 14, 1236055.

[50] Prisa, D., & Caro, S. (2023). Alternative substrates in the cultivation of ornamental and vegetable plants. GSC Biological and Pharmaceutical Sciences, 24(01), 209-220.

[51] Saurabh, K., Roy, H. S., Shubha, K., Sundaram, P. K., Prakash, V., Koley, T. K., ... & Singh, R. R. (2025). Transforming rice straw into eco-friendly growing medium for microgreens: a solution for agricultural waste management. Frontiers in Sustainable Food Systems, 9, 1556396.

[52] Paglialunga, G., El Nakhel, C., Proietti, S., Moscatello, S., Battistelli, A., Formisano, L., ... &Rouphael, Y. (2023). Substrate and fertigation management modulate microgreens production, quality and resource efficiency. Frontiers in Sustainable Food Systems, 7, 1222914.

[53] Thepsilvisut, O., Sukree, N., Chutimanukul, P., Athinuwat, D., Chuaboon, W., Poomipan, P., ... &Ehara, H. (2023). Efficacy of agricultural and food wastes as the growing media for sunflower and water spinach microgreens production. Horticulturae, 9(8), 876.

[54] Charloq, C. (2024). Analysis of Bioactive Components of Pakcoy Microgreens (Brassica rapa L.) on Variations of Planting Media. JURNAL AGRONOMI TANAMAN TROPIKA (JUATIKA), 6(2), 471-480.

[55] Photchanachai, S., Tantharapornrerk, N., Pola, W., Muangkote, S., &Bayogan, E. R. V. (2017). Coconut coir media sterilization method for growing Chinese kale microgreens. In IV Asia Symposium on Quality Management in Postharvest Systems 1210 (pp. 51-58).

[56] Nur, T. P., &Gofar, N. (2023). Growth and yield of indoor-cultivated mustard microgreens against the duration of LED irradiation and variations in planting media. JurnalLahan Suboptimal: Journal of Suboptimal Lands, 12(2), 172-183.

[57] Weber, C. F. (2016). Nutrient content of cabbage and lettuce microgreens grown on vermicompost and hydroponic growing pads. Journal of Horticulture, 3(4), 1-5.

[58] Maru, R. N., Wesonga, J., Okazawa, H., Kavoo, A., Neondo, J. O., Mazibuko, D. M., ... & Orsini, F. (2024). Evaluation of growth, yield and bioactive compounds of Ethiopian kale (Brassica carinata A. Braun) microgreens under different LED light spectra and substrates. Horticulturae, 10(5), 436.

[59] Toscano, S., Cavallaro, V., Ferrante, A., Romano, D., &Patané, C. (2021). Effects of different light spectra on final biomass production and nutritional quality of two microgreens. Plants, 10(8), 1584.

[60] Shibaeva, T. G., Rubaeva, A. A., Sherudilo, E. G., &Titov, A. F. (2023). Continuous lighting increases yield and nutritional value and decreases nitrate content in Brassicaceae microgreens. Russian Journal of Plant Physiology, 70(6), 118.

[61] Hernández-Adasme, C., Palma-Dias, R., &Escalona, V. H. (2023). The effect of light intensity and photoperiod on the yield and antioxidant activity of beet microgreens produced in an indoor system. Horticulturae, 9(4), 493.

[62] Frąszczak, B., Kula-Maximenko, M., & Li, C. (2024). The suitability of Algae Solution in pea microgreens cultivation under different light intensities. Agriculture, 14(10), 1665.

[63] Dhaka, A. S., Dikshit, H. K., Mishra, G. P., Tontang, M. T., Meena, N. L., Kumar, R. R., ... & Praveen, S. (2023). Evaluation of growth conditions, antioxidant potential, and sensory attributes of six diverse microgreens species. Agriculture, 13(3), 676.

[64] Vetchinnikov, A., Uromova, I., Novik, I., Druzhkova, O., Dydykina, M., &Zhadaev, A. (2025). The effect of air temperature on the growth and development of hemp microgreens grown using aeroponics. In E3S Web of Conferences (Vol. 613, p. 02004). EDP Sciences.

[65] Weerakkody, W. A. A. U., Devasinghe, D. A. U. D., Wijayawardhana, H. C. D., &Wickramasinghe, W. M. D. M. (2023). Effect of Growing Media and Foliar Applications on Growth, Yield, and Shelf Life of Mustard (Brassica nigra L.) Microgreens. Sri Lankan Journal of Agriculture and Ecosystems, 5(1).

[66] Murphy, C., & Pill, W. (2010). Cultural practices to speed the growth of microgreen arugula (roquette; Eruca vesicaria subsp. sativa). The Journal of Horticultural Science and Biotechnology, 85(3), 171-176.

[67] Lerner, B. L., Strassburger, A. S., & Schäfer, G. (2024). Cultivation of arugula microgreens: seed density and electrical conductivity of nutrient solution in two growing seasons. Bragantia, 83, e20230183.

[68] Signore, A., Somma, A., Leoni, B., & Santamaria, P. (2024). Optimising sowing density for microgreens production in rapini, kale and cress. Horticulturae, 10(3), 274.

[69] Briatia, X., Jomduang, S., Lumyong, S., Kanpiengjai, A., &Khanongnuch, C. (2017). Enhancing Growth of Buckwheat Sprouts and Microgreens by Endophytic Bacterium Inoculation. International Journal of Agriculture & Biology, 19(2).

[70] Fayezizadeh, M. R., Ansari, N. A., Sourestani, M. M., &Hasanuzzaman, M. (2023). Balancing yield and antioxidant capacity in Basil microgreens: an exploration of nutrient solution concentrations in a floating system. Agriculture, 13(9), 1691.

[71] Sulistiya, S. (2021). Response To The Growth And Results Of Microgreens Brocoly Planted Hydroponically With Various Planting Media And Addition Of Coconut Water Sources Of Nutrition And Hormone. JurnalPertanianAgros, 23(1), 217-229.

[72] Syahriana, T. N., & Ala, H. A. (2025). Effectiveness of Cocopeatnut Water and Various Growing Media on the Growth and Yield of Mustard Microgreens (Brassica juncea L.). AGROGENESIS Journal of Sustainable Agriculture and Innovation, 1(1), 53-63.

[73] Li, T., Lalk, G. T., Arthur, J. D., Johnson, M. H., & Bi, G. (2021). Shoot production and mineral nutrients of five microgreens as affected by hydroponic substrate type and post-emergent fertilization. Horticulturae, 7(6), 129.

[74] Jones-Baumgardt, C., Llewellyn, D., Ying, Q., & Zheng, Y. (2019). Intensity of sole-source light-emitting diodes affects growth, yield, and quality of Brassicaceae microgreens. HortScience, 54(7), 1168-1174.

[75] Roihan, A. R. (2021). Effect of natural growth regulatory substance (pgr) and differences of planting media on chlorophil content number of vegetablestomates and area of vegetablestomates microgreens broccoli (Brassica oleracea L.). International Journal of Applied Biology, 5(2), 60-61.

[76] LL Ntsoane, M., E. Manhivi, V., Shoko, T., Seke, F., M. Maboko, M., & Sivakumar, D. (2023). The phytonutrient content and yield of Brassica microgreens grown in soilless media with different seed density. Horticulturae, 9(11), 1218.

[77] Samuolienė, G., Brazaitytė, A., Viršilė, A., Jankauskienė, J., Sakalauskienė, S., &Duchovskis, P. (2016). Red light-dose or wavelength-dependent photoresponse of antioxidants in herb microgreens. Plos One, 11(9), e0163405.

[78] Gustianty, L. R., Zulia, C., & Yoga, M. (2023). Growth And Results of Some Microgreens of Order Caryophyllales on Different Plant Media. Journal of Scientific Research, Education, and Technology (JSRET), 2(3), 1452-1460.

[79] Dembele, D. M., Nguyen, T. T. A., Bregard, A., Naasz, R., Jobin-Lawler, F., Boivin, C., &Dorais, M. (2021). Effects of growing media and fertilization rates on the organic production of baby leafy vegetables. In IV All Africa Horticultural Congress-AAHC2021: Transformative Innovations in Horticulture 1348 (pp. 141-154).

[80] Ebert, A. W. (2013). Sprouts, microgreens, and edible flowers: the potential for high value specialty produce in Asia. SEAVEG 2012: High Value Vegetables in Southeast Asia: Production, Supply and Demand, 216-227.