**Biodegradable Growth Media Alternatives for Sustainable Hydroponic Farming**

**Abstract**

The practice of hydroponic farming needs inert growth materials to surround plant root. However, materials like rockwool and perlite present environmental insecurities as they are not biodegradable. This research evaluates three biodegradable material options including coconut coir, peat moss, and biochar for their effects on plant development and nutrient storage in addition to sustainability evaluation. The experimental data shows that using biodegradable substrates leads to higher water storage capacity together with better microbial function along with lower waste production. Research outcomes validate the use of sustainable hydroponic substrate materials for promoting extended environmental sustainability in farming systems without soil.

Keywords: Hydroponics, Biodegradable Growth Media, Sustainable Agriculture, Coconut Coir, Biochar, Peat Moss

**1. Introduction**

The hydroponic farming system emerged as an innovative production approach which combines resource-maximization and soil-minimalism together with controlled growing conditions for plant development. Non-biodegradable substrates which include rockwool, perlite and expanded clay pellets spread sustainability issues throughout hydroponic systems. These materials produce landfill pollution which worsens hydroponic system environmental impact while generating sustainability concerns for future operations (Lim et al., 2020; Vinci and Rapa, 2019). The research effort to examine biodegradable materials for usage as replacements has intensified through the identification of coconut coir, peat moss and biochar as promising substitutes since these materials exhibit organic properties together with high water retention potential and decreased environmental influence (Both et al., 2023; Zhao et al., 2022; Ashpreet et al., 2023). Scientists extensively research coconut coir as an appropriate hydroponic substrate because it originates from coconut husk fibers. Scientific research shows that coir substrates provide effective growth support to plants since studies reveal coir maintains essential chemical development properties unchanged (Lim et al., 2020). Hydrophilicity in coir promotes efficient water retention thus making it appropriate for hydroponic system applications (Both et al., 2023; Schulker et al., 2020). Coir's physical characteristics along with its moisture retention and root aeration functionality are essential for plant health development (Both et al., 2023; Schulker et al., 2020; Tuckeldoe et al., 2023).

Hydroponic applications demonstrate strong performance potential when utilizing coir instead of usual growing materials. The performance of coir as a hydroponic substrate matches traditional substrates such as rockwool when used for growing melons and strawberries according to Lim et al. (2020), Aurdal et al. (2022), and Tuckeldoe et al. (2023). The introduction of coir into hydroponic systems both enhances sustainability efforts and carries beneficial effects on how plants absorb nutrients through its stable foundation for root development (Zheng et al., 2024; Zhao et al., 2022; Inkaew et al., 2024). The organic nature of coir in hydroponic applications helps decrease reliance on chemical fertilizer consumption since it acts as a nutrition source for the substrate (Zheng et al., 2024; Tuckeldoe et al., 2023).

Hydroponic systems use peat moss as a biodegradable choice because it maintains water well and provides great aeration properties. The extraction procedure for peat creates substantial environmental problems because it endangers vital ecosystems that store carbon and support biodiversity (Gruda, 2019). Coconut coir stands apart from other alternatives because it functions as a renewable agriculture waste product that offers sustainable production methods (Mariotti et al., 2020; Ravindranath, 2019). The coir production process utilizes agricultural waste to achieve waste reduction goals while promoting a circular economy in agricultural operations according to Ravindranath (2019) and Lebedeva et al. (2022).

Biochar represents a possible hydroponic substrate substitute because it arises from organic matter pyrolysis into carbon-rich material. These unique physical characteristics in biochar promote better nutrient absorption and microbial activity within hydroponic substrates according to Rosli et al., 2023 (Machado & Hải, 2021). Biochar combined with coir and compost has proven effective for enhancing plant development and yield production according to Rosli et al., 2023 and Machado & Hải, 2021. Utilizing biochar in hydroponic systems produces two positive effects by promoting plant productivity and maintaining soil quality while storing carbon which helps build sustainable agricultural methods (Rosli et al., 2023; Machado & Hải, 2021).

Research lacks thorough evaluation of the performance capabilities of biodegradable substrates in hydroponic systems when compared to traditional hydroponic substrates. Studies conducted by Zheng et al. (2024) and Tuckeldoe et al. (2023) and Zhao et al. (2022) showed the possibilities of coconut coir and peat moss and biochar in plant cultivation however researchers need to explore their optimal usage and long-term effects on nutrient systems in hydroponic environments. University researchers need to perform a more comprehensive study of organic substrates alongside different nutrient solutions because this assessment is critical for optimizing their benefits when used in hydroponics (Zheng et al., 2024; Tuckeldoe et al., 2023; Zhao et al., 2022).

Evaluations must be performed to determine the economic feasibility of using biodegradable substrates in production since they must consider both manufacturing expenses and availability alongside consumer market preferences. Supporting the adoption of coconut coir in hydroponic farming depends on building a strong supply network due to its rising recognition for sustainability and performance (Ravindranath 2019; Lebedeva et al. 2022). Consistency in hydroponic crop production and quality demands standardized practices for biodegradable substrate use (Zheng et al., 2024; Tuckeldoe et al., 2023; Zhao et al., 2022) and standardized practices need development.

The move towards biodegradable alternatives for hydroponic farming establishes a major advance towards sustainability and greener environmental practices. Hydroponic agriculture gains sustainability through the utilization of coconut coir together with peat moss and biochar which effectively aid plant growth while resolving non-degradable substrate problems. The development of these biodegradable materials requires additional research to determine how effective they are as well as how to optimize their integration into hydroponic systems. The hydroponic industry will strengthen environmental food production systems when it selects sustainable resources as primary components.

**Research Objectives**

1. Plants undergoing growth in biodegradable cultivation mediums need to be studied for their performance evaluation.

2. Researchers must perform tests concerning the ability of different substrates to store water and hold nutrients.

3. The assessment of both water conservation and active ingredient accumulation within biodegradable hydroponic growth media will happen.

**2. Materials and Methods**

**2.1 Experimental Design**

Three biodegradable media served as the foundation for this study that took place in a controlled hydroponic greenhouse.

The coconut coir product comes from coconut husks where researchers highlight its strong ability to hold water.

The organic matter peat moss helps improve both substrate air circulation and nutrient intake ability.

The charred organic biochar substance brings multiple advantages through its ability to nourish microbes while managing nutrient cycles.

All experiments utilized Rockwool as the standard medium for testing purposes. Each treatment block included three plant species: lettuce, basil and tomatoes under three different biodegradable media structures.

**2.2 Growth Conditions and Nutrient Solution**

A standardized hydroponic nutrient solution with essential macronutrients and micronutrients served to cultivate all the plants. The growing conditions maintained the following environmental factors:

- Temperature: 22–26°C

- Humidity: 55–65%

- pH level: 5.5–6.5

- EC (electrical conductivity): 1.5–2.5 mS/cm

The growth lights used an LED setup for a 14-hour cycle of light exposure.

**2.3 Data Collection**

The following parameters were measured:

- Plant Growth Performance: Height, root development, biomass accumulation, and yield.

- Water Retention Capacity: The ability of each medium to retain moisture over a 24-hour period.

-Nutrient Retention Efficiency: Analysis of nitrogen (N), phosphorus (P), and potassium (K) retention.

- Decomposition Rate: The biodegradability of each medium over a 12-week period.

**2.4 Statistical Analysis**

Analysis of Variance (ANOVA) was conducted to compare plant growth, water retention, and nutrient-holding capacity across different media. Tukey’s post hoc test determined significant differences at p < 0.05.

**3. Results and Discussion**

**3.1 Plant Growth Performance**

Biodegradable media supported comparable or superior plant growth compared to rockwool. Coconut coir demonstrated the highest plant height and biomass yield, followed by peat moss and biochar.

Table 1 : Plant Growth Performance

|  |  |  |  |
| --- | --- | --- | --- |
| **Growth Medium**  | **Lettuce Height (cm)** | **Basil Biomass (g)** | **Tomato Yield (g/plant)** |
| Coconut Coir  | 25.3 ± 1.2  | 42.5 ± 3.1  | 340 ± 15  |
| Peat Moss  | 24.1 ± 1.0  | 39.2 ± 2.8  | 310 ± 14  |
| Biochar  | 23.5 ± 1.3  | 35.8 ± 2.5  | 290 ± 13  |
| Rockwool | 22.8 ± 1.1  | 38.6 ± 2.9  | 300 ± 14  |

Coconut coir facilitated superior root development due to its balanced aeration and water retention properties, contributing to higher plant biomass.

**3.2 Water Retention and Nutrient-Holding Capacity**

The ability of a growth medium to retain moisture and nutrients directly affects plant health and hydroponic system efficiency.

Table 2 : Water Retention and Nutrient-Holding Capacity

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Growth Medium  | Water Retention (%) | Nitrogen Retention (mg/kg) | Phosphorus Retention (mg/kg) | Potassium Retention (mg/kg) |
| Coconut Coir  | 85.2 ± 2.3  | 32.4 ± 1.8  | 18.2 ± 1.3  | 29.5 ± 2.1  |
| Peat Moss  | 79.5 ± 2.1  | 30.1 ± 1.6  | 16.8 ± 1.2  | 27.3 ± 2.0  |
| Biochar  | 72.8 ± 2.0  | 28.5 ± 1.4  | 15.2 ± 1.1  | 25.9 ± 1.8  |
| Rockwool  | 65.3 ± 1.9  | 26.7 ± 1.3  | 14.9 ± 1.0  | 24.7 ± 1.6  |

Coconut coir exhibited the highest water retention, reducing the need for frequent irrigation. Biochar improved nutrient retention, benefiting long-term plant health by stabilizing nitrogen and phosphorus levels.

**3.3 Decomposition and Environmental Impact**

Biodegradability is a critical factor in evaluating the sustainability of hydroponic growth media. Over 12 weeks, biochar exhibited the slowest decomposition rate, while peat moss degraded most rapidly.

Table 3 : Decomposition and Environmental Impact

|  |  |  |
| --- | --- | --- |
| Growth Medium  | Decomposition (%) over 12 Weeks | Environmental Impact Score |
| Coconut Coir  | 65 ± 5  | Low  |
| Peat Moss  | 78 ± 6  | Moderate  |
| Biochar | 52 ± 4  | Very Low  |
| Rockwool | 5 ± 1  | High  |

Rockwool’s minimal degradation confirms its environmental drawback, whereas coconut coir and peat moss offer promising biodegradable solutions with reduced waste accumulation.

**3.4 Advantages of Biodegradable Hydroponic Growth Media**

The use of such materials generates sustainability by lowering non-biodegradable waste production while supporting circular agricultural practices.

The substance maintains water retention together with nutrient levels while fostering beneficial microbial functions.

- Cost-Effectiveness: Readily available and renewable, reducing long-term farming expenses.

**3.5 Challenges and Considerations**

The decomposition speed of certain biodegradable materials makes them require regular maintenance through replacement.

The organic media dimension creates pH changes that need periodic checks due to their instability.

The sustainability of biodegradable media remains valuable but the monetary investment needed during purchase exceeds normal commercial options.

**4. Conclusion**

The research examined demonstrates that coconut coir, peat moss, and biochar act as successful environmentally friendly solutions for hydroponic media replacement of rockwool. The material assists plant growth positively and enhances nutrient and water retention functions for environmental sustainability. Sustainable and eco-friendly agricultural practices receive support through hydroponic farming when biodegradable substrates are implemented.

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**5. References**

1. Aurdal, S., Woznicki, T., Haraldsen, T., Kuśnierek, K., Sønsteby, A., & Remberg, S. (2022). Wood fiber-based growing media for strawberry cultivation: effects of incorporation of peat and compost. Horticulturae, 9(1), 36. https://doi.org/10.3390/horticulturae9010036
2. Both, A., Choudhry, D., & Cheung, C. (2023). Eco-friendly fabrication of coco coir composites for hydroponic cultivation: a green chemistry approach. New Journal of Chemistry, 47(11), 5488-5497. https://doi.org/10.1039/d3nj00226h
3. Gruda, N. (2019). Increasing sustainability of growing media constituents and stand-alone substrates in soilless culture systems. Agronomy, 9(6), 298. https://doi.org/10.3390/agronomy9060298
4. Inkaew, Y., Kawee‐ai, A., Supasin, S., & Pankasemuk, T. (2024). Comparison of coconut coir and soil cultivations for hemp production: plant growth and production yield. International Journal of Research Publication and Reviews, 5(3), 511-515. <https://doi.org/10.55248/gengpi.5.0324.0619>
5. Kailashkumar B., Priyadharshini K., Logapriya M. Hydroponic Cultivation: Factors Affecting Its Success and Efficacy. Int. J.Environ. Clim. Change. [Internet]. 2023 Sep. 6 [cited 2025 Feb. 18];13(10):2403-10. Available from: https://journalijecc.com/index.php/IJECC/article/view/2905
6. Lebedeva, D., Hijmans, S., Mathew, A., Subbotina, E., & Samec, J. (2022). Waste-to-fuel approach: valorization of lignin from coconut coir pith. Acs Agricultural Science & Technology, 2(2), 349-358. https://doi.org/10.1021/acsagscitech.1c00248
7. Lim, M., Choi, S., Jeong, H., & Choi, G. (2020). Characteristics of domestic net type melon in hydroponic spring cultivars using coir substrates. Horticultural Science and Technology, 38(1), 78-86. https://doi.org/10.7235/hort.20200008
8. Machado, R. and Hải, B. (2021). Physicochemical characteristics of substrates of the mixture of coir with municipal solid waste compost and with biochar. Acta Horticulturae, (1320), 399-404. https://doi.org/10.17660/actahortic.2021.1320.53
9. Mariotti, B., Martini, S., Raddi, S., Tani, A., Jacobs, D., Oliet, J., … & Maltoni, A. (2020). Coconut coir as a sustainable nursery growing media for seedling production of the ecologically diverse quercus species. Forests, 11(5), 522. https://doi.org/10.3390/f11050522
10. Ravindranath, A. (2019). Coir pith – a medium for oil absorption. Cord, 35(01), 13. https://doi.org/10.37833/cord.v35i01.9
11. Reji, A., Kaushal, S., & Shubham, S. (2023). Organic hydroponics: the future of farming. Current Journal of Applied Science and Technology, 42(38), 1-11. https://doi.org/10.9734/cjast/2023/v42i384247
12. Rosli, N., Abdullah, R., Yaacob, J., & Razali, R. (2023). Effect of biochar as a hydroponic substrate on growth, colour and nutritional content of red lettuce (lactuca sativa l.). Bragantia, 82. https://doi.org/10.1590/1678-4499.20220177
13. Schulker, B., Jackson, B., Fonteno, W., Heitman, J., & Albano, J. (2020). Comparison of water capture efficiency through two irrigation techniques of three common greenhouse soilless substrate components. Agronomy, 10(9), 1389. https://doi.org/10.3390/agronomy10091389
14. Tuckeldoe, R., Maluleke, M., & Adriaanse, P. (2023). The effect of coconut coir substrate on the yield and nutritional quality of sweet peppers (capsicum annuum) varieties. Scientific Reports, 13(1). https://doi.org/10.1038/s41598-023-29914-0
15. Vinci, G. and Rapa, M. (2019). Hydroponic cultivation: life cycle assessment of substrate choice. British Food Journal, 121(8), 1801-1812. https://doi.org/10.1108/bfj-02-2019-0112
16. Zhao, Z., Xu, T., Pan, X., Susanti, S., White, J., Hu, X., … & Ng, K. (2022). Sustainable nutrient substrates for enhanced seedling development in hydroponics. Acs Sustainable Chemistry & Engineering, 10(26), 8506-8516. https://doi.org/10.1021/acssuschemeng.2c01668
17. Zheng, L., Liu, X., & Ge, L. (2024). Improved evaluation of seedling cultivation efficiency in coconut coir substrate through the addition of diverse nutrient sources.. https://doi.org/10.20944/preprints202404.1276.v1