

Improving Mangrove Restoration Efficacy Through Husk-Assisted Stability and Arbuscular mycorrhizal Fungi in Nutrient Facilitation

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Abstract. Mangrove ecosystems are vital for coastal resilience, serving as natural barriers against erosion, nurseries for marine life, carbon sinks, and biodiversity hotspots. However, they are rapidly declining due to natural and human-induced pressures. Two major threats are tidal erosion, which dislodges young propagules before roots can anchor, and crab predation. To address these challenges, this study explores the combined use of *Cocos nucifera* (husk waste) and *Arbuscular mycorrhizal* (AM) fungi as a low-cost, sustainable restoration method. Coconut husks were chosen for their lignin and cellulose content, offering physical stability, moisture retention, and gradual nutrient release. AM fungi were used to enhance nutrient uptake and plant resilience. Four environmental treatments were tested over four months, and results showed that the combination of coconut husk with fungi achieved the highest growth performance, increasing root amount by 103.6% compared to the control and increasing leaf length by 30.1-38.1% compared to the other treatments in the first month. Additionally, it showed a 27.6-50.5% increase in root amount compared to the other environmental groups and a 19.1-40.5% increase in leaf length in the fourth month. This indicates that combining agricultural waste and symbiotic fungi can significantly improve mangrove propagule survival.

1 Introduction

Environmentally friendly methods based on the integration of environmental protection and sustainable use of natural resources are becoming more significant to make the ecological balance in the world acceptable. Mangrove ecosystems are valuable coastal ecosystems that prevent shore loss, are an important carbon source, and provide valuable nurseries to marine biodiversity. The ecological interactions, such as symbiosis associations with fungi, often determine the existence of the more ecologically sensitive ones, enhancing them to endure nutrient-restrained habitats [1]. Conservation and restoration of mangroves is a direct contribution to the Sustainable Development Goals (SDGs) of the United Nations. In particular, they can help in SDG 13 (Climate Action) by carbon sequestration [2,3], in SDG 14 (Life Below Water), by preserving

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marine biodiversity [4,5], and in SDG 15 (Life on Land) by protecting degraded coastal ecosystems [6,7].

Mangroves have been extremely challenged despite their significance. The propagules are often washed away by tide erosion, and the root systems are undermined by crab predation (*Uca rapax*). As a result, root systems have low survival rates [8]. Past research recommends that coconut husks can be used as a stabilizer in the soil and promote retention of moisture [9], and the *Arbuscular mycorrhizal* (AM) fungi increase uptake of nutrients [1]. Nonetheless, little has been done on their joint use for mangrove restoration. Against this background, this research aims to bridge the existing gap in the literature on the cooperation between coconut waste and AM fungi to enhance propagule survival and growth. Although a lot of research has been done on the personal gains of organic waste [8,9] and symbiosis-forming fungi [10,11], their combined abilities to prevent coastal erosion, reforestation, curtailed nutrient pools, as well as crab predation, an issue still facing propagule development and viability, have not been well investigated [12,13].

Although a considerable body of research has been conducted in the area of mangrove reintroduction research, most of the currently applied restoration strategies depend on either physical interventions or biological ones without focusing on the way in which both mechanisms can be synergistic. Whereas past research has shown the personal gains of organic compounds like *Cocos nucifera* husks in enhancing moisture retention, reduction of sediment disturbance [8,9], and the use of *Arbuscular mycorrhizal* (AM) fungi in enhancing nutrient uptake, stress tolerance, and root branching [1,10,11,14], there are limited studies on the ecological outcome of the combination of these two elements. This gap is especially important since established successful propagules in dynamic coast must rely concomitantly on physiological performance and structural anchorage. Their combined impacts are thus important in the formulation of resilient, nature-based restoration practices that have the ability to improve the early propagule formation and increase the long-term stability of the ecosystem.

Arbuscular mycorrhizal (AM) fungi are an important functional element of plant-microbe symbioses in coastal ecosystems, which promote physiological functions that significantly increase propagule establishment during unfavorable environmental conditions. AM fungi will enhance and expand the absorptive surface area of the mangrove root systems through the intraradical arbuscules and extraradical networks of hyphae [10,11], and due to this, they will improve uptake of both immobile and micronutrients that are limited to tidal fluctuations in the coastal soils [1]. The fungi, in turn, offer several adaptive benefits in return for photosynthetically produced carbon compounds, among them the increased osmotic regulation, salinity stress tolerance [10], and improved hydraulic conductivity. These mutualistic associations were proven to affect plant allometry, root system architecture, and patterns of biomass allocation, which ends up enhancing ontogenic survival and competitiveness in shoreland ecosystems in the initial stages of their development [10,15,16]. This symbiotic process makes us able to incorporate this into restoration measures, and this way, it gives us a biologically based process of enhancing propagule survival and functional resilience in degraded mangrove areas.

This paper, hence, investigates the significance of coconut husk wastes and AM fungi in enhancing the growth of mangroves as depicted in the length of the leaf and the stem, the number of roots, and the survival of the mangroves. It also looks into the wider ecological implications of such treatments to soil quality, biodiversity, and water environments within the immediate surroundings. The proposed study will assist in coming up with a scientific low-cost and sustainable restoration plan based on renewable materials that are locally available. The report will facilitate knowledge of the significance of plant-microbe-substrate interactions in seashores, and will be applied in the future to enhance the strategies in mangrove conservation and ecosystem resilience. The experiment would be carried out in the course of seven months (April to October 2025), of which the major part would take four months. An experimental test was also done to determine the effectiveness and viability of the use of coconut husk waste.

2 Experimental Method

The experimental design employed was quantitative, designed to establish the impact of the addition of coconut husk waste and *Arbuscular mycorrhiza* on the growth of mangrove propagules. The relative efficacy was measured by setting up four treatment groups: control, mangrove propagules with *Cocos Nucifera*, propagules inoculated with *Arbuscular mycorrhiza*, and a mix of *Cocos nucifera* and *Arbuscular mycorrhiza* propagules. The experiment would be carried out in Surabaya, East Java Province, Indonesia, between the months of April and October 2025 on a strictly regulated condition, which would permit the measurement of the length of leaves and stems and the growth of the roots (root quantity) to be measured accurately.

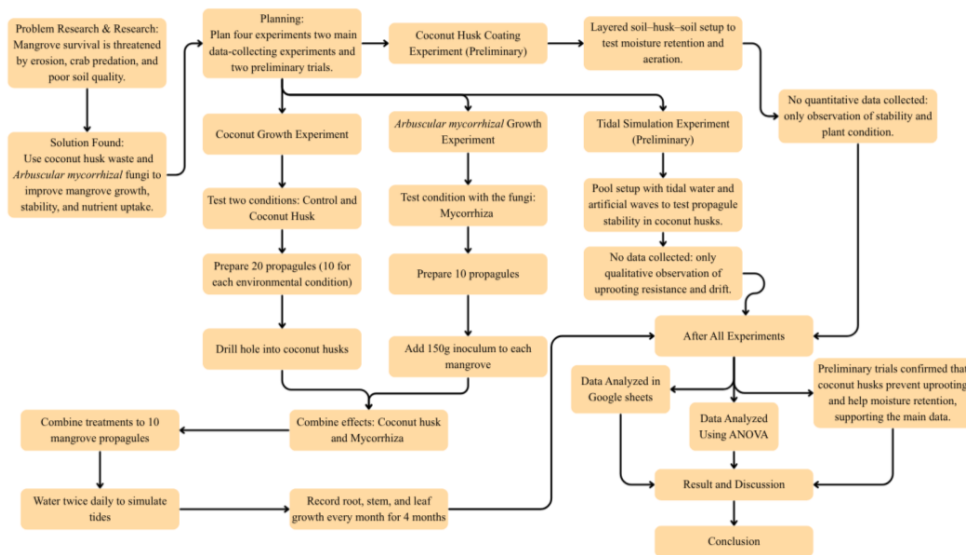


Fig. 1. Schematic Diagram of Experimental Methods

To get a clear picture of this research, a schematic diagram has been drawn down using the general outline of the experiment and the methodology of the research is outlined visually. This overview highlights how the treatment groups were organized and how the experimental components relate to one another. This schematic diagram of the experimental methods presented in Fig. 1 indicates the scheme of the four treatment groups (C, N, M, and NM) and the main procedural components which are the basis of the study design.

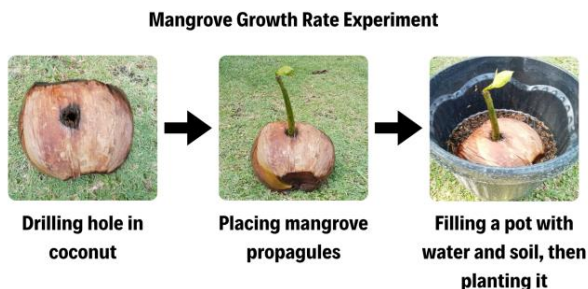


Fig. 2. Experimental Methodology of Mangrove Growth Rate Experiment

The main goal of this investigation was to compare the growth patterns of mangrove propagules grown with coconut husks with those grown without them, by planting them directly into the soil medium. The experimental procedure shown in Fig. 2 included background preparation of each coconut husk, with an exact aperture drilled at the crown to fit the propagule, allowing the stem to pass through the opening while providing a tight, retentive interface at the base. After this customization, single mangrove propagules were placed in the modified husks, and their root systems grew in the fibrous inside of the husk matrix. Each husk-propagule setup was then placed in a cultivation pot with a moist loamy medium, and with the aim of keeping the medium moist, supplemental irrigation at dawn and dusk was added during the study to mimic tidal variations. Parameters of measurable growth, including leaf length, stem growth, and roots, were meticulously recorded after every four weeks, and this offered a strong dataset in quantifying the comparison of the four treatment groups. This methodological paradigm was to provide the limits and boundaries on whether the coconut husk offers a natural protective coating, and aids in maintaining moisture and offering nutrients, which will have a positive influence on the first ontogenic development of mangrove propagules. This experiment is the major source of data as long as it takes place between June and September 2025.



Fig. 3. Experimental Methodology of *Arbuscular mycorrhizal* Growth Experiment.

The overall aim of the current study was to determine the combined effect of *Arbuscular mycorrhizal* (AM) fungi and coconut husk substrates on the growth of the mangrove propagules. Fig. 3 showed the experimental process, involving preparation of fungal inoculums, which were strictly measured to an amount of 150 g per pot to ensure that all treatments had the same amount of inoculums. The inoculum was placed directly on the soil surface before planting, and the inoculated propagules (coconut husks) were later applied to the pots, ensuring direct contact between the plant roots and the AM fungal inoculum.

It is also common knowledge that AM fungi can form symbiotic partnerships with plant roots, thereby increasing nutrient uptake, especially phosphorus and nitrogen, and acting as a buffer against adverse abiotic conditions such as salinity. The ecological importance of mycorrhizal associations in mangrove ecosystems has been well documented in the literature due to this symbiosis.

To help clarify the possible synergistic effect of fungal inoculation used along with the use of coconut husks, the experiment used three unique treatment conditions to compare propagules in the treatment groups that were inoculated with AM fungi, propagules that had no inoculation with AM fungi, and propagules that had been inoculated with AM fungi but not implanted into coconuts. This was a comparative design that was aimed at isolating the contribution of each component.

The interest parameters, such as leaf and stem lengths and the number of roots, were measured and documented systematically throughout the study and provide quantitative data to test the effect of each fungal treatment on the growth and resilience of the mangrove. A strong statistical analysis of treatment effects was achieved through frequent reporting of these measures. This experiment is the main source of data, with it lasting from June until September 2025.

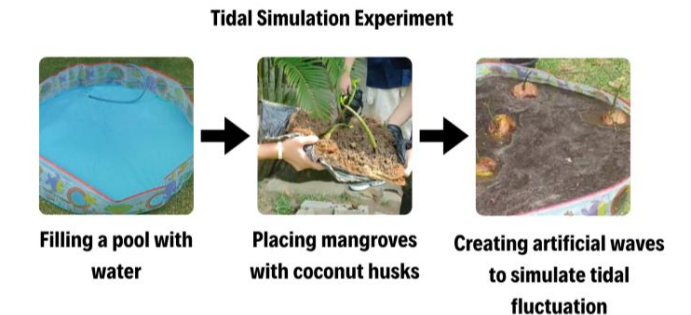


Fig. 4. Preliminary Experimental Methodology of Tidal Simulation Experiment.

A preliminary experiment that tested the potential of the coconut husks to stabilize mangrove propagules in tidal conditions was carefully tested in a controlled experiment. The experimental design used a simulated coastal basin, as seen in Fig. 4, created by pouring seawater into a small plastic aquarium. Previously inoculated mangrove propagules that were inoculated in coconut husks were placed in the tank, thus providing an environment that was closely related to near-shore growth dynamics.

The mechanical production of waves was done manually to estimate the hydrodynamic forces that can be seen during the occurrences of high and low tide, to not only represent a tidal rise and fall. The stability of and displacement of the propagules through the trial were carefully observed. This installment made it possible to gauge the potential capacity of the coconut husks to hinder the drift, to overturn, and uproot the propagules in the presence of the wave motions.

The preliminary test suggests that coconut husk biomaterials may contribute to stabilizing propagules under tidal conditions, although further trials are needed to confirm their effectiveness in real coastal environments. Although this research is an initial study and does not provide extensive data, the experiment was conducted between April and June of 2025.

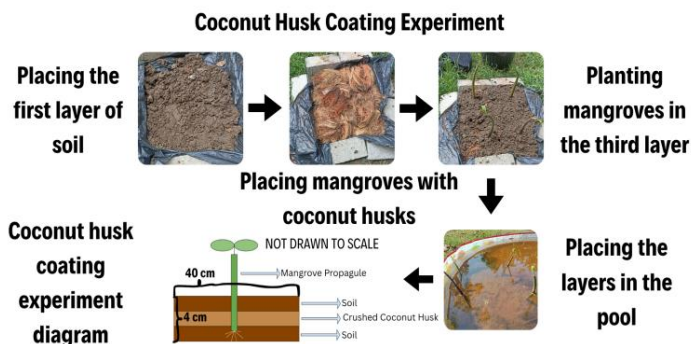


Fig. 5. Preliminary Experimental Methodology of Coconut Husk Coating Experiment.

The experiment shown in Fig. 5 aims to determine the viability of the use of pulverized coconut husks as an individual or a layer on a conventional topsoil bed. The experimental program began with the deposition of a layer of conventional topsoil, which was subjected to a layer of crushed coconut husk, which was supposed to serve as a natural moisture-retaining and aeration medium. Later, a second layer of soil was added over the husk mat, and mangrove propagules were carefully sprinkled over the high-quality section of this apparatus. The design was to

determine whether the stratified structure would stimulate better root proliferation, hydric exchange, and nutrient uptake.

A schematic diagram was used to represent the architectural verticality of the stratification, with the relative thicknesses of the constituent layers approximately equal, and the spatial relationship between propagule roots and their substrates was provided. Lastly, the composite stratification was flushed in a basin full of water to simulate littoral environmental conditions. Systematic observations were to be conducted to have both propagule growth and survival measures, thus revealing whether the stratified soil-husk system was more destructive and stable than the conventional monosubstrate cultivation. Even though this experiment is an initial investigation, the data-gathering process has yet to be implemented.



Fig. 6. Root Measurement Diagram of the Mangrove Propagule

To achieve uniformity in the assessment of root development, the standard measurement procedure was used on all propagules, where the fixed reference points are used to determine the number of roots and the branching patterns of roots. This procedure enabled the correct comparison of treatments and reduced subjectivity variation with respect to observation. The method of measurement is shown in Fig. 6.

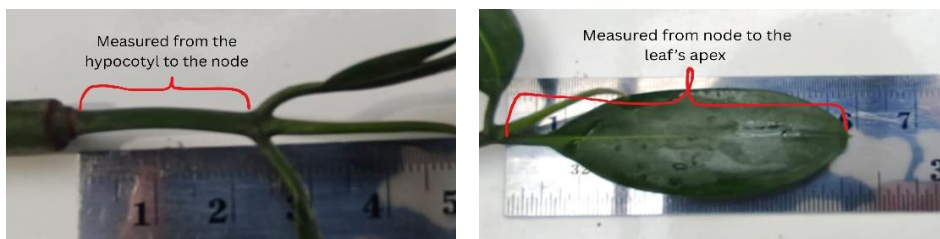


Fig. 7. Stem Measurement Diagram (A) and Leaf Measurement Diagram (B) of the Mangrove Propagule

Stem elongation was recorded using uniform anatomical reference points so that vertical growth could be measured reliably across all treatment groups. This ensured that differences in stem length reflected true physiological responses rather than measurement inconsistency. The procedure used for stem assessment is depicted in Fig. 7A.

Leaf length was measured using a uniform reference system that extends from the node to the apex, allowing comparisons across treatments and time points to be more consistent. This approach made sure that observed differences in leaf growth reflected actual physiological changes rather than measurement inconsistencies. The measurement framework used for leaf assessment is illustrated in Fig. 7B.

3 Results and Discussion

The experiment lasted four months, and systematic assessments were done to establish the impact of all these environmental treatments on the growth performances of the mangrove propagules. Measures were taken at predetermined points in time and gathered together as quantitative data, which reflected variation in early establishment, physiological development, and long-term growth responses. All parameters, such as stem length, leaf length, and the number of roots, were chosen as important biological indicators of the overall health, effectiveness of nutrient acquisition, and structural stability of the propagules. These measures were then tabulated and compared between the treatment groups in order to see both long-term and short-term impacts of the amendments. In order to facilitate clear interpretation, the comparative structure of growth outcomes assessed at the second and fourth months, which are the early adaptive stage and late maturation stage, is summarized in Table 1 as shown below.

In the four-month experimental phase, four different environmental treatments were administered as illustrated in Table 1, which outlines the structure of each treatment group. The numerical growth results were analyzed separately using the graphs presented in the subsequent figures. Environmental treatments were administered as follows. C refers to the Control treatment, where propagules were kept in the absence of exogenous amendments. N is the coconut Husk treatment, where propagules were sown in coconut husks as natural stabilizers and moisture-retaining substrates. M is the treatment of the Mycorrhiza, which is the inoculation of *Arbuscular mycorrhizal* (AM) fungi to improve the uptake of nutrients and development of the root system. Lastly, NM identifies the treatment of the combined coconut husk and Mycorrhiza, which was used to test the possible synergy between the two amendments and their effects on mangrove growth performance.

The results achieved within the second and fourth months of the experiment were compared in order to conduct the analysis. Comparing these two discrete time instances, the research aims to measure not only the adaptation dynamics in the early stages but also the performance of mangrove propagules under the combined treatment conditions in the long run.

The analysis of the growth during the mid-experiment and the long-term effectiveness of the treatments was performed to compare the results of the second and fourth months of the experiment. The reason behind this type of time-based sampling was to ensure that the stress of handling the propagules was minimal, since too often it could have been detrimental to establishing roots and the general health of the plant. The research compared these two important time points in evaluating the dynamics of adaptation and the performance persistence of mangrove propagules, especially on the long-term advantages of combined Coconut Husk and Mycorrhiza (NM) treatment [14].

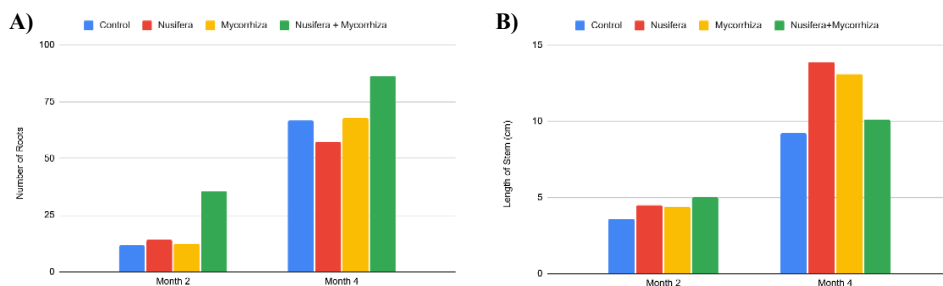




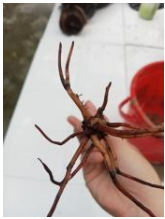













Fig. 8. Number of Roots (A) and Stem Length (B) among 4 months

Table 1. Comparison of Month 2 and Month 4 Experimental Results

Treatments	Control (C)	Coconut Husk (M)	Mycorrhiza (N)	Coconut Husk and Mycorrhiza (NM)
Roots (Month 2)				
Roots (Month 4)				
Stem and Leaf (Month 2)				
Stem and Leaf (Month 4)				

Across four months, root biomass increased in all treatments, but the NM combination produced the largest roots. In the second month, NM experienced root growth increase by 205.1%, 155.0%, and 187.9% when compared to C, N, and M, respectively. While in the fourth month, NM experienced root growth increase by 29.5%, 50.5%, and 27.6% when compared to C, N, and M, respectively. Over the 4 months of experimentation, NM averaged 56.9% monthly growth. This early and sustained divergence suggests a synergistic effect that improves water and nutrient uptake and likely explains the greater growth seen in stems and leaves. The increase in the number of roots, as seen in Fig. 8A, shows that NM has the most roots in the fourth month, indicating the most significant acceleration in root growth, supporting the conclusion that the combined treatment produces a synergistic effect beyond the individual contributions of *Nucifera* and *Mycorrhiza*.

Stem development presented a more interesting result, which shows evidence of strategic energy investment. Throughout the four months, as indicated in Fig. 8B, the result showed that in all the treatments, the stem length was constantly increasing, meaning that the propagule was healthy in each treatment condition. Compared to other environmental groups in the second month, NM shows increases in stem growth of 38.9%, 11.1%, and 13.6% relative to C, N, and M, respectively.

However, during the fourth month, NM increased stem growth by 9.8% compared to C. But as observed in Fig. 8B, N and M had longer stems, and NM registered a 27.3% and 22.9% lower growth of the stem compared to N and M, respectively. The final result of NM showed that the overall stem development was 64.2% over the months. This trend can be attributed to a general trade-off in the mycorrhizal symbiosis of plants: initial energy is invested in developing extensive root-fungus systems rather than in vertical stem extension. This was further enhanced by using coconut husks, which provided a moist, stable microenvironment that supported root growth. Thus, the NM plants were temporarily reduced in stem elongation to establish a broader physiological base for long-term sustainability.

This trend is attributed to early trade-offs in terms of energy allocation that are usually observed in plants in mycorrhizal symbiosis. In early development, plants with *Arbuscular mycorrhiza* (AM) inoculations tend to use this energy to build up massive root-fungus systems instead of vertical stem extensions [1,13]. This is a strategic investment that enhances the nutrient absorption and the ability to absorb water, which is in line with the methodology of integrating AM with organic substrates [12]. This effect was further enhanced by the use of coconut husk, which provided a moist and stable microenvironment [9] to support root growth and colonization, which helps in stabilization processes that are commonly needed in restoration [8]. Consequently, the NM plants temporarily became restricted in vertical stem growth to establish a better physiological base. In the long run, this basis leads to increased stability, resilience, and long-term growth under the coastal stresses like erosion and salinity [4,5,6]. Therefore, still, the NM stems were shorter, but it is a strategic adaptive allocation of long-term existence and not poor performance.

Leaf development data, as shown in Fig. 9, demonstrates the sustained superiority of the combined treatment (NM) at both the mid-point and end of the experiment. By the second month (Fig. 9A), the NM treatment was the only group to develop a fourth and fifth leaf, indicating accelerated foliar initiation. Quantitatively, NM recorded increases in total leaf growth of 66.1%, 53.4%, and 62.3% relative to the Control (C), Coconut Husk (N), and Mycorrhiza (M) treatments, respectively.

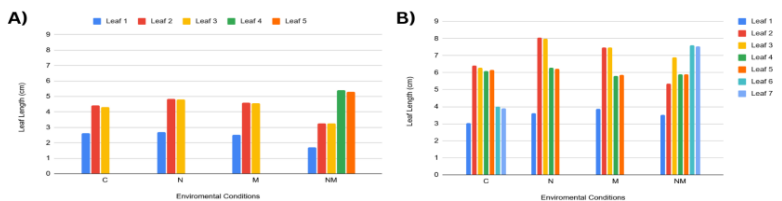


Fig. 9. Leaf lengths measured at months 2 (A) and 4 (B)

This quick multi-leaf growth indicated that the joint exploitation of *Cocos nucifera* husk and *Arbuscular mycorrhiza* (AM) fungi established an ideal symbiotic and micro-environmental environment that facilitated an effective take-up of the nutrients and photosynthetic growth. This kind of behavior is consistent with prior research indicating that AM symbiosis can boost nutrient uptake and early leaf development in growing plants [1,13], and organic substrates like coconut husks can enhance aeration, water retention, and stability and create favorable conditions to support continued leaf growth [8,9]. The comparatively slower extension of the individual leaves in the NM group suggests a trade-off in energy allocation, with the resources focused on the

production of new leaves rather than extending the existing ones, also a well-established fact in mycorrhizal species [12,15,16].

The fourth month augmented the long-term benefit of the NM treatment (Fig. 9B). The growth of the leaves in the NM treatment was increased by 19.1%, 32.8%, and 40.5% as compared to C, N, and M, respectively. In addition, the NM treatment had the most developed foliar development, where the sixth and seventh leaves were strongly developed. Although the control group was also starting to develop such leaves, they were much smaller and much less vigorous, highlighting the synergistic effect of using coconut husk and mycorrhizal fungi in the long term.

4 Conclusion

Coconut husk waste and *Arbuscular mycorrhizal* (AM) fungi represent accessible, low-cost, nature-based materials that can support early mangrove propagule growth and strengthen restoration efforts. The husks of coconuts can also serve as physical barriers against tidal energy and predation, at the same time enriching soil by the slow decomposition of the remains. At the same time, AM fungi boost nutrient uptake, induce root branching, and increase stress tolerance, thus increasing propagule resilience in nutrient-depleted and erosion-prone ecosystems [17, 18].

Four months of experimental results revealed that the composite treatment of coconut husks with AM fungi (herein referred to as NM) had the most potent effect on growth performance across all measured parameters, compared with the control and single-treatment groups. There was an increase of root biomass in the NM treatment of 103.6% compared to the control, an increase of 60.0% compared to the nucifera treatment, and an increase of 52.4% compared to the mycorrhiza treatment. The patterns of leaf development were similar to these results: after the initial month, NM leaves were 30.1% and 38.1% longer than those of other groups. At the end of the trial, the NM plants portrayed the appearance of two different leaves (Leaves 6 and 7), which are associated with high levels of maturity, health, and progressive leaf development.

The treatment's effectiveness was also supported by stem development; NM stems grew 2.4 cm in the first month, an excellent result compared to other treatments, and achieved the highest overall growth performance across all measured parameters. During the intermediate months (Months 3 and 4), the stems of NM were slightly shorter than those in single-treatment groups, likely due to an early investment in the formation of a root-fungal network. In Month 4, though, the NM plants had already shown the highest vigor and sustainability of growth in all parameters studied, including the root, stem, and leaf ones.

Overall, synergistic treatment with coconut husk and AM fungi increased by an average of 6.3-103.6% mangrove propagule growth as compared to other treatments, which supports a strong synergistic interaction. This finding supports the hypothesis that the use of agricultural waste with the help of beneficial fungi not only increases the mangrove growth but also promotes a cyclic economy by the bioconversion of biodegradable waste into an ecological growth medium.

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References

1. B. Rodrigues, "Diversity of arbuscular mycorrhizal fungi in mangrove ecosystem-a review", *J. Mycopathol. Res.* **60**, 155-165 (2022).
<https://www.imskolkata.org/article1/003-06-22.pdf>

2. L. Emerton, “Economic assessment of ecosystems as components of water infrastructure”, *J. Aust. Water Assoc.* **34**, 25-28 (2021).
3. L. Pendleton, et al. “Estimating Global “Blue Carbon” Emissions from Conversion and Degradation of Vegetated Coastal Ecosystems”, *PLoS ONE* **7**, 1-7 (2012). <https://doi.org/10.1371/journal.pone.0043542>
4. J. Sue, D. Friess, A. Gasparatos, “A meta-analysis of the ecological and economic outcomes of mangrove restoration”, *Nat. Commun.* **12**, 5050 (2021) <https://doi.org/10.6084/m9.figshare.12901382.v6>
5. N. Asari, M. Suratman, N. Ayob, N. Hamid, “Mangrove as a Natural Barrier to Environmental Risks and Coastal Protection”, *Mangroves: Ecol. Biodivers. Manag.*, 305-322 (2021). https://doi.org/10.1007/978-981-16-2494-0_13
6. P. Zeng, Y. Wang, W. Huang, “Quantitative simulation and verification of carbon neutralization potential upgrade law in urban agglomerations”, *Ecol. Indic.* **151** (2023). <https://doi.org/10.1016/j.ecolind.2023.110285>
7. D. Murdiyarto, et al. “The potential of Indonesian mangrove forests for global climate change mitigation”, *Nat. Clim. Chang.* **5**, 1089–1092 (2015). <https://doi.org/10.1038/nclimate2734>
8. R. Raju, M. Arockiasamy, “Coastal Protection Using Integration of Mangroves with Floating Barges: An Innovative Concept”, *J. Mar. Sci. Eng.* **10**, 612 (2022). <https://doi.org/10.3390/jmse10050612>
9. A. James, D. Yadav, Valorization of coconut waste for facile treatment of contaminated water: A comprehensive review (2010–2021), *Environ. Technol. Innov.* **24**, (2021). <https://doi.org/10.1016/j.eti.2021.102075>
10. Y. Akaji, T. Inoue, T. Taniguchi, S. Baba, Arbuscular mycorrhizal fungal communities of a mangrove forest along a salinity gradient on Iriomote Island. *Plant Soil* **472**, 145–159 (2022). <https://doi.org/10.1007/s11104-021-05193-4>
11. S. Paul, et al. “Seasonal Diversity of Arbuscular Mycorrhizal Fungi (AMF) in the Mangrove Forests of Bakkhali, Sundarban, India”, *Environ. Nat. Resour. J.* **22**, 420–430 (2024). <https://doi.org/10.32526/enrj/22/20240042>
12. H. Lee, H. Kim, E. Park, B. Lee, “Beyond carbon: a systematic review of multiple ecosystem services of mangroves”, *J. Coast. Conserv.* **29**, 58 (2025). <https://doi.org/10.1007/s11852-025-01148-4>
13. E. Barbier, “The protective service of mangrove ecosystems: A review of valuation methods”, *Mar. Pollut. Bull.* **109**, 676-681 (2016). <https://doi.org/10.1016/j.marpolbul.2016.01.033>
14. A. Ellison, E. Farnsworth, R. Merkt, “Origins of mangrove ecosystems and the mangrove biodiversity anomaly”, *Glob. Ecol. Biogeogr.* **8**, 95-115 (1999). <https://doi.org/10.1046/j.1466-822X.1999.00126.x>
15. Q. Zhang, L. Zhang, J. Weiner, J. Tang, X. Chen, “Arbuscular mycorrhizal fungi alter plant allometry and biomass–density relationships”, *Ann. Bot.* **107**, 407–413 (2010). <https://doi.org/10.1093/aob/mcq249>
16. M. Wang, et al. “Effects of arbuscular mycorrhizal fungi on plant growth and herbivore infestation depend on availability of soil water and nutrients”, *Front. Plant Sci.* **14** (2023). <https://doi.org/10.3389/fpls.2023.1101932>
17. A. Yusuf, “The roles of arbuscular mycorrhizae in supporting the mangrove growth”, *J. Health Technol. Sci.* **2**, 71-79 (2021). <https://doi.org/10.47918/jhts.v2i1.221>
18. R. F. Yenny, Z. Millah, D. Firnia, H. T. Jayanti, A. Susanto, “The Growth Response of Propagules *Rhizophora mucronata* in Soaking Coconut Water and Applying NPK Fertilizer”, *J. Biol. Trop.* **23**, 220–229 (2023). <https://doi.org/10.29303/jbt.v23i2.6038>