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Optimization of Adaptive Floating Raft System Planting Media in Lebak Swamp for Pakcoy Plant Growth (Brassica rapa L.)

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Abstract

This study aimed to evaluate the effect of planting media composition in an adaptive floating raft system on the growth of pakcoy (Brassica rapa L.) cultivated in lebak swamp areas. Floating raft systems are expected to address challenges associated with high water-level fluctuations commonly found in lowland swamps while maintaining planting media stability. Three growing media compositions consisting of ultisol soil, manure, and husk charcoal with three different ratios: M1 (2:1:1), M2 (1:1:2), and M3 (1:1:1). Observed parameters included media pH, temperature, moisture content, and pakcoy growth characteristics, namely plant height, number of leaves, leaf width, and fresh and dry biomass. The results indicated that the M3 growing medium provided the most favorable conditions for pakcoy growth, as reflected by superior vegetative growth and biomass accumulation. In addition, the M3 treatment exhibited more stable moisture and temperature conditions, supporting optimal water availability for plant development. Crop water requirements were estimated using the Modified Penman method, showing an increasing trend in water demand along the growth stages. Overall, the adaptive floating raft system combined with an appropriate planting media composition proved effective in supporting stable pakcoy growth under fluctuating water-level conditions in lebak swamp environments.

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1. Introduction

Peat swamp lands in Indonesia cover an area of more than 20 million hectares, making them potentially viable for development as productive agricultural areas (Paiman et al., 2020). The existence of peat swamp forests contributes to supporting national food security, especially in areas facing land conversion pressures, soil degradation, and increasing food demand (Nearti et al., 2024). However, peat swamp forests are still categorized as suboptimal land due to their extreme and highly dynamic hydrological characteristics (Az-Azahra et al., 2024). In a study (Puspitahati et al., 2024), the water level in peat swamp forests can change drastically with the seasons, ranging from prolonged flooding

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during the rainy season to drying up during the dry season. These hydrological fluctuations increase the risk of crop failure (Lakitan et al., 2019), especially in mineral soil-based cultivation systems that are unable to adapt to changes in water levels. This challenge is exacerbated by the impacts of climate change. Increased rainfall variability, flooding and drought, and rising extreme temperatures make the hydrological patterns of swamps increasingly difficult to predict (Salimi et al., 2021). According to (Rejekiningrum et al., 2022), mineral soil-based agricultural systems are less effective in coping with rapid and unpredictable environmental changes. Therefore, adaptive cultivation technology innovations are needed to maintain water supply and planting media stability in fluctuating conditions (Sule et al., 2025; Manokaran et al., 2025).

One potential technological approach is the floating raft system (floating agriculture). Floating raft systems are designed to follow changes in water level so that plants continue to receive a sustainable supply of water and nutrients (Chowdhury & Moore, 2017). In floating raft systems, the growing medium plays an important role as a water provider and root support to sustain plant growth (Muhammed et al., 2024). The physical and chemical characteristics of the growing medium, such as pH, temperature, and moisture content, greatly affect water retention, aeration, and root zone comfort (Muhammed et al., 2024). Environmental factors such as air temperature, humidity, wind speed, and light intensity also affect the rate of evapotranspiration, which can determine crop water requirements (Lai et al., 2022). Crop water requirement (CWR) is calculated based on climate variables such as temperature, solar radiation, wind, and air humidity through ET_0 estimation and crop coefficient (Kc). The accuracy of determining water requirements greatly affects water use efficiency and crop productivity. In pakcoy crops, (Hutabalian & Arif, 2023) showed that the Etc value in the pocket fertigation irrigation system produced significant differences in water footprint and crop yield, indicating that the accuracy of water requirements is a critical factor for productivity. From the aspect of growing media, (Chhetri et al., 2022) mentions that variations in media types such as cocopeat, sponge, and perlite produce different growth responses in lettuce and pakchoi due to differences in porosity, aeration, and water storage capacity. Additionally, (Veazie et al., 2025) stated that growing media pH that is too low or too high can inhibit nutrient uptake and reduce growth, making the optimal pH range important for nutrient uptake efficiency.

Leafy vegetables such as pakcoy are known to be highly sensitive to media moisture, temperature, and microenvironmental conditions. The combination of planting media composition and watering frequency has a significant effect on plant height, number of leaves, and pakcoy yield, and is influenced by the degree of media acidity (Seran et al., 2022). Media with good aeration and high water storage capacity directly increase plant height, leaf width, and fresh weight, which are key indicators of productivity (Chhetri et al., 2022). Based on this study, it is important to analyze various growing media compositions, taking into account pH, temperature, and media moisture, environmental conditions, and crop water requirements. Assessing the effect of soil composition on

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pakcoy growth (plant height, number of leaves, leaf width, wet and dry weight), and measuring crop water requirements in an adaptive floating raft system in a swampy environment. The results of this study are expected to form the basis for the design of optimal growing media and support the development of a more efficient, stable, and swampy hydrogeological characteristics-appropriate adaptive floating raft system.

2. Material and Methods

2.1 Research Location and Time

The research was conducted in the experimental field of the Aquaculture Laboratory, Faculty of Agriculture, Sriwijaya University and the Soil and Water Engineering Laboratory, Agricultural Engineering Study Program, Faculty of Agriculture, Sriwijaya University. Data collection was carried out during one growth cycle of pakcoy plants, from planting to harvesting.

2.2 Equipment and Materials

The equipment used in this study included an anemometer, hygrometer, time-lapse camera, moisture meter, pH meter, a 6-in-1 soil meter, digital scales, and a timer. An Arduino UNO–based floating monitoring system equipped with soil moisture sensors (YL-69 and FC-28) and a temperature sensor (DS18B20) was employed to monitor environmental and media conditions. A soil oven was used for determining crop water requirements. In addition, long-term hydrometeorological data (10-year records) were obtained from the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG).

The materials used in the study consisted of ultisol soil, manure, rice husk charcoal, and pakcoy (Brassica rapa L.) seedlings.

2.3 Research Method

This study utilizes three different planting media compositions, with ratios determined based on mass. Each treatment was conducted in triplicate. The comparative treatments for the composition of the planting media (ultisol soil: manure: husk charcoal) were M1 (2:1:1), M2 (1:1:2), and M3 (1:1:1). Following the preparation of the planting media according to the specific treatments, the previously nursery-grown pakcoy (Brassica rapa L.) seedlings were transplanted.

2.4 Observation Parameters

This study used field observation with a descriptive and quantitative approach. Data were collected through direct observation of the adaptive floating raft system with three treatments of planting media composition. The growing media parameters included growing media pH, growing media temperature, and growing media humidity, which were measured using a 6-in-1 soil meter and a digital thermometer-hygrometer. Additional environmental data (temperature, humidity, and wind speed) were obtained from the South Sumatra Climatology Station and used to calculate plant

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hydrological parameters, including evapotranspiration using the Modified Penman method, crop water requirements, and pakcoy plant growth (plant height, number of leaves, leaf width, wet weight, and dry weight of plants).

2.5 Data Analysis

All analysis results are presented in tables and graphs to facilitate interpretation of the dynamics of the growing medium, plant response, and water availability in the floating raft system.

3. Results and Discussion

The Arduino UNO-based floating monitoring system with humidity sensors (YL-69, FC-28) and temperature sensors (DS18B20) can be seen in Figure 1. The height of the planting medium submerged in water in this study was measured using a ruler. The results obtained were 3.09 cm in each treatment.

Figure 1. Arduino UNO R3-based floating raft (personal documentation).

3.1 pH of Planting Media Soil

Daily soil pH fluctuations in the three growing media treatments (M1, M2, M3) (Figure 2) were generally in the range of 5.9–6.9, which is classified as slightly acidic to nearly neutral, ideal for pak choi growth.

Treatment M1, M2, and M3 showed relatively stable. Rice husk charcoal functions as a pH buffer that can increase soil pH through cation absorption and hydrogen ion (H+) reduction. Rice husk charcoal also contains silica and carbon, which play a role in increasing cation exchange capacity (CEC) (Purwanto et al., 2021; Lehmann et al., 2015; Yao et al., 2025). Treatment M3 showed the best pH stability with relatively small pH fluctuations in the range of 6.0–6.8. A balanced mixture of ultisol soil, manure, and rice husk charcoal allows the pH to remain stable, as the combination of these three materials works synergistically in regulating soil acidity, which plays a role in the decomposition and acid neutralization processes (Trejo-Téllez et al., 2022).

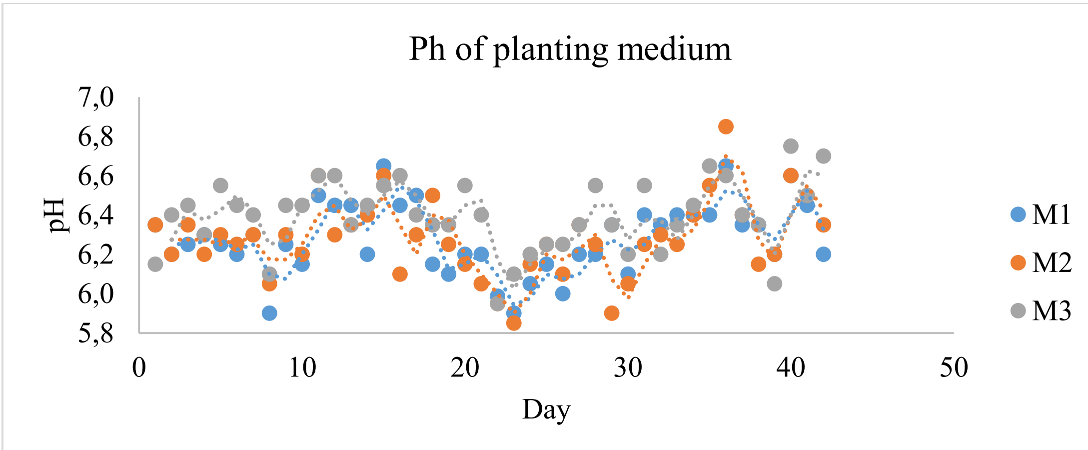

Figure 2. pH of the planting medium.

3.2 Planting Media Temperature

Daily fluctuations in growing medium temperature indicate temperature variations occurring in the three treatments (M1, M2, M3) during the study period between 28.1°C and 33.3°C (Figure 3). Growing media with a higher composition of rice husk charcoal (treatment M2) tended to have a slightly more stable temperature because rice husk charcoal has a better ability to absorb and store heat (Cannavo et al., 2022).

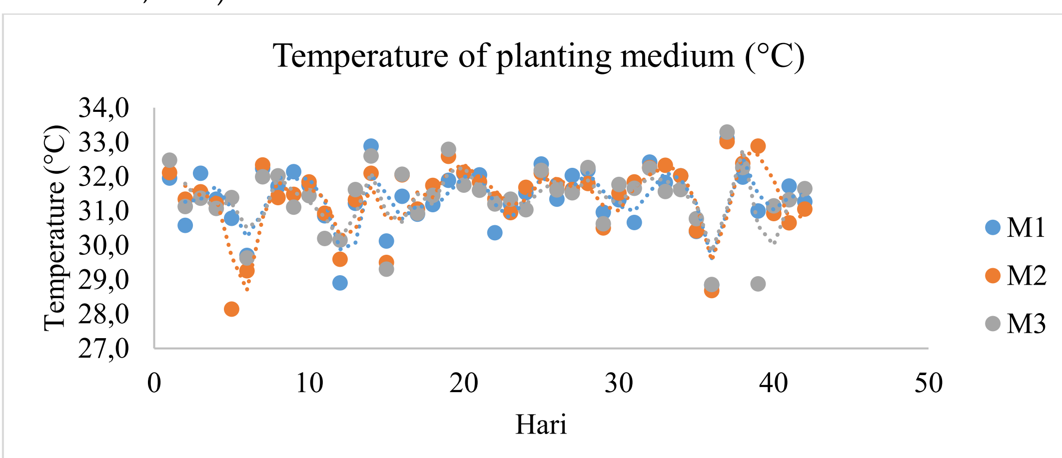

Figure 3. Temperature of planting medium.

The more stable temperature in treatment M2, which contained more charcoal husk, supported a more efficient decomposition process and reduced extreme temperature changes, thereby supporting plant growth in maintaining soil temperature. In addition, there were lower temperature fluctuations in M3. According to a study (Peake et al., 2016), planting media rich in organic materials, such as charcoal husks, can increase water retention capacity and stabilize soil temperature fluctuations. Therefore, proper soil temperature regulation using the appropriate material composition (treatment M2) can contribute to increased fertilizer efficiency and plant growth. Research (Junior et al., 2018) shows that higher soil temperatures resulting from optimal organic material composition can increase the rate of organic material mineralization and increase the availability of nutrients for plants.

3.3 Planting Media Moisture Content

The moisture content of the planting media in the Arduino UNO-based floating raft system (Figure 4) showed average humidity levels across all treatments (M1, M2, and M3) of 71.3%, 70.2%, and 68.5%, respectively. Fluctuations in soil moisture are closely aligned with daily variations in soil temperature. This condition is caused by higher temperatures increasing the evaporation rate from the growth media. Furthermore, since the media in the floating raft system is positioned near the surface, its response to ambient temperature changes occurs relatively quickly. The soil moisture values tended to be at a high level, indicating that the floating raft system can maintain optimal soil moisture for plant growth (Han et al., 2024).

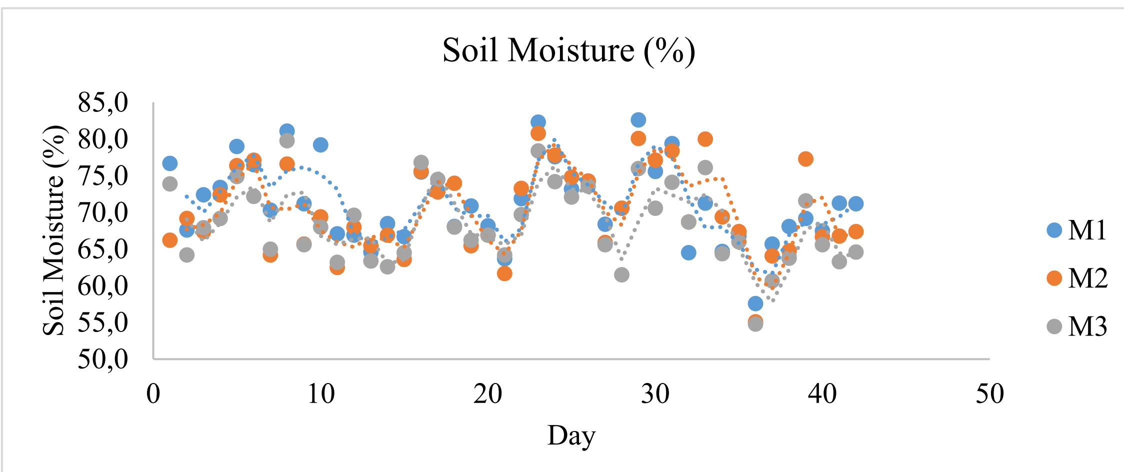

Figure 4. Soil Moisture.

In treatment M2, the more dominant use of husk charcoal showed better soil moisture stability compared to treatments M1 and M3. This indicates that a higher organic matter composition can help maintain soil moisture in the long term. A study (Gautam et al., 2024) mentions that the use of organic materials such as husk charcoal in planting media can increase soil moisture retention and affect water availability for plants. In addition, research (Bogati et al., 2025) shows that adequate soil moisture significantly increases microbial enzyme activity and microbial community diversity, supporting mineralization processes and nutrient availability for plants.

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3.4 Environmental Conditions

The environmental conditions observed in the study included average air temperature (°C), air humidity (%), and wind speed (km/hour). The average environmental data results (Figure 5) show that air humidity (%) was in the range of 80%-90%. The air temperature (oC) remained stable in the range of 25°C-30°C throughout the year. The optimal air humidity for pakcoy plants ranges from 75%-90% and the temperature ranges from 19°C-27°C (Umam et al., 2019). Wind speed (km/h) tends to be low, ranging from 1.12 km/h to 1.91 km/h. These conditions indicate that the environmental parameters are optimal for pakcoy growth.

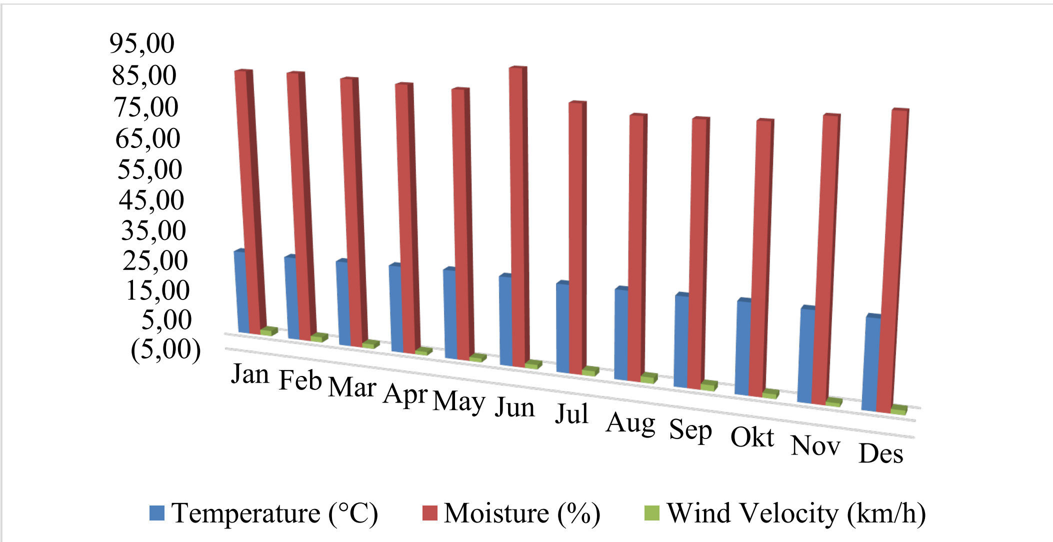

Figure 5. Average environmental data.

Constant and normal soil temperatures are more conducive to the activity of soil microorganisms that function to dissolve nutrients, support plant root systems, reduce heat stress, and facilitate optimal plant growth. Meanwhile, at temperatures that are too high or too low, microbial activity will decrease, resulting in a reduction in the availability of nutrients for plants (Qu et al., 2023; Chen et al., 2022). Under high RH conditions, the evaporation process from the growing medium slows down because the atmospheric pressure for evaporation or the vapor gradient is lower. Plants will use water more efficiently due to reduced water loss through evaporation, which increases water use efficiency by plants. Wind speed (km/h) (Figure 5) plays an important role in floating raft systems. Relatively low to moderate wind speeds indicate that surface air exchange and evaporation from the growing medium do not occur excessively, so the rate of water loss from the growing medium through evaporation into the air does not increase dramatically (Fan et al., 2022; Heidari & Jamali, 2023).

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3.5 Potential Evapotranspiration

Based on the calculations shown in Figure 6, the monthly potential evapotranspiration for the last 10 years is 2.05 mm/day in January, 2.33 mm/day in February, 2.48 mm/day in March, 2.48 mm/day in April, 2.68 mm/day in May, June is 2.49 mm/day, July is 2.76 mm/day, August is 3.06 mm/day, September is 3.08 mm/day, October is 2.65 mm/day, November is 2.18 mm/day, and December is 1.93 mm/day. The average monthly potential evapotranspiration (ETo) over the last 10 years was 2.51 mm/day. Plant evapotranspiration is influenced by plant morphology, namely leaf size (Daud et al., 2021).

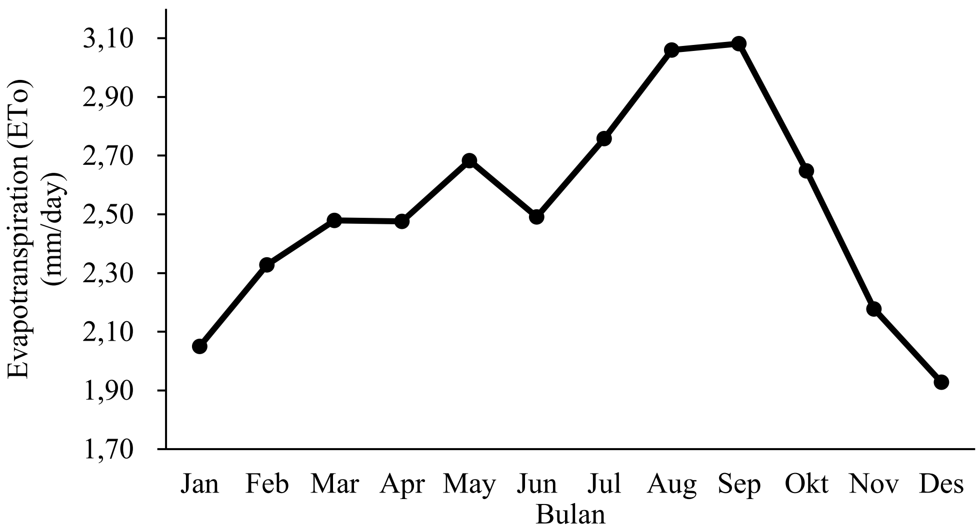

Figure 6. Potential evapotranspiration (mm/day).

3.6 Crop Water Requirements

Changes in the water requirements (ETc) of pakcoy (Figure 7) show three growth phases: early phase, middle phase, and late phase. In the early phase, water requirements were recorded at 1.30 mm/day, increasing to 1.88 mm/day in the middle phase, and reaching 2.73 mm/day in the late growth phase.

Pakcoy plants in the study (Pereira et al., 2024) showed a significant increase in evapotranspiration in the pre-harvest phase due to an increase in the leaf area index (LAI). Leafy vegetables such as pakcoy are very responsive to changes in solar radiation and air humidity, making the late growth phase a critical point in crop water requirements. Additionally, a study (Gurlen et al., 2020) mentions that an increase in plant biomass in the late generative phase will increase the transpiration rate and water requirements, especially in Brassicaceae species such as pakcoy. They emphasize that fast-growing leafy plants have an increasing ETc pattern until the maximum leaf maturation phase. According to a study (Pereira et al., 2024), hydroponic and floating raft systems are able to maintain

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consistent water availability so that plants remain in optimal conditions even though water requirements increase in the final growth phase.

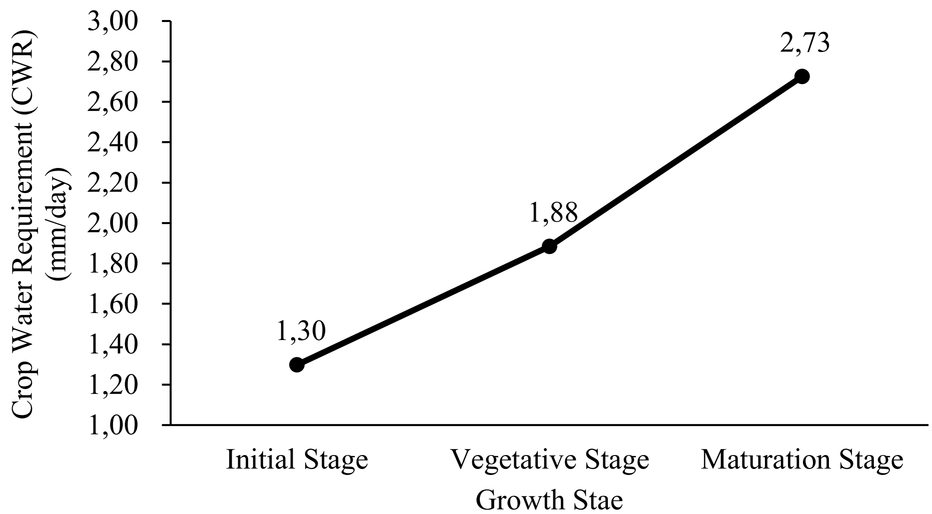

Figure 7. Crop water requirements.

3.7 Pakcoy Plant Growth

3.7.1 Plant Height (cm)

Plant height development of pakcoy throughout the research period (Figure 8). Treatment M1 showed slower growth compared to the other treatments, with plant height reaching approximately 10 cm on day 40. Treatment M2 reached approximately 14 cm, while treatment M3 reached approximately 18 cm.

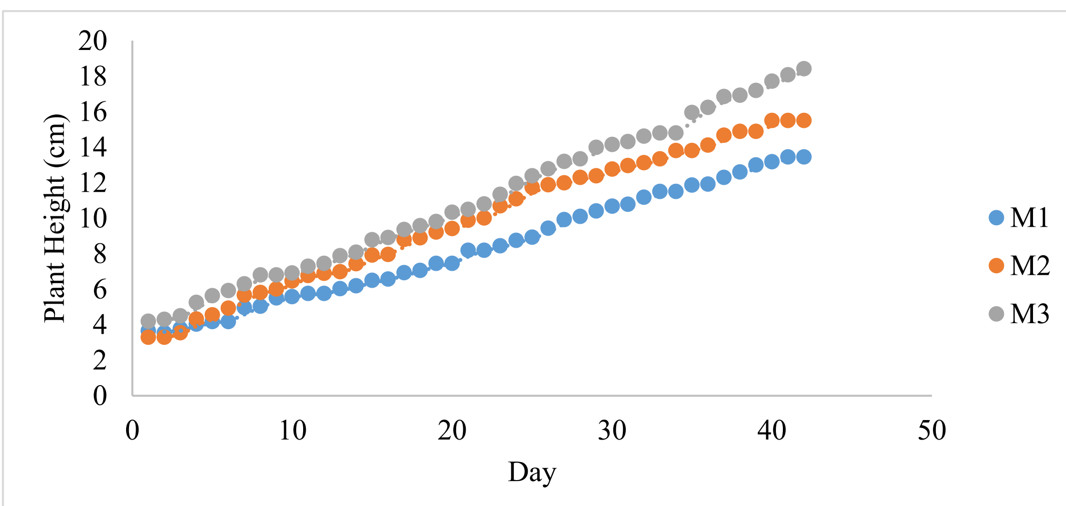

Figure 8. Plant height.

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Pakcoy plant height growth (Figure 11) in treatment M3 showed the highest growth, followed by M2 and M1, indicating that the M3 medium had the most optimal hydraulic physical characteristics to support water supply in the floating raft system. This condition supports the physiological processes of plants that require a continuous supply of water (Wu et al., 2022a; Malík & Tlustoš, 2025a). In treatment M3, optimal capillarity and water-holding capacity allow roots to obtain nutrients and oxygen more efficiently, thereby promoting faster vegetative growth (Kumar, 2025a; Muslimah et al., 2024a). These findings are in line with research stating that porous growing media with good water retention can increase nutrient absorption and improve root development in water-based hydroponic systems (Nurhidayati et al., 2021a).

The adaptive floating raft system used in this study also serves to reduce the risk of water stress due to hydrological changes in lowland swamp areas. The appropriate growing medium acts as a buffer against excess or insufficient water, ensuring that the roots remain in optimal aeration conditions (Balliu et al., 2021a). Recent research shows that the success of leafy crops such as pakcoy in hydroponic systems is largely determined by the physical characteristics of the medium that regulates the water-air relationship in the root zone (Ła´zny et al., 2022a). Therefore, M3 can be considered the most suitable medium for providing a stable hydro-physical environment for pakcoy growth in adaptive floating raft systems.

3.7.2 Leaf Width (cm)

The development of pakcoy plant width throughout the research period (Figure 9). In treatment M1, leaf width reached approximately 6 cm on day 45. In treatment M2, it reached approximately 8 cm. Meanwhile, in treatment M3, it reached 10 cm.

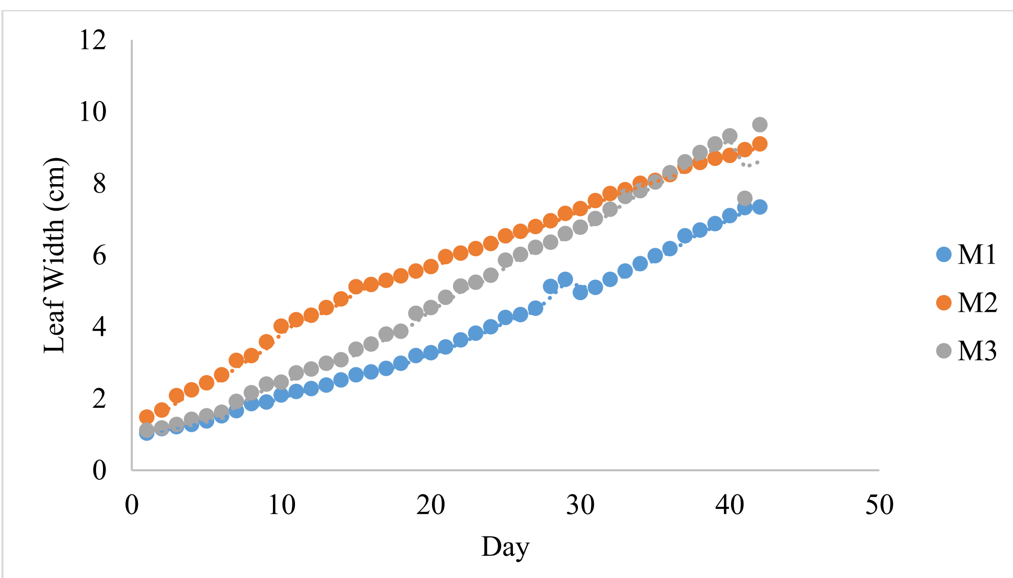

Figure 9. Leaf width (cm).

In the leaf width graph (Figure 8), it can be seen that treatments (M1, M2, M3) showed a significant increase in leaf width. This indicates that the media has an optimal balance of aeration and water retention to support wider leaf growth. Sufficient water availability and stable moisture maintenance greatly affect leaf morphological growth, especially in hydroponic plants or floating raft systems (Chhetri, 2022). Research by (Schafer & Lerner, 2022) states that media containing more micro-pores with better water retention capacity allows plants to form larger leaves, due to a more stable water supply to support the photosynthesis process. These results indicate the importance of a balance between water retention capacity and aeration in the growing medium to support plant leaf morphology. Thus, this study shows that the best growing medium composition for leaf width is M3 (Mankiewicz et al., 2022).

3.7.3 Number of Plant Leaves (pieces)

The development of the number of pakcoy leaves throughout the research period (Figure 10). In treatment M1, it reached around 15 pieces on the 45th day. In treatment M2, it reached around 20 pieces. Meanwhile, in treatment M3, it reached more than 22 pieces.

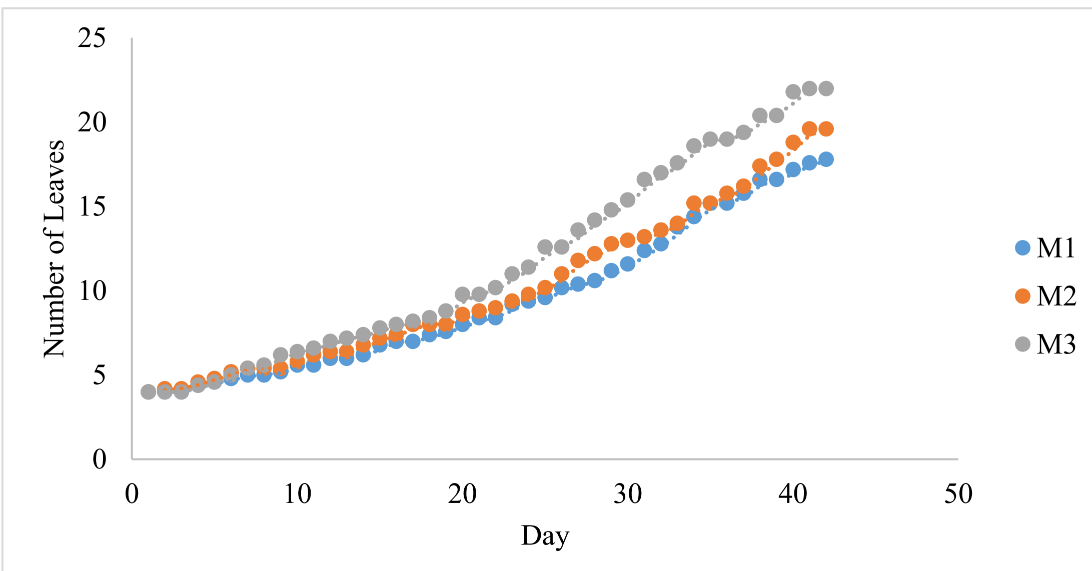

Figure 10. Number of Leaves.

Treatment M3 showed the highest growth, indicating that the M3 medium had the most optimal hydraulic physical characteristics to support water supply in the floating raft system. Media with good capillarity was able to attract and retain water in the root zone despite fluctuations in water levels in the swamp environment, thereby promoting faster vegetative growth (Muslimah et al., 2024b; Malík & Tlustoš, 2025; Wu et al., 2022b ; Kumar, 2025b; Nurhidayati et al., 2021b).

The adaptive floating raft system used in this study also serves to reduce the risk of water stress due to hydrological changes in peat swamp land. The right growing medium acts as a buffer against

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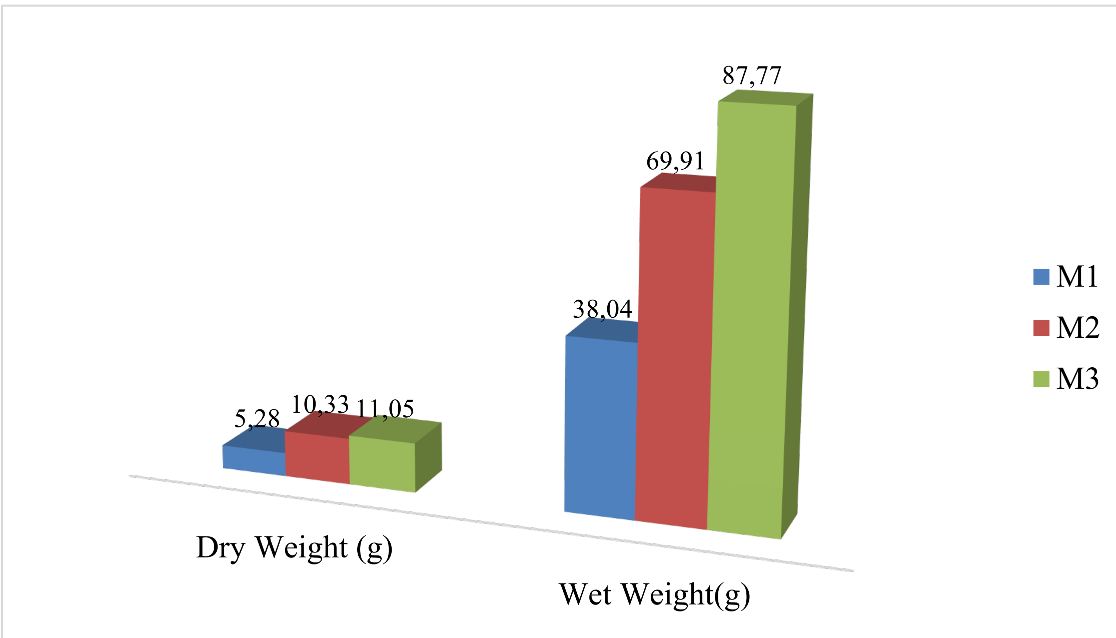
excess or lack of water, so that the roots remain in optimal aeration conditions (Balliu et al., 2021b). Therefore, M3 can be said to be the most suitable medium in providing a stable hydro-physical environment for pakcoy growth in an adaptive floating raft system.

3.7.4 Wet and Dry Weight of Plants

Comparison between the wet weight and dry weight of pakcoy plants in the three treatments (Figure 11). Based on the results of the study, the average wet weight of plants in treatment M1 was recorded at 38.04 g, which then decreased to an average dry weight of 5.28 g. In treatment M2, the average wet weight was 69.91 g, with an average dry weight of 10.33 g. Meanwhile, in treatment M3, the wet weight of the plants reached 38.04 g, and the dry weight was 5.28 g.



The wet and dry weights of the plants (Figure 11) show that the M3 treatment produced higher results in both wet and dry weights. This indicates that media with optimal capillarity, such as M3, not only supports better vegetative growth but also increases water and nutrient absorption, which directly affects the wet and dry weights of plants (Gaikwad & Mallick, 2020). In this study, the floating raft system used can provide a stable water supply, especially in media that are able to retain water well. This allows plants to thrive even in environments with high water fluctuations, such as those found in swampy areas. Based on research by Solanki (Solanki et al., 2017), a floating raft system with a medium that has good water retention capabilities can increase the efficiency of water and nutrient absorption by plants, which ultimately contributes to an increase in plant biomass, including wet weight and dry weight.

4. Conclusion

This study concludes that the adaptive floating raft system combined with the M3 growing media composition (ultisol soil, manure, and rice husk charcoal at a 1:1:1 ratio) provided the most favorable conditions for pakcoy growth. The M3 medium maintained more stable pH, moisture and temperature conditions, thereby supporting efficient water availability and nutrient uptake.

5. Acknowledgement

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6. AI Writing Statement

During the preparation of this manuscript, the authors used ChatGPT (OpenAI) to assist with language editing, grammar improvement, and manuscript organization. The AI tool was not used to generate research data, perform data analysis, interpret findings, or draw scientific conclusions. All content was critically reviewed, edited, and approved by the authors, who accept full responsibility for the final version of the manuscript.

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