JASSU
Journal of Agrosociology and Sustainability
JASSU 3(2): 193–208
ISSN 3025-1362

Institute for Advanced Science, Social and Sustainable Future
MORALITY BEFORE KNOWLEDGE

Effect of physical properties of germination substrate on marigold (*Tagetes erecta* L.) seedling growth

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Received Date: July 20, 2025 Revised Date: September 29, 2025 Accepted Date: January 1, 2026

ABSTRACT

Background: Marigold (*Tagetes erecta* L.) is a herbaceous plant widely cultivated for ornamental and ecological purposes. Its cultivation is strongly influenced by environmental factors, especially nutrient availability in the growing media. This study aimed to examine the effect of different seedling media compositions on their physical properties and the growth of marigold (*Tagetes erecta* L.) seedlings. Previous studies suggest that the physical properties of seedling media, such as porosity and water-holding capacity, play a crucial role in early plant development. **Methods:** The experiment was conducted using a Completely Randomized Block Design (RCBD) with one factor—media composition. The treatments included M0 (ready-to-use commercial media), M1 (husk charcoal [2]: cocopeat [1]: bamboo compost [1]), M2 (husk charcoal [1]: cocopeat [2]: bamboo compost [1]), and M3 (husk charcoal [1]: cocopeat [1]: bamboo compost [2]). Data collection included plant height, number of leaves, root length, number of roots, fresh weight, and dry weight. Data were analyzed statistically to determine the significance of treatment effects. **Findings:** The composition of the growing media significantly influenced marigold seedling growth. Media with a higher proportion of cocopeat (M2) resulted in greater porosity, which in turn supported better seedling development. This was evidenced by higher values in plant height, number of leaves, root length, root count, fresh biomass, and dry biomass compared to other treatments. **Conclusion:** The study concludes that the M2 media composition (husk charcoal [1]: cocopeat [2]: bamboo compost [1]) provides optimal physical conditions for marigold seedling growth. **Novelty/Originality of this article:** This research offers new insights into the effect of media physical properties on marigold seedling performance, particularly highlighting the beneficial role of increased cocopeat content in enhancing media porosity and seedling growth.

KEYWORDS: bamboo compost; bulk density; cocopeat; charcoal; porosity.

1. Introduction

Marigold (*Tagetes erecta* L.) is a species of herbaceous plant that is commonly utilized as a barrier or hedge plant in the cultivation of various crops. This plant plays an important role in agricultural systems, as it can serve both aesthetic and functional purposes, such as protecting the main crops from pests or providing visual separation between planting areas. Morphologically, marigold flowers are characterized by their large size and bright coloration, ranging from yellow to deep orange. These vivid hues not only make the marigold highly attractive as an ornamental or cut flower but also increase its popularity in landscape decoration and ceremonial uses. Furthermore, the intensely colored flower crown of marigold contains natural pigments that can be extracted and used as a source of natural dye, offering an eco-friendly alternative to synthetic colorants (Pratiwi et al., 2016).

Cite This Article:
Defitrianida, A. W. (2026). Effect of physical properties of germination substrate on marigold (Tagetes erecta L.) seedling growth. *Journal of Agrosociology and Sustainability*, *3*(2), 193-208. https://doi.org/10.61511/jassu.v3i2.2026.2116

Marigold is one of the plants that has potential because it has many functions. The culinary sector marigolds are used as natural dyes and decoration materials and the agricultural sector is used as a biological agent to attract pest predators, as well as a component of ornamental plants in the tourism sector (Kurniati, 2021). Other roles can be as medicine, as well as livestock and poultry feed. This flower contains natural antioxidants, anti-bacterial, antinematode (Nugroho et al., 2019). Marigold flowers have long been known in Indonesia, but have not been developed on a large scale because they are not among the superior flowers such as orchids, chrysanthemums, jasmine, raphis, heliconia, leather leaves, roses, and others. The demand for marigold flowers in Bali is estimated at 8 tons per day with revenues reaching 100-200 billion rupiah per year. In the Bandungan area, Semarang Regency, marigolds are commercially cultivated for the purpose of flower production, seedlings, or as decoration for tourist sites. Nationally, the demand for flowers in Indonesia reaches 40 tons per day (Kurniati, 2021).

Marigold cultivation is influenced by environmental factors, especially nutrient availability. Nutrient availability is the main requirement to increase production. Naturally, nutrients are available in the soil, but not all soils provide enough nutrients to support plant growth and development. However, the green revolution increased the use of chemical fertilizers. Excessive use of chemicals in agricultural cultivation can cause serious problems for the sustainability of agricultural land (Walianggen, 2022) due to decreased soil fertility.

Sustainable agriculture is utilizing natural materials in crop cultivation activities with the aim of maintaining the quality of soil fertility. Sustainable agricultural management is based on the principles of health, ecology, justice and protection. The principle of health is to pay attention to preserving and improving the health of soil, plants, animals and the earth, as well as humans as a whole (Walianggen, 2022). Modern green technologies are broadly grouped into four main areas, namely renewable energy sources, sustainable transportation waste management and recycling, and energy-saving solutions (Ivukina & Skvortsova, 2024). The field of waste recycling is the main focus in this research. Utilization of rice milling waste into husk charcoal, coconut husk waste into cocopeat, and bamboo leaf litter into compost as a nursery medium for marigold plants because it has nutritional content.

Husk charcoal can spur the growth of good microbes, regulate soil pH, retain moisture, and suppress pathogenic microbes (Sofhia et al., 2015). Husk charcoal also has a high cation exchange capacity (CEC) so that it can bind soil cations that are beneficial for plant growth. As in long bean plants, the provision of husk charcoal can increase plant growth and development such as plant height and plant fresh weight compared to no treatment (Walianggen, 2022). The application of 25 g of coffee husk and 25 g of husk charcoal in robusta coffee nurseries increases the growth of stem diameter and number of leaves (Rosdiana et al. 2025). Cocopeat is the result of coconut husk extraction which has good water holding capacity, rich in organic matter content, and high NPK content (Pratiwi et al., 2017). Coconut fiber is able to provide N, P, and K elements needed for plant vegetative growth (Palungan, 2015), such as in kale plants (Khan et al., 2019). Cocopeat also has a direct effect on root system growth because it can increase soil chemical content and improve soil physical properties by providing macro and micro nutrients. The application of 50% cocopeat has a good effect in increasing the growth of the number of leaves, plant height, and stem diameter in robusta coffee nurseries (Anjarsari et al., 2024). The composition of 80% cocopeat can increase the growth of rubber seedlings (Cahyo et al., 2019).

Bamboo compost can increase the total porosity of the media by 70-90% in plants (Marliana et al., 2022). Bamboo compost can improve soil chemical properties due to its high organic matter content, which enhances soil fertility and stimulates microbial activity. In addition, bamboo compost has potential as an organic bioremediation agent, particularly for reducing heavy metal contamination such as Pb, Cd, Cu, and Zn (Andriyani et al., 2024). Bamboo compost as a source of potassium in *Brassica oleracea* plants for plant growth and resistance. In addition, bamboo compost can increase soil pH, total nitrogen, organic carbon, and soil microbial activity (Lestiyani et al., 2023). The application of compost in robusta coffee nurseries on peatlands can improve the physical, biological, and textural properties of the soil, so that the soil becomes looser and can store more water (Rosmalinda & Sopiana, 2024).

Besides chemical improvements, the physical properties of the seedling media are also important. Growing media must have a balanced physical structure between air and water to support root growth and prevent root hypoxia or drought stress. This structure is influenced by particle size, shape, texture, and arrangement (Singh et al., 2023). Characterization of cocopeat-based media mixed with organic materials shows significant differences in bulk density, porosity, water-holding capacity, moisture content, and evaporation rate (Kalaivani & Jawaharlal, 2019). The addition of compost and husk charcoal can also improve bulk density and soil moisture in degraded lands (Nasution & Fitria, 2023). Media with good physical characteristics can provide an optimal environment for marigold seedling growth. Therefore, the purpose of this study was to evaluate the effect of different seedling media compositions (husk charcoal, cocopeat, and bamboo compost) on the physical properties of the media (bulk density, particle density, and porosity) and their relationship to the growth of marigold (*Tagetes erecta* L.) seedlings.

2. Methods

2.1 Materials and experimental design

The research was conducted at Orchid House, Leuwikopo Experimental Garden (6°33'45.15 "N and 106°43'11.91 "E) at an altitude of 178.6 m above sea level, IPB Campus, Dramaga District, Bogor Regency, West Java, Indonesia. Testing the physical properties of seedlings media was conducted at the Faculty of Animal Science Laboratory. The research was conducted from February to April 2023. The tools used in this study were 128-hole seedling trays, agricultural tools, ovens, and scales. The oven was used for porosity analysis and total dry weight measurement. The main materials used were marigold seeds, husk charcoal, cocopeat, bamboo compost, and ready-to-use media.

This research was conducted based on an environmental design using a one-factor Completely Randomized Block Design (RCBD), namely media composition. The treatment combination consisted of M0 (ready-to-use media), M1 (2 husk charcoal: 1 cocopeat: 1 bamboo compost), M2 (1 husk charcoal: 2 cocopeat: 1 bamboo compost), and M3 (1 husk charcoal: 1 cocopeat: 2 bamboo compost) (Table 1).

Table 1. Comparative composition of growing media

Treatments	Husk charcoal	Cocopeat	Bamboo compost
M0 (ready-to-use media)	-	-	-
M1	2	1	1
M2	1	2	1
M3	1	1	2

2.2 Experimental preparation and treatments

Seedlings were grown in 128-hole seedling trays in the greenhouse. Treatments consisted of various compositions of husk charcoal, cocopeat, and bamboo compost as organic materials without the addition of fertilizers. Each treatment was replicated seven times, with one seedling per hole as one replicate, resulting in a total of 28 experimental units.

2.3 Testing the physical properties of seedlings media

The physical properties tested were bulk density, particle density, and porosity. The test method is based on the method described by Indonesian Center for Agricultural Land Resources Research and Development (2006). Bulk density is the measurement of soil weight in a given volume. Particle density is the ratio of soil mass to soil particle volume after oven drying. Porosity is the ratio between the volume of empty space (pores) in a material and the total volume of the material. The tools and materials used are rings, calipers, paper, 100 ml volumetric flasks, pistols and mortar, funnels, sieves, ovens, scales, and air-free water.

Bulk density (g/cm^3) was tested by taking the mixed media using a 7.4 cm diameter soil sample ring. The sample ring was first weighed and measured to determine its weight and volume. The media in the sample ring was weighed and then transferred to a container to be baked at 103 °C for 24 hours until the weight was constant, then weighed again. The content weight was obtained using the following formula:

$$\text{Bulk density} = \frac{(Mass\ of\ media)}{(Total\ volume)} \quad \text{(Eq. 1)}$$

Particle density (g/cm^3) was calculated by smoothing the media that had been dried in an oven at 103 °C for 24 hours. The pureed media was taken as much as 20 g and put into a measuring flask or measuring cup with a capacity of 100 ml and then weighed again to get the weight of the flask + media. Water was brought to a boil to remove dissolved air. The media that has been mixed in the flask is given air-free water and measured to 100 ml and weighed to get the weight of the flask + media + water. The volume of solids was obtained by calculating: 100 - ((weight of flask + media) - (weight of flask + media + water)). Specific gravity was obtained using the following formula:

$$\text{Particle density} = \frac{(Mass\ of\ media)}{(Volume\ of\ solids)} \quad \text{(Eq. 2)}$$

Porosity (%) is calculated based on the value of the weight of contents and specific gravity with the following formula:

$$\text{Porosity} = \left(1 - \frac{BD}{PD}\right) x\ 100 \quad \text{(Eq. 3)}$$

BD stands for Bulk specific gravity and PD stands for Particle density.

2.4 Observation parameters

Plant height (cm) was measured weekly from the soil surface to the highest tip of the plant by allowing the top leaf to drop naturally. This parameter was used to observe vertical growth under each treatment. The number of leaves (leaf) was counted weekly by recording only fully opened leaves. This parameter represents vegetative growth and the plant's photosynthetic capacity. Root length (cm) was measured at the end of the treatment after carefully uprooting and cleaning the plants. The measurement was taken from the base of the stem to the tip of the longest root using a ruler. The number of roots (root) was counted at the end of the treatment by recording the primary roots emerging from the stem base. This parameter indicates the plant's ability to absorb water and nutrients. Plant fresh weight (g) was measured at the end of the treatment by weighing all plant parts (roots, stems, and leaves) using a digital scale. The results reflect the total fresh biomass of the plant. Plant dry weight (g) samples were oven-dried at 50 °C for 3 × 24 hours and then weighed. Dry weight represents the total biomass accumulation resulting from photosynthetic activity during growth.

2.5 Data analysis

Data obtained from seven replicates for each treatment were statistically analyzed to determine the effect of the applied treatments on the observed parameters. The analysis of variance (ANOVA) was performed using the F-test with the help of the Statistical Analysis System (SAS) software and Microsoft Excel to identify significant differences among treatments. When the results showed a significant effect, a further post-hoc analysis was conducted using Duncan's Multiple Range Test (DMRT) at the 5% significance level to compare the mean values between treatments and determine which treatments differed significantly from one another. This approach ensures that the statistical interpretation of the data is accurate and reliable for drawing conclusions regarding the treatment effects.

3. Results and Discussion

3.1 Media conditions

Bulk density, particle density, and porosity are important physical properties that describe the degree of soil compaction, which directly influences soil aeration, root penetration, and water infiltration capacity. These parameters determine how easily air and water can move through the soil pores, thereby affecting plant growth and nutrient absorption. Based on the data presented in Table 2, each growing medium exhibits distinct values of bulk density, particle density, and porosity. The observed variations indicate that different media possess different structural characteristics and pore arrangements, which in turn influence their ability to retain and transmit air and water within the root zone.

Table 2. Bulk density, particle density, and porosity of planting media

Treatment	Bulk density (g/cm^3)	Particle density (g/cm^3)	Porosity %
M0	0.28	1.25	77.20
M1	0.23	0.95	76.18
M2	0.17	0.95	81.82
M3	0.19	0.95	79.55

Notes: M0 = ready-to-use media; M1= Husk charcoal [2]: Cocopeat [1]: bamboo compost [1]; M2= Husk charcoal [1]: Cocopeat [2]: bamboo compost [1]; M3= Husk charcoal [1]: Cocopeat [1]: bamboo compost [2]

The volume density of the media ranged from 0.17-0.28 g/cm^3 and the particle density ranged from 0.95-1.25 g/cm^3. M0 had the highest volume density and particle density. Volume density is an important indicator that reflects the level of soil compaction. High volume density values indicate compacted soil, which inhibits root growth, reduces aeration, and restricts the movement of water and nutrients in the soil. High volume density is associated with low organic matter content, total nitrogen, available phosphorus and available iron (Duan et al., 2019). Meanwhile, particle density indicates soil mineral and chemical characteristics that are important in determining other soil physical properties, such as porosity (Di Giuseppe et al., 2016). In addition, particle density determines the performance of the growing medium against water and air (Bartley et al., 2022) as it affects the water storage capacity (Suhu et al., 2022).

For particle density treatments M1, M2, and M3 did not show significant differences. The effect of low volume density on plants helps root development, air circulation in the soil, and optimal water absorption (Özdemir et al., 2022). Meanwhile, particle density determines the efficiency of soil pore space to estimate the soil's ability to support the root system. A low particle density value due to an abundance of organic matter means the soil is lighter and has better aeration and drainage to support plant growth (Khalil et al., 2015).

Porosity determines how much space is available for air, water, and root growth. In plant growth, porosity plays a role in facilitating root growth, improving soil aeration, increasing nutrient infiltration, maintaining root zone moisture (Cai et al., 2023), and reducing mechanical stress on roots (Karyati et al., 2018). The porosity test values ranged from 76.18% to 81.82%. The highest porosity percentage was found in treatment M2, followed by treatment M3, M0, and M1. Large porosity is important for root aeration. However, too large porosity can cause rapid water loss, while small porosity makes it difficult for water to be absorbed by the roots despite high water content (Zangiabadi et al., 2020).

Based on research on red areca nut plants, the highest maximum absorption capacity is found in the composition of cocopeat media 1: 1 and 2: 1 (110.15% and 174.65%), so cocopeat has good water binding ability (Pratiwi et al., 2017). Moringa seeds with soil + cocopeat media had a water content of 27.09% and soil + bamboo leaf powder 18.31%, which resulted in higher porosity, but low organic carbon content and cation exchange capacity (CEC) of soil + cocopeat. Meanwhile, soil + bamboo leaf powder had moderate organic carbon content, but low cation exchange capacity (CEC). Phosphorus (P) availability was high in cocopeat soil and bamboo leaf powder soil (Sawaludin et al., 2018).

In anthurium plants, bamboo compost can increase the total porosity of the growing medium by 70-90%, resulting in a balanced ratio between porosity and density, so that root growth and water absorption are not disturbed due to good aeration and water drainage (Marliana et al., 2022). Husk charcoal media has the ability to absorb and store nutrient solutions so that nutrients can be easily available to plants when needed (slow release). The properties of husk charcoal media are light, easy to absorb water, not easily eroded, and as a source of potassium (Hayati, 2006). The organic carbon content in husk charcoal explains the reason for the higher volume density of the media with higher composition of husk charcoal correlating with volume density.

3.2 Marigold seedling growth

The growing medium affects the early physiological components of the plant, such as germination percentage, sprout emergence rate, seed vitality value, germination index and value, and imbibition duration (Bhardwaj, 2014). The growing medium also directly affects the basic functions of plant physiology (roots, stems, leaves) and indirectly affects seedling quality, as well as plant performance after planting (Fadıllıoğlu & Başay, 2023). Based on Table 3, parameters that have a very significant effect are plant height, root length, number of roots, plant fresh weight, and plant dry weight. While the number of leaves parameters had no significant effect.

Table 3. Mean plant height, number of leaves, root length, number of roots, total fresh weight of plants, and total dry weight of plants in various compositions at 6 weaks after treatment

Treatments	Parameters					
	PH (cm)	NL (leaf)	RL (cm)	NR (root)	FP (g)	DP (g)
M0	$6.69^{b} \pm 1.29$	$7.71^{a} \pm 0.76$	$4.04^{c} \pm 1.61$	$7.86^{a} \pm 3.39$	$0.26^{b} \pm 0.10$	$0.01^{c} \pm 0.00$
M1	$9.36^{a} \pm 0.79$	$7.86^{a} \pm 1.21$	$7.93^{ab} \pm 3.61$	$7.86^{a} \pm 1.77$	$0.52^{a} \pm 0.16$	$0.05^{a} \pm 0.01$
M2	$8.80^{a} \pm 0.68$	$8.71^{a} \pm 1.50$	$10.36^{a} \pm 2.58$	$7.86^{a} \pm 2.41$	$0.52^{a} \pm 0.17$	$0.05^{a} \pm 0.02$
M3	$8.91^{a} \pm 1.40$	$8.00^{a} \pm 1.96$	$5.47^{bc} \pm 1.96$	$4.00^{b} \pm 1.63$	$0.32^{b} \pm 0.07$	$0.03^{b} \pm 0.01$
F-Test	**	ns	**	**	**	**

Notes: Numbers followed by the same letter in the same column indicate values that are not significantly different based on DMRT test (α = 0.05). Notation: M0 = ready-to-use media; M1= Husk charcoal [2]: Cocopeat [1]: bamboo compost [1]; M2= Husk charcoal [1]: Cocopeat [2]: bamboo compost [1]; M3= Husk charcoal [1]: Cocopeat [1]: bamboo compost [2]; PH= plant height; NL= number of leaves; RL= root length; NR= number of roots; FP= Fresh Weight of Plants; DP= Dry Weight of Plants ± = standard deviation; ** = highly significant; ns = not significant

Media with abundant pores allow optimal oxygen circulation to the roots, supporting root cell respiration, so that more energy is generated for stem elongation and cell division (Onwubiko & Enwereji 2023). Media that are rich in organic matter and have appropriate porosity prevent root diseases (such as dumping-off) by providing optimal oxygen circulation in the root zone (Bhardwaj, 2014).

An optimized medium encourages a deeper and more extensive root system, which serves as the uptake of nutrients and water, and supports plant metabolism. Good roots support sturdier and stronger stems, indicating good photosynthetic conditions, efficient flow of water and nutrients, and support for leaf growth (Fadıllıoğlu & Başay 2023). Growth of leaves and stems indicates good cell division activity (Bhardwaj, 2014). The number of developed leaves is directly related to the photosynthetic capacity of the plant (Fadıllıoğlu

& Başay, 2023). An increase in biomass indicates efficient metabolic activity, which is the result of a balance between water, air and nutrients. This favors the synthesis of structural compounds and enzymes (Mahmoud et al., 2019). Large biomass indicates optimal photosynthetic activity, as well as increased synthesis of proteins and structural tissues (Ardli et al., 2024).

Treatments M1 and M2 showed good growth at the end of observation due to the dominance of husk charcoal and cocopeat. Husk charcoal has the ability to increase cation exchange capacity (CEC) and provide micronutrients (NPK) that are important in protein synthesis, enzymes, and growth hormones (Ardli et al., 2024). Meanwhile, cocopeat provides high porosity, high water-holding capacity, and good air absorption, and helps maintain moisture in the root zone to support cell turgor and cell elongation.

3.3 Plant height

Plant height showed significant differences starting from the second week after planting and continued to vary until the end of the observation period. During the early growth stage, particularly at two weeks after planting, the treatments M1 and M2 exhibited the highest plant height compared to other treatments, indicating a faster initial growth response. However, at three weeks after planting, the plant height under treatment M1 began to decline relative to treatment M2, which maintained a higher and more consistent growth trend. This suggests that the effect of each treatment on plant height may vary over time depending on the plant's adaptation to the growing conditions (Table 4).

Table 4. Average plant height of marigold seedlings at 6 WAT

Treatments	1 WAT (cm)	2 WAT (cm)	3 WAT (cm)	4 WAT (cm)	5 WAT (cm)	6 WAT (cm)
M0	2.06 ± 0.13	2.66^{b} ± 0.23	2.97^{a} ± 0.86	3.47^{b} ± 1.08	4.66^{b} ± 1.38	6.68^{b} ± 1.29
M1	2.56 ± 0.62	3.46^{a} ± 0.69	3.79^{ab} ± 0.86	5.51^{a} ± 1.12	7.18^{a} ± 1.31	9.35^{a} ± 0.79
M2	2.64 ± 0.34	3.34^{ab} ± 0.27	4.18^{a} ± 0.82	5.44a ± 1.31	6.8^{a} ± 0.99	8.8^{a} ± 0.68
M3	2.68 ± 0.54	3.7^{a} ± 0.76	3.8^{ab} ± 1.14	4.86^{a} ± 1.63	6.52^{a} ± 1.39	8.91^{a} ± 1.40
F-Test	ns	**	*	*	**	**

Notes: Numbers followed by the same letter in the same column indicate values that are not significantly different based on DMRT test (α = 0.05). Notation: M0= ready-to-use media; M1= Husk charcoal [2]: Cocopeat [1]: bamboo compost [1]; M2= Husk charcoal [1]: Cocopeat [2]: bamboo compost [1]; M3= Husk charcoal [1]: Cocopeat [1]: bamboo compost [2]; WAT= Weak After Treatment; ± = standard deviation; ** = highly significant; ns = not significant

The results of previous research, the composition of cocopeat media and husk charcoal can increase the height of orchid plants because the media can fulfill the needs of the elements needed for growth (Nugroho & Raden, 2021). The addition of husk charcoal to the media increased the height growth of jabon seedlings by 18.13% - 28.36% (Supriyanto & Fiona, 2010). Husk charcoal is rich in oxygen (48.18%) and carbon (28.01%), making it highly porous and effective for adsorption. It also contains silicon (16.40%), which enhances structural stability, and essential minerals like Na (3.54%), Cl (2.16%), Fe (0.23%), K (0.11%), and Mg (0.07%). This natural composition makes rice husk charcoal an efficient, eco-friendly adsorbent for removing contaminants such as heavy metals (Tuas & Masduqi, 2019).

At the age of 4 - 6 months after planting, the treatments M1, M2, and M3 were not significantly different and the values were higher than M0. The availability of nutrients can increase the rate of photosynthesis which can increase assimilate production. The effect of vegetative growth is shown by an increase in plant height (Irawan et al., 2015). The application of bamboo compost in rosewood nurseries can accelerate plant height growth because bamboo compost contains P and K elements that function to improve soil structure (Gumelar et al., 2021). In addition, the porosity of M2 is good for plant growth.

3.4 Number of leaves

Leaves are the main organ for photosynthesis, so more leaves mean greater potential for photosynthate production, which is important for overall plant growth, including further leaf development (Parasana et al., 2013). There was no significant difference in the number of leaves between the initial and final observations in all treatments. The number of leaves at 4 months after planting and 5 months after planting differed significantly. Treatment M1, M2, and M3 did not differ significantly at 4 months after planting, but at 5 months after planting, treatment M3 had the lowest number of leaves (Table 5). In red-tipped plants using cocopeat as a growing medium, height and number of leaves increased at various stages of plant age due to the presence of nutrients such as N, P, and K required for vegetative growth (Palungan, 2015).

Table 5. Average number of leaves on marigold seedlings over 6 WAT

Treatments	1 WAT (leaf)	2 WAT (leaf)	3 WAT (leaf)	4 WAT (leaf)	5 WAT (leaf)	6 WAT (leaf)
M0	2 ± 0	2 ± 0	3.2 ± 1.03	5.11^{a} ± 1.05	5.87^{a} ± 1.13	7.71 ± 1.76
M1	2 ± 0	2 ± 0	3.4 ± 0.97	6^{a} ± 0	5.87^{a} ± 0.35	7.85 ± 1.21
M2	2 ± 0	2 ± 0	4 ± 0	6^{a} ± 0	6.5^{a} ± 1.20	8.1 ± 1.50
M3	2 ± 0	2 ± 0	3.2 ± 1.03	6^{a} ± 0	4.5^{b} ± 1.69	8 ± 0.58
F-Test	ns	ns	ns	**	**	ns

Notes: Numbers followed by the same letter in the same column indicate values that are not significantly different based on DMRT test (α = 0.05). Notation: M0= ready-to-use media; M1= Husk charcoal [2]: Cocopeat [1]: bamboo compost [1]; M2= Husk charcoal [1]: Cocopeat [2]: bamboo compost [1]; M3= Husk charcoal [1]: Cocopeat [1]: bamboo compost [2]; WAT= Weak After Treatment; ± = standard deviation; ** = highly significant; ns = not significant

Leaves function for photosynthetic activities that can produce carbohydrates used for growth and development. An increase in the number of leaves increases the entry of light, CO2, and water through leaf stomata so that photosynthesis increases. Longer and wider leaves have many stomata, thus increasing the flow of CO^2 used in photosynthesis. Nutrient uptake is essential for plant physiological growth. Limited NPK supply reduces the rate of cell division, cell expansion and cell permeability. Therefore, the number of leaves is reduced due to decreased net photosynthesis (Ismail-Embong et al., 2021).

3.5 Root length and number of roots

Treatment M2 produced plants with the longest roots and the highest number of roots compared to the other treatments, indicating that this medium provided better support for root development. However, statistical analysis showed no significant difference in the number of roots between treatments M1 and M2, suggesting that both media offered similarly favorable conditions for root formation (Table 6).

Table 6. Average root length and number of roots

Treatments	Root length (cm)	Number of roots (root)
M0	4.04^{c} ± 1.61	7.85^{a} ± 3.39
M1	7.92^{ab} ± 3.61	7.85^{a} ± 1.77
M2	10.35^{a} ± 2.58	7.85^{a} ± 2.41
M3	5.47^{bc} ± 1.96	4^{b} ± 0.07
F-Test	**	**

Notes: Numbers followed by the same letter in the same column indicate values that are not significantly different based on DMRT test (α = 0.05). Notation: M0= ready-to-use media; M1= Husk charcoal [2]: Cocopeat [1]: bamboo compost [1]; M2= Husk charcoal [1]: Cocopeat [2]: bamboo compost [1]; M3= Husk charcoal [1]: Cocopeat [1]: bamboo compost [2]; WAT= Weak After Treatment; ± = standard deviation; ** = highly significant; ns = not significant

This finding indicates that the combination of soil with organic materials such as cocopeat can improve the physical properties of the growing medium, enhance aeration and water-holding capacity, and consequently promote healthier and more extensive root growth. These results are consistent with previous research, which reported that a mixture of soil and cocopeat increased the number of roots in moringa seedlings at 56 days after planting (Sawaludin et al., 2018). Root length and number are closely associated with root weight, as greater root length and a higher number of roots generally contribute to increased root biomass.

The development of longer and more abundant roots enhances the plant's ability to absorb water and nutrients efficiently, which in turn promotes overall plant growth. In red betel plants grown in a mixture of coconut husk charcoal and bamboo leaf compost, there was a noticeable increase in root number, fresh root weight, and dry root weight, indicating that the composition of the growing medium strongly influences root performance (Marliana et al., 2022). Similarly, the use of mixed media such as cocopeat, peat, and charcoal bark was found to increase both the fresh and dry weights of nutmeg roots. These media possess larger pore spaces with an adequate number and distribution of pores, allowing root tips to penetrate easily and facilitating rapid root expansion. Such extensive root spread contributes to a substantial increase in both fresh and dry root weights compared to other growing media (Mariana, 2017). In addition, husk charcoal is known to be effective in absorbing nutrient solutions, providing good drainage, high permeability, and excellent porosity, all of which create favorable conditions for optimal root growth (Koesriharti & Istiqomah, 2016).

3.6 Fresh and dry weight of plants

Media that can support better growth will allow for more efficient absorption of water and nutrients, which in turn supports overall vegetative growth and biomass accumulation (El-Quasni et al., 2014). The total fresh weight of plants in treatment M1 and M2 had higher masses compared to treatments M0 and M3 Meanwhile, the highest total dry weight of plants was found in treatments M1 and M2, followed by treatment M3 and M0 (Table 7). Fresh weight and dry weight are positively correlated, as fresh weight increases, dry weight also increases. Similarly, soil + cocopeat media increased the dry weight of moringa seedlings (Sawaludin et al., 2018).

Table 7. Average fresh and dry weight of plants

Treatments	Fresh weight of plants (g)	Dry weight of plants (g)
M0	$0.26^{b} \pm 0.10$	$0.01^{c} \pm 0.00$
M1	$0.51^{a} \pm 0.16$	$0.04^{a} \pm 0.01$
M2	$0.51^{a} \pm 0.17$	$0.04^{a} \pm 0.02$
M3	$0.31^{b} \pm 0.07$	$0.02^{b} \pm 0.01$
F-Test	**	**

Notes: Numbers followed by the same letter in the same column indicate values that are not significantly different based on DMRT test (α = 0.05). Notation: M0= ready-to-use media; M1= Husk charcoal [2]: Cocopeat [1]: bamboo compost [1]; M2= Husk charcoal [1]: Cocopeat [2]: bamboo compost [1]; M3= Husk charcoal [1]: Cocopeat [1]: bamboo compost [2]; WAT= Weak After Treatment; ± = standard deviation; ** = highly significant; ns = not significant

An increase in total plant dry weight indicates better seedling growth (Silalahi & Manullang 2020). The increase in dry and fresh weight of plant vegetative biomass is due to the characteristics of the physical properties of the growing medium, such as water holding capacity. Growing media with optimal water holding capacity ensures sufficient water availability for plant needs, which is essential for cell turgor and fresh biomass growth (Erdal & Aktaş 2025). High fresh weight is caused by a larger volume of tissue, while high dry weight is caused by an increase in structural dry matter due to optimal photosynthesis (Fadilah et al., 2025).

Cocopeat and coconut shell charcoal increase the porosity of the growing medium, thus facilitating oxygen supply to the roots. Good aeration supports efficient root respiration activity, aiding the conversion of nutrients into energy for biomass synthesis, resulting in increased plant dry weight (the result of photosynthesis and accumulation of structural tissues such as cellulose). Cocopeat contains essential nutrients such as NPK. Nitrogen (N) supports leaf and stem growth (fresh weight), Phosphorus (P) promotes cell division and root development (dry weight and root length), and Potassium (K) increases enzyme activity and distribution of photosynthetic products (Fadilah et al., 2025). In pakcoy plants, growing media containing cocopeat functions as an exchange of air and nutrients, keeping the growing media loose and fertile, as well as pores for air and light exchange (Muslimah et al., 2024). Meanwhile, media with husk charcoal increased the total dry weight by 23.33% - 65.64%, which showed a higher effect in promoting root development, which had a positive impact on crown growth (Supriyanto & Fiona 2010).

3.7 Marigold seedling quality

This experiment is expected to produce high-quality seedlings that are vigorous, adaptive, and capable of sustaining growth after transplanting. In general, the quality of seedlings is determined by various physiological and morphological characteristics that reflect their ability to survive and grow under field conditions. High-quality seedlings are typically characterized by a strong capacity to produce new roots rapidly, a fast rooting response in the growing medium, and a well-developed root system that allows efficient absorption of water and nutrients. Additionally, leaves that are well adapted to sunlight ensure optimal photosynthetic activity, while a large stem base diameter provides structural strength and stability. A balanced stem-to-root ratio indicates proportional growth between the aboveground and belowground parts of the plant, contributing to better nutrient allocation. Furthermore, seedlings with sufficient carbohydrate reserves and optimal mineral nutrient content are more resilient to environmental stress during transplantation. The successful formation of beneficial symbioses, such as mycorrhizal and rhizobium infections, also plays a crucial role in enhancing nutrient uptake and overall plant health (Wilson & Jacobs, 2005; Nurhasybi et al., 2019).

The medium with a composition of husk charcoal (1): cocopeat (2): bamboo compost (1) (M2) had the highest number of leaves (Fig. 1). Seedling height is correlated with the number of leaves, which is related to photosynthetic capacity and transpiration area. Taller seedlings have better competitive ability against weeds and exhibit superior genetic traits. However, the larger transpiration area in taller seedlings can cause stress when planted in dry fields, especially before root development. Seedlings that are too tall are difficult to plant, unstable, and susceptible to wind damage (Nurhasybi et al., 2019).

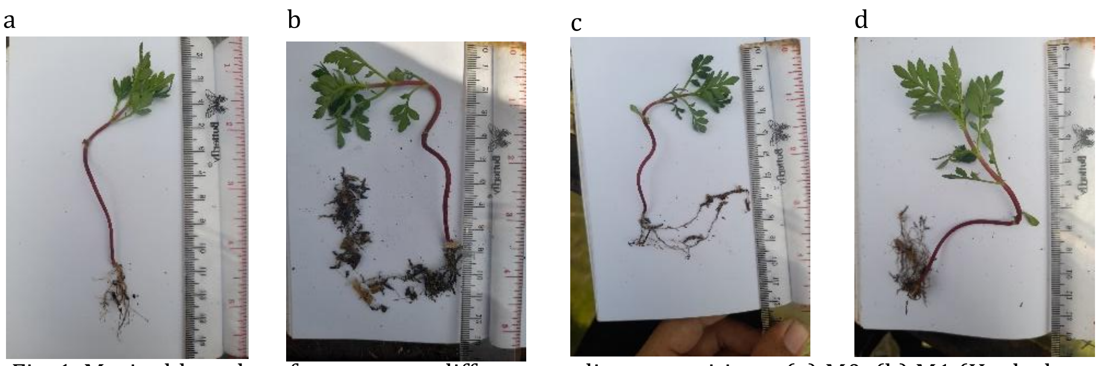

Fig. 1. Marigold seed performance on different media compositions: (a) M0; (b) M1 (Husk charcoal [2]: Cocopeat [1]: bamboo compost [1]); (c) M2 (Husk charcoal [1]: Cocopeat [2]: bamboo compost [1]); (d) M3 (Husk charcoal [1]: Cocopeat [1]: bamboo compost [2])

One criterion for ready-to-plant seedlings is having numerous roots that form a compact clump with the medium. Specific seedling requirements are determined based on seedling height measurements, ability to adhere to the medium, and number of leaves (Nurhasybi et al., 2019). Marigold seedlings planted in media with higher cocopeat content (M2) have more and longer roots (Fig. 2). This indicates a well-developed root system with new roots capable of growing rapidly. Seedlings that can grow and develop well have good prospects under extreme conditions. Seedlings with deep root systems can grow well in dry areas and are more competitive during the early growth stage in fields infested with weeds (Nurhasybi et al., 2019).

Fig. 2. Media holding capacity of Marigold Seed Media in Different Media Compositions: (a) M0 (ready-to-use media); (b) M1 (Husk charcoal [2]: Cocopeat [1]: bamboo compost [1]); (c) M2 (Husk charcoal [1]: Cocopeat [2]: bamboo compost [1]); (d) M3 (Husk charcoal [1]: Cocopeat [1]: bamboo compost [2])

Measurements of fresh weight and total dry weight of plants grown in a medium of husk charcoal: cocopeat: bamboo compost at ratios of 2:1:1 and 1:2:1 did not show significant differences. Seedlings with larger stem weights have greater photosynthetic capacity and growth potential, but this increases stress on dry land before root development. Seedlings with higher root weights tend to grow and survive better than those with lower root weights (Nurhasybi et al., 2019).

Large root length and dry weight indicate good absorption of the media by the plants, which supports the development of a strong and active root system. Cocopeat has high water absorption and fine pores that are able to retain moisture, thus forming a physical structure of the media that supports strong absorption and good root growth. The high root holding capacity of the media helps the roots to cling tightly to the media when lifted from the seedling tray or transferred to the field, thus reducing transplant stress (Hazarika., 2022). The holding capacity of the media is indirectly reflected in root length, root fresh and dry weight, and seedling stability and development. Media that are able to retain water, provide sufficient aeration, and have a balanced physical structure will be better able to support root attachment, seedling growth, and the quality of plant physiology (Fadıllıoğlu & Başay 2023).

4. Conclusions

The composition of the growing medium affects plant growth. A growing medium with a higher proportion of cocopeat (M2 (Husk charcoal [1]: cocopeat [2]: bamboo compost [1])) showed lower bulk density and higher porosity compared to other treatments, which facilitated root penetration and improved nutrient and water absorption. In addition to porosity, other factors also contributed to better seedling performance. Cocopeat increased water-holding capacity, bamboo compost supplied essential nutrients, and husk charcoal enhanced aeration and gas exchange. These complementary physical and chemical properties supported optimal root development, leading to greater plant height, leaf number, root length, root number, fresh weight, and dry weight. Therefore, a seedling medium composed of charcoal, cocopeat, and bamboo compost (1:2:1) is effective in improving seedling quality. For future research, it is suggested to evaluate the adaptability and performance of marigold seedlings in field conditions after transplanting, to confirm the effectiveness of different media compositions under practical cultivation environments.

Acknowledgement
The author wishes to express gratitude to the lecturers of the Advanced Hirticulturae course in the Agronomy and Horticulture Department at IPB University for their guidance in conducting this research.

Author Contribution
The author contributed to the research, as well as the drafting and revision of the manuscript.

Funding
This research received no external funding.

Ethical Review Board Statement
Not available.

Informed Consent Statement
Informed consent was obtained from all subjects involved in the study.

Data Availability Statement
Primary data is based on requests due to confidentiality or ethical constraints.

Conflicts of Interest
The author declares no conflict of interest.

Declaration of Generative AI Use
During the preparation of this work, the author(s) used a generative AI tool to assist in paraphrasing certain sections for clarity and Grammarly to assist in improving the grammar and academic tone of the manuscript. After using these tools, the author(s) reviewed and edited the content as needed and took full responsibility for the content of the publication.

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