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The implementation of sustainable urban agriculture: response of mustard (*Brassica juncea* L.) towards planting media composition of top soil, biochar and manure at vertical farming

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Abstract. The study investigates the growth and yield response of mustard to different planting media of soil, biochar, and manure as planting media, within a vertical cultivation technique. Three-month research was carried out at the Screen House of Agroclimatology Laboratory, Faculty of Agriculture, Papua University, employing a Completely Randomized Design (CRD) with four treatments and triplicates. The results of the analysis of variance revealed that at 2 weeks after planting (WAP) period demonstrated a statistically significant effect of growing media composition on mustard height. Notably, Soil:Biochar (M1) treatment exhibited the highest plant height, surpassing Soil:Biochar:Manure (M3) treatment. Although biochar addition had an insignificant effect compared to control (M0) and Soil:Manure (M2) treatments, Soil: Biochar still achieved the greatest height. Further significance tests revealed that Soil:Biochar treatment recorded the longest leaf length, a measure not significantly different from Soil:Manure and Soil:Biochar:Manure treatments, but notably different from control which produced the shortest leaf length. Moreover, the Soil:Manure treatment presented the highest yield in terms of plant fresh weight compared to other treatments. While Soil:Biochar and Soil:Biochar:Manure treatments did not show statistical differences, their results were higher than control. In conclusion, the Soil:Manure treatment displayed the highest yield for plant dry weight and total plant weight per pot compared to other treatments, where control consistently performed the lowest. These findings underscore the efficacy of the Soil: Manure treatment in optimizing mustard growth and yield within a vertical cultivation system.

Key words: biochar, manure, mustard, planting media, urban agriculture, verticulture.

INTRODUCTION

Mustard (Brassica juncea L.) is a highly commercial horticultural crop (Tanwar & Goyal, 2021) with promising applications in the industrial sector (Fan et al., 2017). The growing population of Indonesia, coupled with an increasing awareness of nutritional needs, has led to a rise in demand for mustard. It is primarily consumed for its leaves or flowers, which contain significant nutritional value. According to Thomas et al. (2012), 100 g of mustard wet weight includes vitamin A (0.09 mg), vitamin B10 (2 mg), vitamin C (not specified), calcium (Ca) (220 mg), phosphorus (P) (38 g), iron (Fe) (2.9 g), protein (2.3 g), fat (0.3 g), and carbohydrates (4.0 g).

The rapid increase in Indonesia's annual population, as mentioned earlier, has exerted pressure on limited agricultural areas. Some agricultural lands have been transformed into industrial zones, residential areas, and offices, creating an opportunity for the intensive development of vertical cultivation. Verticulture represents a noteworthy example of urban farming, characterized by a vertical plant cultivation technique that arranges plants vertically to optimize land usage (Eigenbrod & Gruda, 2015; Beacham et al., 2019). In simpler terms, it involves farming by utilizing columns arranged vertically (Al-Chalabi, 2015; Beacham et al., 2019; Loman Jan Luciano, 2018). When verticulture is implemented, the number of plant populations in a given area can increase by 3 to 10 times compared to conventional agriculture, depending on the model or design of the planting media container. This vertical system is particularly well-suited for adoption by farmers or individuals with limited land who wish to cultivate numerous plants more sustainably (Barthel & Isendahl, 2013; Oh & Lu, 2023), contributing to future food security (Eigenbrod & Gruda, 2015).

One crucial factor significantly influencing the growth and production of plants in a vertical cultivation system is the composition of the growing media. The ideal planting media composition should effectively provide nutrients and ensure water availability to support the growth and production of plants (Landis et al., 1990). In simpler terms, the soil structure in the planting media must be sufficiently loose to allow flexibility for plant root growth. Typically, the composition of the planting media mixture can include various materials, although the common practice involves creating a mixture comprising loose topsoil, rice husk ash, and organic fertilizer.

In a vertical farming system, fertilization is a crucial factor to be considered for enhancing plant growth and production (De Bon et al., 2009; Orsini et al., 2013). Among the organic fertilizers, manure stands out. Manure encompasses the collective excrement of various animal species, urine, plant materials, straw, as well as residues from livestock feed and human household waste (Gross & Glaser, 2021). Notably, chicken manure boasts a relatively high nutrient composition compared to other types of manure. On average, chicken manure contains 55% H_2O, 1.00% N, 0.8% P_2O_5, and 0.42% K_2O (Gross & Glaser, 2021).

In addition to fertilization, in sustainable soil management (Kaur et al., 2020; Koul et al., 2022; Kumar & Bhattacharya, 2021), biochar is charcoal that is formed through the combustion process of organic matter without oxygen (pyrolysis) at a temperature of 250 °C–500 °C (Fang et al., 2015; Brassard et al., 2019). The use of biochar is being taken into account as it is capable of stimulating the activity of soil micro-organisms (Ladygina & Rineau, 2013; Rutigliano et al., 2014) and can increase soil aggregates (Kookana et al., 2011). Biochar is not consumed by microbes directly like other organic materials (Cross et al., 2016) and it does not disturb the carbon-nitrogen balance in the long run (Clough & Condron, 2010), and is even able to hold and allow more water and nutrients available to plants (Lin et al., 2022).

The availability and uptake of plant nutrients are strongly related to soil pH, with the organic matter and ash content in biochar playing a role in enhancing soil pH and quality, thereby improving nutrient utilization (Tsai & Chang, 2019). Moreover, depending on the nature of biochar production or feedstock, the organic matter component of biochar contains nitrogen, while the ash component contains phosphorus and potassium (Jindo, 2020). Additionally, biochar has a notable impact as negative ions result from oxidation and reduction reactions between biochar particles and oxygen in the soil. Consequently, biochar can effectively retain nutrients for plant uptake (Bolan et al., 2022; Joseph et al., 2010).

The presence of biochar has been shown to elevate microbial activity around plant roots (Ayaz et al., 2021; Murtaza et al., 2021). The fermentation process in biochar contributes to an increased surface area, acting as an attractant for microbes and extending their lifespan in organic matter. This, in turn, has additive effects on soil fertility and plant growth (Zhang et al., 2023). Through microbial activity and biochar absorption, biologically rich nutrients undergo breakdown (Kocsis et al., 2022) and are converted into readily available forms for plants (Rondon et al., 2007). Biochar can function as a nutrient source and serve as a fertilizer (Ding, 2016). Additionally, biochar has the potential to reduce leaching of nitrogen and other nutrients, thereby enhancing crop yields. It may also enhance microbial C-use efficiency and support the stability of active soil organic carbon fractions, promoting long-term carbon sequestration. Studies have demonstrated that the combined application of biochar and manure increases crop yields, as seen in the case of turnips (Nouar et al., 2019). Therefore, the addition of other inputs such as manure is a recommended approach to enhance the concurrent efficiency of using biochar. However, there is a lack of research on media composition under vertical farming specifically for mustard.

This study aims to determine the growth and yield of mustard (*Brassica juncea* L.) due to different composition of growing media on vertical cultivation techniques. While the benefit of the research is to provide information material those who are dealing with limited cultivated areas to increase crop production especially on mustard cultivation.

MATERIALS AND METHODS

Experimental site description

A 3-month experiment was conducted in 2022 at the Screen House of the Agroclimatology Laboratory, Faculty of Agriculture, Papua University, located in Manokwari, Indonesia. The research site is characterized by lowland topography, which is relatively uniform, and the soil exhibits characteristics of deep, well-drained, and calcareous alluvium soil, predominantly alkaline in reaction. The environmental conditions during the experiment included a mean temperature of 27.5 °C, humidity at 81.3%, and a total rainfall of 255.3 mm (Central Statistics Agency Manokwari Regency, 2023).

Experimental design and treatments

The materials utilized in the experiment included mustard seeds, chicken manure, biochar from coconut shells, top soil and sand. Mustard seeds, representing lowland varities, were obtained from commercial shops. The verticulture pots were arranged as a completely randomized design (CRD) comprising twelve experimental units with four treatments in three replicates. The treatments consisted of M0 : control (topsoil soil); and combination of treatments as follows: M1 : soil : biochar (1:1); M2 : soil : manure (1:1) and M3 : soil : biochar : manure (1:1:1).

Experiment procedures

The research implementation covered three stages. In the initial stage, we prepared the planting media by combining soil and manure. The soil used in the planting media composition was sourced from the top layer of soil (10 cm-depth). After removing grass and dirt, we horizontally hoed the soil, adhering to the top layer criteria, and subsequently cleared it of any large boulders before shifting it. The prepared manure was obtained in the form of ready-to-use chicken manure. Prior to application, the chicken manure underwent a cleaning process to remove unnecessary objects such as stones, wood, and plastic. It was the ground and sieved to achieve a finer texture for optimal utilization in the planting media.

The second stage involved the construction of verticulture using paralon pipes (Fig. 1), following the method outlined by Werdhany (2012). This process included preparing a 6-inch paralon, divided into three parts, each measuring 4 m in length, resulting in three paralon verticulture pots with a total length of 130 cm. For each pipe, 6 rows of alternating holes were measured and marked, with a distance of 20 cm between each hole, totaling 24 holes. The use of high-quality PVC pipe, characterized by thickness and hardness, was emphasized. To create holes in the PVC pipe, a drill was employed, utilizing a round drill attachment and a 'heat gun'. To prevent the planting medium from falling through, the tops of the holes were intentionally left attached and unremoved. For the drilled paralon to be securely positioned, it was recommended to soften it with a 'heat gun' before pressing it down into place. The heating process was focused on the specific area intended for indentation, ensuring that it became soft enough to be molded before pressing it into the desired shape.

Figure 1. PVC verticulture pots.

In the third stage, we employed the kontiki method (Nurida et al., 2015) to produce biochar. This involved creating a conical hole with an upper diameter and depth of 150 cm and 75 cm, respectively, with the flexibility to adjust the diameter as needed. A fire was initiated at the bottom center of the hole using flammable materials, such as wood leftovers. In the kontiki model, oxygen is restricted from falling below the fire, allowing it to burn solely at the designated point of combustion. Gradually, coconut shells were added to the lit kontiki when the fire burned steadily at temperatures between 400–450 °C. New raw materials were introduced when almost all previously added materials had been burned. From a practical standpoint, burning using kontiki cannot be completed all at once; instead, raw materials are added gradually, little by little, according to the volume of the kontiki. This process continued until all the coconut shells were burnt. Once all the raw materials turned black into charcoal and there were no more flames, all burning coals were extinguished with water to prevent further burning. In a single trial lasting less than 1 hour, approximately 6 kg of coconut shell raw material produced biochar. After allowing it to cool sufficiently, the biochar was dried and ground as needed before application.

Cultural Practices

The nursery phase involved sowing mustard seeds in plastic trays filled with a mixed medium of soil and sand in a 1:2 ratio, adequately watered. The seeds were evenly spread at a depth of 1 cm and lightly covered with soil. Regular watering was maintained by using a hand sprayer once a day until the seeds were fully hydrated, and the seedlings were ready for transplantation into verticulture pots. For the experimental treatments, the planting media prepared according to specific treatments were placed in verticulture pots, left for a day to reach field capacity before growing seedlings. Planting was conducted simultaneously to ensure uniform plant growth, either 15 days after sowing or when two young leaves had emerged. The vertical planting technique was adjusted based on the number of holes created, with one selected seedling planted in each vertical hole. Consequently, each verticulture pot served as an experimental unit, comprising 24 mustard plants.

Plant maintenance activities during the experiment encompassed various tasks, including replanting, regular watering, weeding, and pest and disease control. Harvesting was carried out using two methods: uprooting the entire plant along with its roots and cutting the base of the above-ground stem. The harvesting phase occurred 30–40 days after planting (DAP), and well-grown plants in each pot could yield approximately 175 grams. Consistent cultural practices, such as daily watering using a sprayer, were uniformly implemented throughout the experiment to ensure optimal plant growth and development.

Data collection and Statistical Analysis

Observational variables, primarily growth parameters such as plant height and the number of leaves, were recorded between 14 to 35 days after planting for six sample plants within each experimental unit or paralon. Additionally, observations of leaf length and width were conducted as the plants approached the harvesting stage. After harvesting, the components of fresh and dry weights of both plant shoots and roots were meticulously observed and measured.

The collected data were then analysed using analysis of variance (Anova) at the 95% confidence level according to Fisher (1938) to calculated the nature and magnitude of treatment effects revealed by ‘F’-test. If the effect of treatments are statistically significant ($p < 0.05$), means of different sources of variation were compared using Fisher’s least significant difference (*LSD*) test.

RESULTS AND DISCUSSION

The analysis of variance of observed growth and yield components showed variation in the effect of planting media composition treatments on observed variables. The summary of analysis of variance is given in Table 1.

Table 1. Recapitulation of analysis of variance of observed variables

No	Observed variable	F-statistics	Notation	Coefficient of Variance (%)
1	Plant Height 1 WAP (cm)	3.61	ns	20.68
2	Plant Height 2 WAP (cm)	6.26	*	11.23
3	Plant Height 3 WAP (cm)	1.69	ns	17.31
4	Plant Height 4 WAP (cm)	2.93	ns	11.94
5	Plant Height 5 WAP (cm)	3.06	ns	11.21
6	Leaf Number 1 WAP	16.22	**	4.48
7	Leaf Number 2 WAP	2.79	ns	5.44
8	Leaf Number 3 WAP	15.71	**	8.82
9	Leaf Number 4 WAP	5	*	9.67
10	Leaf Number 5 WAP	6.57	*	5.88
11	Leaf Length (cm)	9.35	**	8.96
12	Leaf Width (cm)	2.44	ns	13.83
13	Leaf Area (cm^2)	6.99	*	15.99
14	Plant Fresh Weight (g)	22.34	**	17.70
15	Plant Dry Weight (g)	2.55	ns	25.45
16	Plant Total Weight per Verticulture Pot (g)	2.68	ns	35.44

Notes: ns – Treatments had no significant effect ($p > 0.05$); * – Treatments had significant effect ($p \leq 0.05$); ** – Treatments had significant effect ($p \leq 0.01$); WAP – Weeks After Planting.

Growth Components

Plant growth is the process in plant life that leads to changes in size and influences plant yields. The expansion of plant organ systems is attributed to the growth of plant organs through development and an increase in cellular tissue (Hamant & Traas, 2010).

Fig. 2 illustrates that the planting media composition had no effect during the 1st, 3rd, 4th, and 5th WAP, but a significant effect was observed at 2 WAP. During the early growth stages at 1 and 3 WAP, the control treatment (M0) exhibited the highest plant height, surpassing other treatments and indicating superior initial plant growth. The Soil:Biochar (M1) treatment also demonstrated a more favorable contribution than the other two treatments. However, by 4 and 5 WAP, the Soil:Manure (M2) treatment exhibited a tendency to achieve greater plant height.

The composition of planting media had a significant effect on the height of mustard at 2 WAP. Soil:Biochar gave the highest plant height compared to Soil:Biochar:Manure (M3), although it was not statistically different as compared to control and Soil:Manure treatments. This is presumably because biochar is able to retain and store water as a supporting factor on the initial growth of plants. In addition, biochar also plays a role in providing essential nutrients.

The planting media composition exerted a significant influence on mustard's height at 2 WAP. While Soil:Biochar treatment resulted in the highest plant height compared to Soil:Biochar:Manure, the difference was not statistically significant when compared to control and Soil:Manure treatments. This outcome is likely attributed to the water retention capabilities of biochar (Razzaghi et al., 2020), providing crucial support for the initial growth of plants. Additionally, biochar plays a dual role by supplying essential nutrients and enhancing the physical, chemical, and biological properties of the soil, as indicated by previous studies (Brassard et al., 2019; Murtaza et al., 2021) and to improve and restore the quality of degraded soil as well (Barrow, 2012; Abhishek et al., 2022).

Supporting this, the addition of biochar to soil enhances nutrient availability (Cao et al., 2018), retention (Clough & Condron, 2010), and water retention (Ajayi et al., 2016). For instance, biochar has been noted to enhance the efficiency of nitrogen fertilizer use in plants (Chan et al., 2007).

Plant Height

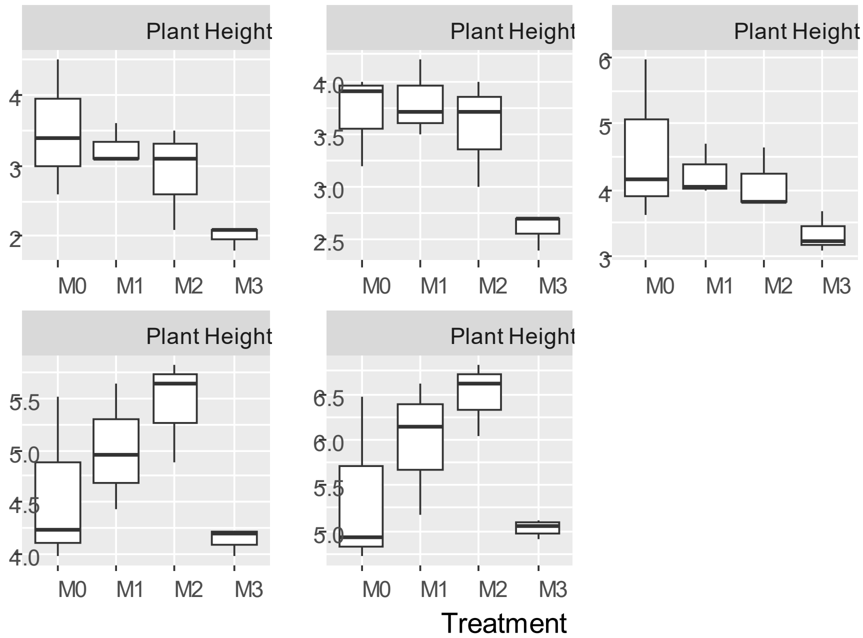

Figure 2. Means of Plant Height due to the Application of Different Planting Media Composition in the Verticulture Technique.

Furthermore, both control and Soil:Manure treatments demonstrated a positive contribution to plant height gain. This may be attributed to the application of the Soil:Manure treatment, which proved effective in providing the necessary nutrients for plant growth. Specifically, decomposed chicken manure in the Soil:Manure treatment contributed macro nutrients such as nitrogen and phosphorus, essential for cell division and the subsequent increase in plant height.

In relation to nutrient content, chicken manure is reported to contain three times more nitrogen than other manures, as highlighted by Aziz et al. (2020). Additionally, phosphorus plays a crucial role in synthesizing ATP as an energy source and serves as a precursor for DNA and RNA, essential nucleic acid compounds. ATP, functioning as an energy source, is vital for cell division and elongation, contributing to increased plant height. Moreover, phosphorus actively promotes cell division, particularly in root organs. The heightened cell division facilitated by the availability of phosphorus has a positive impact on shoot growth, as the development of plant shoots and roots is interconnected. This underscores the significance of phosphorus in fostering overall plant growth and height.

Our result of analysis of variance (Table 1) showed that the composition of planting media had a significant effect on number of plant leaves at 1, 3, 4 and 5 WAP and had no effect at 2 WAP. Based on further tests, Soil:Biochar:Manure treatment gave the best results statistically compared to other treatments at 1 and 3 WAP. At 4 and 5 WAP, Soil:Biochar:Manure treatment gave higher yields than control but did not significantly different from Soil:Biochar and Soil:Manure treatments. The combined treatment of Soil:Biochar:Manure gave the best results for number of leaves (Fig. 3). Nutrients contained in chicken manure are mainly macro nutrients, namely N, P and K where N is needed for vegetative growth of the upper part of plant. Element K to strengthen stem and P to stimulate root growth (Fageria & Moreira, 2011). Manure works synergistically with biochar in supporting the increase in size of mustard. Kookana et al. (2011) suggested that biochar is able to improve fertility by making fertilization more effective, where biochar can bind nutrients, therefore plants can avoid micro-nutrient poisoning and nutrient deficiencies. Another advantage is that biochar is more persistent in the soil (Abhishek et al., 2022), thus all the benefits related on improving soil fertility can work well when organic fertilizers decompose.

Leaf Number

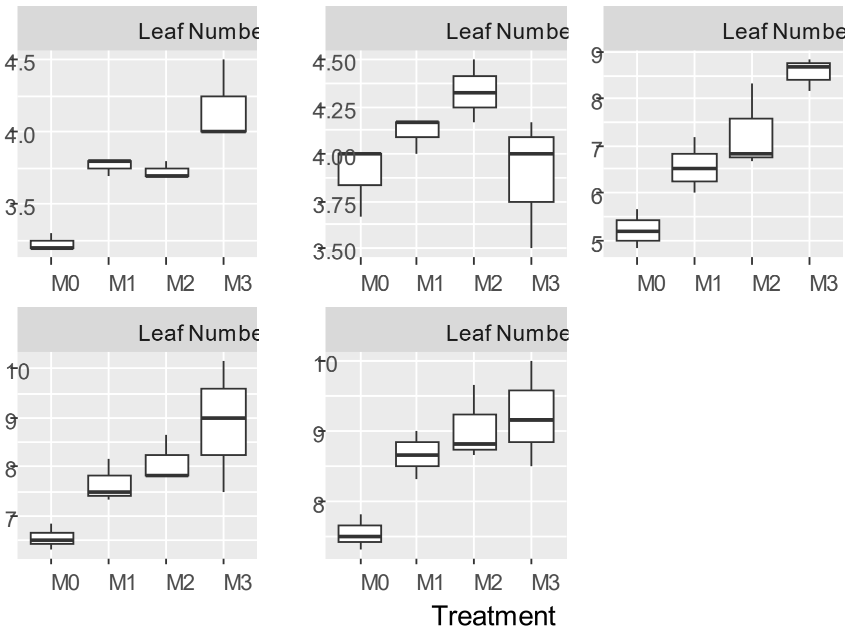

Figure 3. Means of Leaf Number due to the Application of Different Planting Media Composition in Verticulture Technique.

The treatment of planting media composition greatly influenced leaf length of mustard and affected leaf area, but did not affect leaf width (Fig. 4). Post hoc analysis showed that Soil:Biochar treatment gave the longest leaf length which was not different from Soil:Manure and Soil:Biochar:Manure treatments, whereas it was different from control which produced the shortest leaf length. Furthermore, for the leaf area variable, Soil:Manure treatment revealed the widest leaf area followed by Soil:Biochar:Manure treatment and the lowest was expressed by control treatment. In terms of leaf width, regardless the fact that planting media composition showed no statistical effect, there was a tendency that Soil:Biochar:Manure treatment recorded higher leaf width and control treatment contributed the lowest leaf area. Control treatment gave the lowest yield since top soil without being enriched with organic matter and biochar had a minimal role in providing nutrients and water.

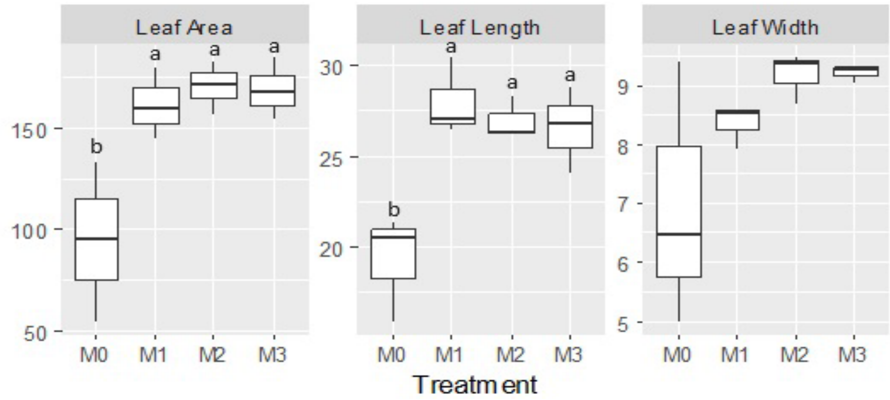

Figure 4. Means of Length, Width and Leaf Area of Mustard Due to Differences of Planting Media Composition in Verticulture Technique; different letters in a same letter indicate significant differences ($p < 0.05$) between treatments according to Fishers Protected; *LSD* test.

Yield Components

Yield component refers to weight of plants observed during harvest including fresh weight, dry weight and total weight per pot as presented in Fig. 5.

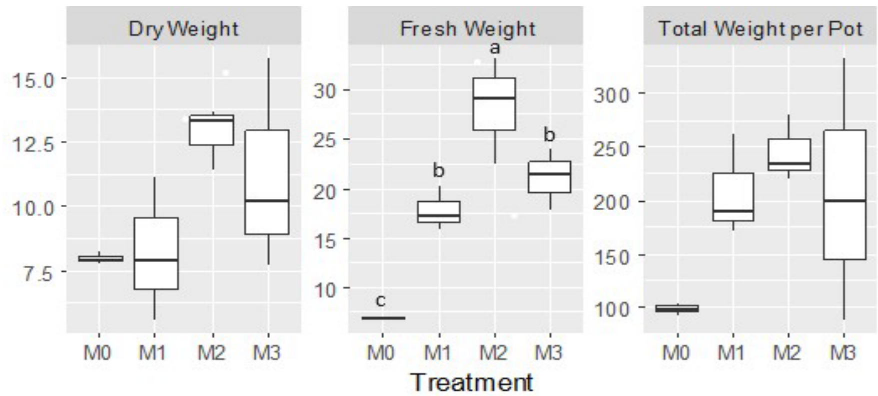

Figure 5. Means of Fresh, Dry and Total Weight per Pot of Mustard Due to Differences of Planting Media Composition in Verticulture Technique; different letters in a same letter indicate significant differences ($p < 0.05$) between treatments according to Fishers Protected; *LSD* test.

Among three variables of plant weight, different growing media composition showed a statistically significant on plant fresh weight (Table 1). From the results of significance test, Soil:Manure treatment gave the highest yield on plant fresh weight compared to other treatments, where Soil:Biochar and Soil:Biochar:Manure treatments were not statistically different, although the results were higher than control treatment. It can be assumed that Soil:Manure treatment independently gave the highest results for plant dry weight and total plant weight per pot compared to other treatments, where control treatment consistently performed the lowest.

Plant fresh weight was positively correlated to plant dry weight and total plant weight per pot. The greater the value of fresh weight, the greater dry weight and total weight per pot are. Soil:Biochar:Manure treatment can simultaneously improve soil fertility, triggered to the availability of nutrients, to promote growth and production because there are macro nutrients playing a vital role. Nutrient content of chicken manure is 1.5% N; 1.3%P; 0.8%K; 4% CaO, 9–11% C/N ratio and contains 57% moisture content (McCall, 1980).

In addition, fresh chicken manure composed of secondary and micronutrients in fresh chicken manure, where calcium and magnesium are in the largest proportion and molybdenum and zinc are the least (Wall & Plunkett, 2021), has higher nutrients than other types of livestock. This is because solid manure in livestock is mixed with liquid manure. Besides containing the nutrients needed by plants, based on the analysis found existing bacteria *lactobacillus archidophilus, lactobacillus mesenteroides* and *streptococcus thermophilus,* small portion of *actynomycetes* and fungi in chicken manure (Li et al., 2020). The presence of bacteria greatly assists decomposition process of organic matter perfectly with good quality, causing nutrients provision for plants as well as physical, chemical and biological properties improvement of the soil (Fries et al., 2005). The application of chicken manure can improve environmental conditions for plant growth (Nyakatawa et al., 2000; Adekiya et al., 2020) which in turn can increase yield (Pujiastuti et al., 2018; Zahanis et al., 2023).

The role of biochar when synergizing with other inputs is to maximize nutrient absorption in plant roots (Mate et al., 2015) which are translocated to shoots. In plant shoots, these nutrients are processed into growth compounds and transported to all parts of plant (Hall et al., 1993). In addition, humus acid from applied soil organic matter has a high cation exchange capacity, ranging from 150–300 m per 100 g and a surface area of 800–900 m^2 per g. The high cation exchange capacity and surface area of humus increase the availability of nutrients and water for plants and reduce soil acidity (Joseph et al., 2010). The availability of sufficient nutrients and water will lead to effective photosynthesis in the formation of carbohydrates, increasing plant growth rate, indicated by a heavier wet weight.

Biochar and chicken manure together act as organic matter which can improve the physical and chemical properties of soil and can also increase number and activity of soil microorganisms. One of the benefits of using biochar is to create a proper habitat for microbial development (Ladygina & Rineau, 2013; Saxena et al., 2013) and symbiotic microorganisms such as mycorrhizae because of their ability to hold water and air and create a neutral environment, especially in acid soils (Mohan et al., 2014; Jeffery et al., 2017). Neonbeni et al. (2020) proved that the application of biochar 5 tons ha^{-1} gave the best plant height, stem diameter, number of leaves, leaf area, flower diameter on cauliflower (*Brassica oleraceae* L.). The application of biochar 9 tons ha^{-1} alone was able to increase plant height, number of leaves, leaf area, fresh weight per plant, dry weight per plant, plant weight per plot. The application of biochar has real potential to improve several soil chemical properties such as soil pH, CEC (Li et al., 2020), and several compounds such as C-organic, N-total, and can reduce the activity of Fe and Al compounds which have an impact on increasing available P (Semita et al., 2017). Other studies confirmed that Rondon et al. (2007) the use of biochar can increase nitrogen fixation (Bolan et al., 2022), improve growth and increase plant yields. Moreover, the combination of biochar with plant residue and non-essential nutrient input enhanced Oryza sativa (L.) growth and yield (Widiasri et al., 2022).

Chicken manure is recognized as a rich source of both macro and micro nutrients, as indicated by Ahmad et al. (2009). Its application has been shown to enhance soil fertility and improve the physical characteristics of soil, as highlighted by Šařec & Žemličková (2016). Moreover, chicken manure serves as a substrate for soil microorganisms, promoting increased microbial activity and accelerating decomposition, as observed in studies by Ilodibia & Chukwuma (2015) and Li et al. (2020).

The high nitrogen (N) content in chicken manure contributes to vigorous vegetative plant growth, leading to substantial gains. This elevated N content also enhances protein levels in the soil, promoting the synthesis of amino acids and proteins in plants. Petit (2004) suggests that when organic fertilizers like chicken manure are applied to the soil, the organic matter breaks down into inorganic compounds through the activity of decomposing microorganisms. This breakdown improves soil structure, making it more porous and facilitating easier nutrient absorption by plants. Several studies support the positive impact of chicken manure on leaf vegetable plants. Anwar et al. (2017), for instance, reported that co-composted manure significantly improved the growth and nutrient availability of spinach. In this context, the application of chicken manure led to variations in dry biomass, phosphorus (P), and potassium (K) contents in spinach shoots. However, nitrogen (N), zinc (Zn), iron (Fe), copper (Cu), and cadmium (Cd) contents in spinach shoots decreased with increasing amounts of leaf litter in the manure amendment. These findings underscore the complex and multifaceted effects of chicken manure on plant growth and nutrient dynamics.

CONCLUSIONS

Based on the findings from the study on the response of mustard growth and yield to various planting media compositions using verticulture techniques, it can be concluded that the treatments did not have a significant effect on plant height, leaf width, plant dry weight, and total weight per pot across all observation times. However, there were effects on the number of leaves, leaf length, leaf area, and fresh weight based on the planting media composition.

Notably, the Soil:Biochar:Manure treatment exhibited the highest number of leaves, while the Soil:Manure treatment showed the best results in terms of leaf area and plant fresh weight. As a recommendation for future research, further experiment into different compositions of biochar and other biosolids in verticulture techniques is suggested. This could provide valuable insights into optimizing plant growth and yield in verticulture techniques.

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