Synergistic Effects of Lignocellulosic Baglog Compost and Biochar on Tomato Plant Growth

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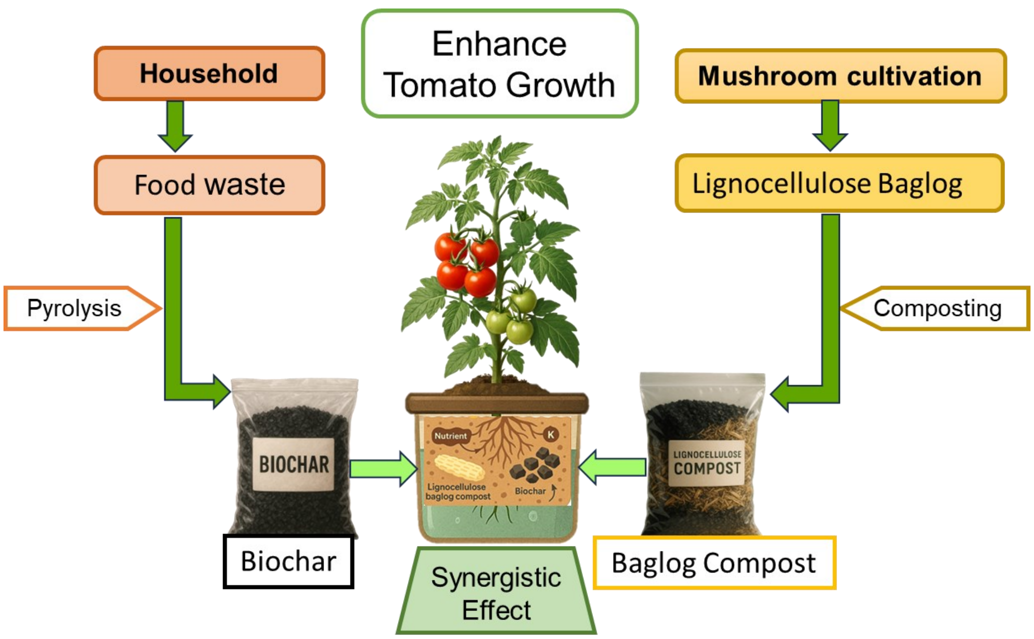
GRAPHICAL ABSTRACT



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Indonesian agriculture faces multifaceted challenges, particularly the need to enhance productivity while maintaining environmental sustainability to ensure high-quality food production. Soil degradation and excessive use of chemical fertilizers have contributed significantly to declining soil fertility and land degradation. This study aims to evaluate the effectiveness of biochar and compost derived from lignocellulosic baglog, spent substrate from *Ganoderma lucidum* mushroom cultivation, to improve soil quality and fertility, especially under sub-optimal soil conditions. The treatments were tested on tomato plants using different application rates. A factorial Completely Randomized Design (CRD) was employed, comprising two factors with three replications. The first factor was the baglog waste compost dosage at four levels: B0 (0 g/polybag), B1 (200 g/polybag), B2 (300 g/polybag), and B3 (400 g/polybag). The second factor was the biochar dosage, also at four levels: K0 (0 g/polybag), K1 (250 g/polybag), K2 (500 g/polybag), and K3 (750 g/polybag). Key growth parameters, plant height, number of leaves, stem diameter, and leaf area, showed notable improvement compared to control plants grown without biochar or baglog compost. Applying both in balanced amounts is essential to promote optimal tomato plant growth.

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Keywords: Biochar; Chlorophyll; Lignocellulose baglog compost; Organic farming; Spent mushroom substrate; Tomato.

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INTRODUCTION

Indonesia, as an agricultural country, has the potential to produce enough food in the form of vast agriculture (Igual *et al*. 2022). However, modern agriculture faces complex challenges involving a balance between increasing productivity and preserving the environment to increase quality food yields (Arifin *et al*. 2022). The main challenge facing sustainable systems in agriculture is degraded soils and over-reliance on chemical fertilizers that cause soil infertility and land degradation (Robles-Aguilar *et al*. 2023).

The vast land is an impetus to further increase the productivity of sub-optimal land for the national food supply (Igual *et al*. 2022). Therefore, improvements are needed to maximize land utilization, such as using soil amendments and fertilizing the soil with organic matter. This is a top priority in restoring degraded land to optimal land use (Amalia and Fajri 2020).

One way to increase agricultural land productivity is to use biochar as a soil conditioner (Arifin *et al.* 2022). Biochar serves as an effective soil amendment for tropical regions by raising the pH of acidic, weathered soils and addressing deficiencies in calcium, magnesium, and potassium. It also supports plant growth and improves fertilizer efficiency by mitigating physical soil constraints (Dewi and Afrida 2022). In addition, several review articles and meta-analyses have evaluated the benefits of biochar as well as its ameliorative roles, such as improving soil quality, agricultural productivity, pH stabilization, increased soil microbial activity, carbon sequestration from soil, and reduction of organic and inorganic pollutants from soil and water media (Duarte *et al*. 2020).

Biochar alone cannot fully meet the nutrient requirements of soil and plants; therefore, it should be complemented with other amendments such as compost. Compost is a decomposed organic material rich in humus, beneficial microorganisms, and essential macro- and micronutrients that support plant growth. (Jonson 2019). An example of compost is spent *Ganoderma* sp. mushroom substrate (MSM), which is used for mushroom cultivation over 6 to 10 cycles within 4 to 6 months. Despite being spent, it still contains residual nutrients that can support plant growth. At this stage, if the mushroom waste is not handled properly, it can cause environmental pollution (Putri *et al.* 2022).

Fertilization is intended to enhance the availability of nutrients for plants in the soil. However, using chemical fertilizers over a long period can cause environmental pollution. In addition, the use of chemical fertilizers can also change the nature of the soil to become hard. Therefore, by utilizing baglog compost into environmentally friendly organic compost, it is expected to increase soil fertility. Compost derived from *Ganoderma* sp. spent mushroom substrate contains essential nutrients, including 1.59% nitrogen (N), 0.7% phosphorus (P), 1.44% potassium (K), and 48.95% organic carbon (C), making it effective in enhancing soil fertility. The combination of biochar and compost can improve soil conditions and increase plant growth (Calderón *et al.* 2015).

Biochar was used as a soil amendment to enhance agricultural productivity, combined with ammonium sulfate [$(NH_4)_2SO_4$] fertilizer, Zwavelzure Ammoniak (ZA), commonly known by its Dutch term, as a source of nutrients. According to the Soil and Fertilizer Instrument Standard Testing Center, ZA fertilizer has a weakness where nitrogen nutrients in the form of NH_3 are easily volatilized. Powlson and Dawson (2021) reviewed 41 publications that reported NH_3 losses in Z fertilizer applications in 16 countries in various soil types and climates. Therefore, the use of ZA fertilizer as a nutrient source in soil has a high risk of NH_3 loss (Ferry *et al*. 2020).

Chemical fertilizers are easily decomposed in nature, so to get optimal fertilization efficiency, the right dose must be applied. Fertilization must also be done frequently because fertilizers cannot be stored for long in the growing medium. This is quite detrimental because the price of chemical fertilizers is quite expensive (Hidayat *et al*. 2023).

Furthermore, the use of chemical fertilizers can lead to water pollution and disrupt the ecosystem. High concentrations of chemical fertilizers enter the soil and contaminate the clean water supply. Nitrogen carried in water and plants will be consumed by humans and animals, causing health problems. Nitrogen poisoning can lead to Deoxyribonucleic Acid (DNA) damage and various chronic diseases, including Alzheimer (Dewi and Afrida 2022).

While previous studies have explored similar approaches, this research introduces a novel substitution of synthetic fertilizers, specifically ZA, with organic compost derived from spent mushroom substrate, usually called baglog, composed of sawdust, bran, calcium carbonate ($CaCO_3$), and *Ganoderma lucidum* fungal isolates. This compost offers essential macro and micronutrients that enhance soil fertility and plant development. Mushroom cultivation inherently relies on lignocellulosic materials such as sawdust, and reusing the resulting waste as compost presents an eco-friendly solution for organic waste management. To date, no studies have reported on the composting of *Ganoderma lucidum* baglogs; most existing literature focuses on *Pleurotus ostreatus* substrates, making this study a significant contribution and a novelty in the field.

While both biochar and lignocellulosic baglog compost are individually recognized for enhancing soil fertility and structure, their combined application remains largely unexplored. The novelty lies in the exploration of synergistic effects, how the interaction between biochar's porous, carbon-rich structure and the nutrient-rich, decomposable organic matter of baglog compost can collectively improve soil quality more effectively than either component alone.

Lignocellulose is an important ingredient in plant compost because it provides structure, a carbon source, and enriches the final compost product. Although lignin decomposes slowly, the result is invaluable for long-term soil health (Izydorczyk *et al*. 2024). The study aimed to evaluate the combined effect of biochar and lignocellulosic baglog waste compost on soil quality and vegetative growth of tomato plants in suboptimal conditions, and to determine optimal application doses that maximize plant development. Additionally, this research evaluates the effectiveness of repurposing agricultural waste, with baglog compost derived from spent mushroom substrates, a resource often underutilized. The hypothesis of this study proposes that a synergistic effect will occur, resulting in greater enhancement of tomato plant growth when biochar and compost derived from spent mushroom substrate (baglog) are combined in a balanced dose, compared to either amendment alone.

EXPERIMENTAL

The experiment was performed from February 2024 to December 2024. The experiment was conducted in a screen house that allowed for natural sunlight exposure, ensuring sufficient light intensity for photosynthesis with the use of 25% artificial shading. The screen house was located at the Science and Technology Area of B J Habibie, National Research and Innovation Agency, Serpong, Setu District, South Tangerang, Banten. The location of biochar sampling from waste was obtained from the manager in Bekasi, West Java. *Ganoderma lucidum* mushroom baglog waste sampling was taken from mushroom waste managers in Bandung. Sample testing was carried out in several laboratories at BRIN, namely the Agro and Biomedical Industrial Engineering Development Laboratory and the Biotechnology Center and Testing Laboratory of the Soil and Fertilizer Instrument Standard Testing Center at the Agricultural Instrument Standardization Agency, Bogor.

Materials and Methods

Planting was carried out in polybags measuring 25 cm x 25 cm which had been mixed with red soil, sand, biochar and baglog waste by the treatment dose when the seedlings were 3 weeks after sowing (had 3 or 4 leaves), then the polybags were placed at a spacing of 20 cm between and within rows, the depth of the planting hole was 5 cm. At the beginning of planting, watering was carried out twice a day until before harvest, using a paddle, and watering was carried out until the soil became moist. Weeding is done by cleaning weeds around the plants by mechanical means and is done every 3 days. The installation of bollards is done on tomato plants as high as 15 cm, installed with a distance of 5 cm from the tomato plants so that the plant stems can grow upright. Pest control was carried out when the tomato plants were 25 days after transplanting using insecticide, spraying on the underside of the leaves once a week.

Design Experiment

The research design used a Factorial Randomized Complete Design (FRCD). The first experimental factor was the lignocellulosic baglog compost dose, with four treatment levels: B0 (0 g/polybag), B1 (200 g/polybag), B2 (300 g/polybag), and B3 (400 g/polybag). The second factor was the dose of biochar, also with four levels: K0 (0 g/polybag), K1 (250 g/polybag), K2 (500 g/polybag), and K3 (750 g/polybag). The weight of a polybag containing growth media is about 5 kg. The study employed 16 treatment combinations (CDs), each replicated three times, resulting in 48 research plots (shelves). Each plot measured 100 cm × 100 cm with a planting distance of 20 cm × 20 cm. Spacing between plots was 50 cm, and between replications was 100 cm. Observations were conducted weekly for 10 days, up to 60 days after transplanting, on plant height, number of leaves, leaf area, and stem diameter.

Chemical Analysis of Soil, Biochar, and Baglog Compost

Soil samples and baglog compost were collected on three occasions and then combined into a composite sample. A representative portion of the composite was taken for analysis at an accredited laboratory, using ISO-standard methods routinely applied by the lab. Table 1 presents a comparative overview of the physical, chemical, and functional characteristics of biochar derived from food waste and compost produced from lignocellulosic baglog substrates.

Table 1. Characteristic of Biochar from Food Waste and Compost from Lignocellulosic Baglog

Characteristic	Biochar	Lignocellulosic Baglog Compost
Material Source	Fruit peels, vegetable scraps, etc.	Spent mushroom substrate (sawdust)
Production Process	Pyrolysis	Aerobic decomposition using Effective Microorganisms 4 (EM4)
Color	Black	Dark brown
Texture	Porous, brittle, lightweight	Crumbly, moist, humus-like
pH	7.0–10.5 (alkaline)	6.0–7.5 (neutral to slightly acidic)
Carbon Content (%)	45–70 (mostly stable carbon)	20–40 (labile and stable carbon)
C/N Ratio	30–80 (high, slow decomposition)	15–30 (optimized for nutrient availability)
Total Nitrogen (%)	0.2–1.0 (low, mostly unavailable)	1.0–2.0 (readily available)
Phosphorus (P_2O_5)	0.2–0.6	0.4–0.8

(%)		
Potassium (K_2O) (%)	0.5–1.5	0.5–1.0
Organic Matter (%)	Low to moderate (inert carbon)	High (30–60%)
Ash Content (%)	10–50	10–30
Fixed Carbon (%)	50–75 (very stable)	<20 (low stability)
Volatile Matter (%)	10–30	40–60
Surface Area (m²/g)	10–300 (porous, increases with pyrolysis temperature)	<10 (not porous)
Moisture Content (%)	<10% (dry and hydrophobic)	30–60% (moist)
Microbial Content	Inert (carrier only)	Rich in microbes (biologically active)
Soil Function	Improves structure, water retention, nutrient holding, and pH buffer	Supplies nutrients, stimulates microbial activity
Decomposition Rate	Very slow (decades)	Fast (within months)
Recommendation Best Use In Soil	Soil amendment, carbon sequestration, pH regulation	Fertilizer, organic matter enrichment

Observation and Data Analysis

Growth parameters included plant height (cm), number of leaves, leaf area (cm²), and stem diameter (cm). Observations were conducted weekly but limited to the vegetative growth phase of tomato plants. Collected data were analyzed using an F-test at the 5% significance level ($\alpha = 0.05$). When significant differences were detected, further analysis was conducted using Tukey's Honest Significant Difference (HSD) test. Statistical analysis was carried out using RStudio software.

Chlorophyll Analysis

Chlorophyll analysis was conducted to assess the greenness of the leaves by measuring chlorophyll a, chlorophyll b, and total chlorophyll content. Chlorophyll content was measured using a spectrophotometric method as follows. Leaf samples were first crushed and homogenized, after which chlorophyll was extracted using organic solvents. In this study, 80% acetone was used for the extraction of chlorophyll a and b, while 80% methanol was employed for the extraction of total chlorophyll. The resulting extract was then filtered and centrifuged to separate the solid residues from the chlorophyll-containing solution. The clear filtrate was analyzed for chlorophyll a and b were quantified using a spectrophotometer at 645 nm and 663 nm, respectively, and at 430 nm and 665 nm for total chlorophyll. Chlorophyll concentration was calculated using an empirical formula based on specific absorbance values and coefficients, as described by Arnon (1949).

$$Chlorophyll\ a\ (\mu g/mL) = 12{,}7 \times A663 - 2{,}69 \times A645 \qquad (1)$$

$$Chlorophyll\ b\ (\mu g/mL) = 22{,}9 \times A645 - 4{,}68 \times A663 \qquad (2)$$

$$Total\ chlorophyll = Chlorophyll\ a + Chlorophyll\ b \qquad (3)$$

Estimation of Nitrogen Content Based on Total Chlorophyll

The nitrogen content was estimated using a linear regression equation derived from prior studies on the correlation between total chlorophyll content and nitrogen concentration (Reis *et al.* 2015). The regression model used in this estimation is presented as follows,

$$N = a.\ Chl + b \qquad (4)$$

where N is the nitrogen content (mg/g dry leaf), Chl is the total chlorophyll content (mg/g dry weight), and *a, b* are the empirical coefficients that depend on the species and measurement method.

Net Photosynthesis Rate Estimation Based on Nitrogen Content

The nitrogen values obtained from total chlorophyll measurements were used to estimate the net photosynthesis rate, applying a simple linear regression model as follows,

$$A = c.\ Chl + d \qquad (5)$$

where A is the photosynthesis rate (μmol CO_2 m^{-2} S^{-1}), Chl is the total chlorophyll content (mg/m^2), and *c, d* are the empirical coefficients based on plant species.

RESULTS AND DISCUSSION

Characteristics of Biochar and Baglog Compost

Biochar derived from food waste is typically rich in carbon content and has a high surface area, making it excellent for improving soil structure, water retention, and microbial activity. Its alkaline pH helps neutralize acidic soils, and its stable structure contributes to long-term carbon sequestration. Nutrient content varies depending on the type of food waste, but it generally includes essential elements like potassium, phosphorus, and calcium in moderate levels. In contrast, compost from lignocellulosic baglog materials (such as used mushroom cultivation substrates) tends to have moderate nutrient content, with more readily available nitrogen, humic substances, and organic matter that support plant growth in the short term. It typically has a neutral to slightly acidic pH, is more biodegradable, and promotes microbial diversity and activity in the soil. However, its carbon stability is lower than biochar, which decomposes more quickly and contributes less to long-term carbon storage. Overall, biochar enhances soil quality over time and stores carbon, whereas compost provides quick nutrient availability and boosts microbial activity. Combining both can create a powerful synergy for sustainable farming practices.

Growth Performance of Tomato

Baglog compost application significantly enhanced the vegetative growth of tomato plants, as evidenced by increased plant height, leaf number, stem diameter, and leaf area compared to the control group without biochar and baglog waste compost (Table 2).

Table 2. Vegetative Growth Data of Tomato Plants at 30 Days after Planting

Treatment	Plant Height (cm)	Number of Leaves	Leaf Area (cm^2)	Stem Diameter
B0K0	1.24b	2ab	0.017b	0.003e
B0K1	2.47ab	9.67cd	0.237b	0.0018c
B0K2	1.53ab	6d	0.223b	0.015c
B0K3	2.16ab	1.57b	0.078b	0.010d
B1K0	3.27ab	1.80b	0.332ab	0.025b
B1K1	2.79ab	7.67cd	0.195b	0.017c
B1K2	1.81ab	9.33cd	0.187b	0.018c
B1K3	1.82ab	11c	0.237b	0.010c
B2K0	5.11a	4.0a	1.072ab	0.033a
B2K1	1.83ab	10.67c	0.223b	0.018c
B2K2	2.52ab	6d	0.451a	0.015c
B2K3	1.94ab	3.33a	0.040b	0.010d
B3K0	4.95a	3.67a	1.459ab	0.035a
B3K1	2.05ab	3.37a	0.364ab	0.010d
B3K2	1.87ab	2.67ab	0.028b	0.011d
B3K3	1.94ab	3.67a	0.060b	0.010d

Note: Values in the same column sharing the same letter are not significantly different at the 5% level (F-test).

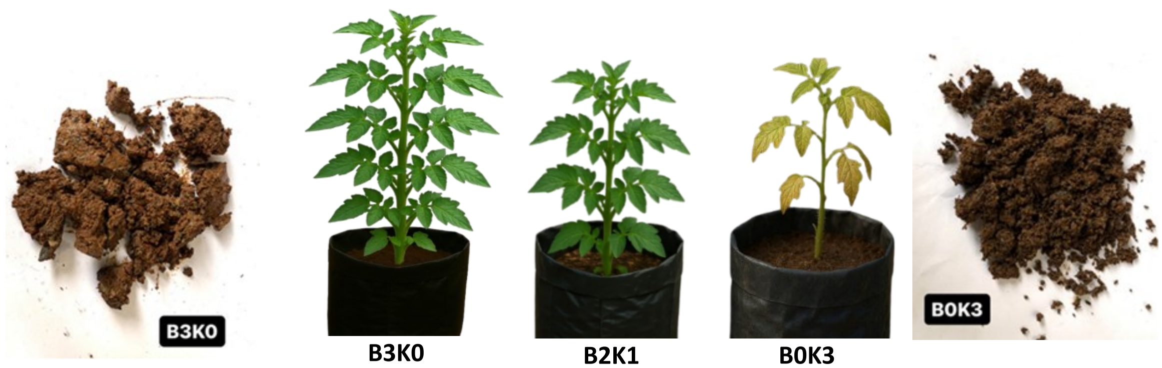
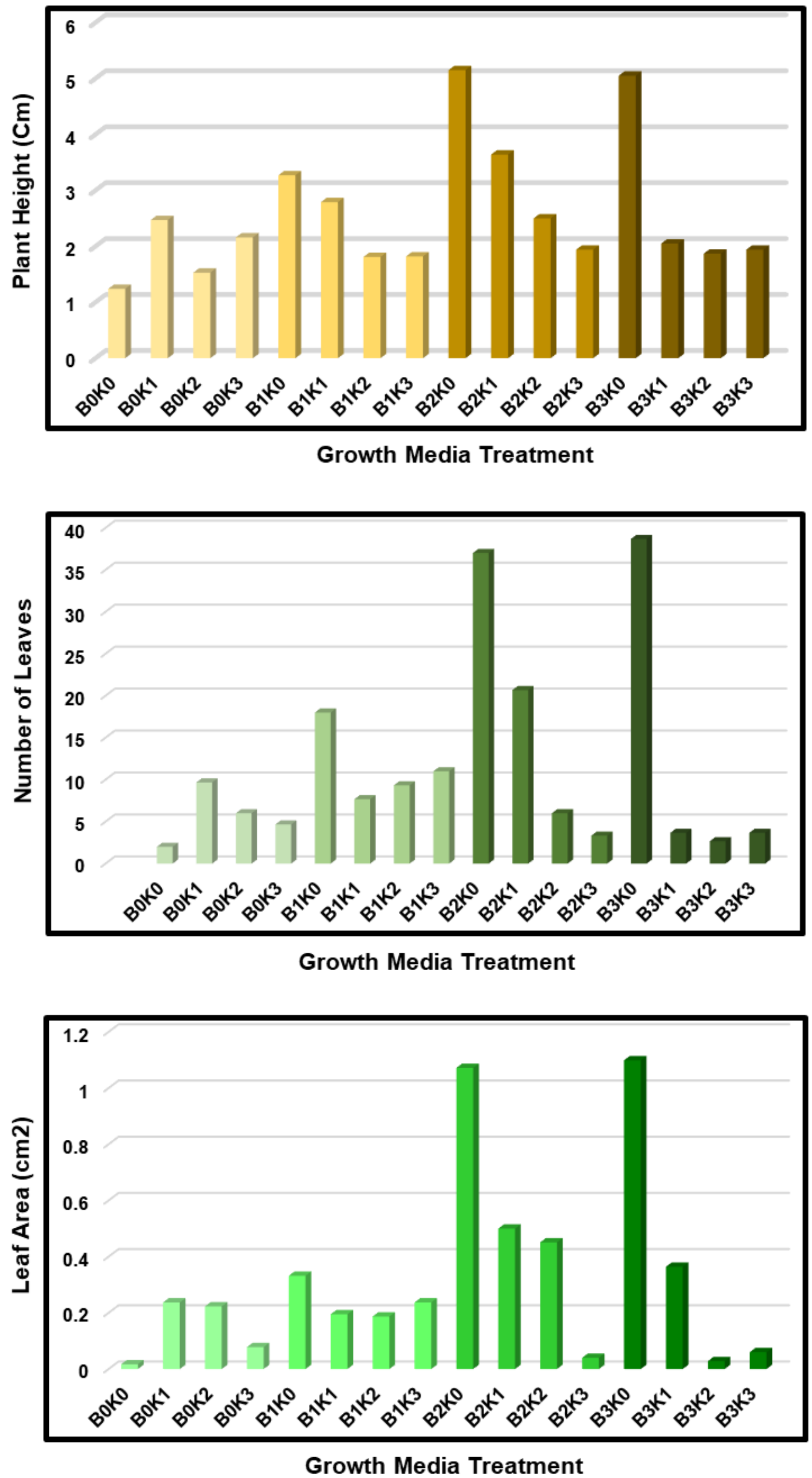


Fig. 1. At 40 days after planting, the tomato plants showed the best growth (left) in media B3K0 with 400 g baglog compost (B3), while the poorest growth (right) was observed in media B0K3 with 750 g biochar (K3). The best synergistic effect of 300 g baglog compost (B2) and 250 g biochar (K1) was observed in treatment B2K1, composition of 6% baglog compost and 5% biochar (center).

Figure 1 shows the best and worst media. The composition of the best media (B3K0) includes soil, sand, and addition of 400 g baglog compost (B3), while the composition of the worst media (B0K3) includes soil, sand, and addition of 750 g biochar (K3). The best synergistic effect of baglog compost and biochar was observed in treatment B2K1, a composition of 300 g (6%) baglog compost (B2) and 250 g (5%) biochar (K1). Figure 2 illustrates the synergistic interaction between baglog compost and biochar across varying dosage combinations.


Plant Height (Cm)
0
1
2
3
4
5
6
B0K0 B0K1 B0K2 B0K3 B1K0 B1K1 B1K2 B1K3 B2K0 B2K1 B2K2 B2K3 B3K0 B3K1 B3K2 B3K3
Growth Media Treatment
Number of Leaves
0
5
10
15
20
25
30
35
40
B0K0 B0K1 B0K2 B0K3 B1K0 B1K1 B1K2 B1K3 B2K0 B2K1 B2K2 B2K3 B3K0 B3K1 B3K2 B3K3
Growth Media Treatment
Leaf Area (cm2)
0
0.2
0.4
0.6
0.8
1
1.2
B0K0 B0K1 B0K2 B0K3 B1K0 B1K1 B1K2 B1K3 B2K0 B2K1 B2K2 B2K3 B3K0 B3K1 B3K2 B3K3
Growth Media Treatment

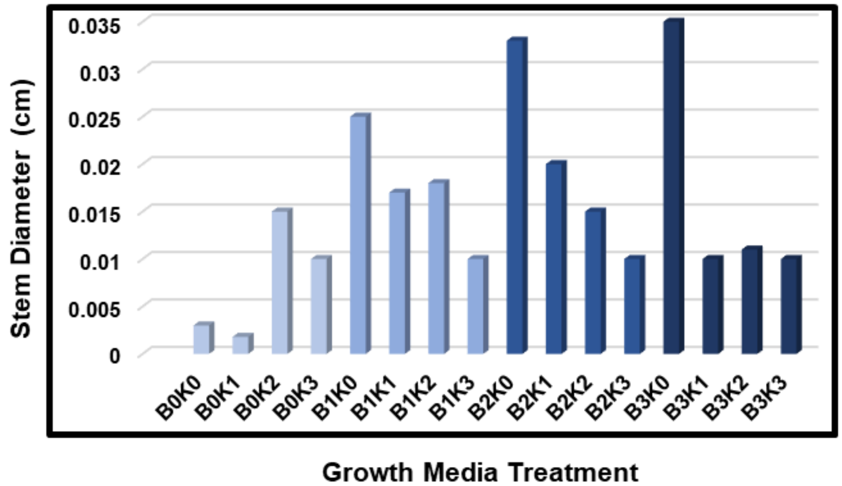


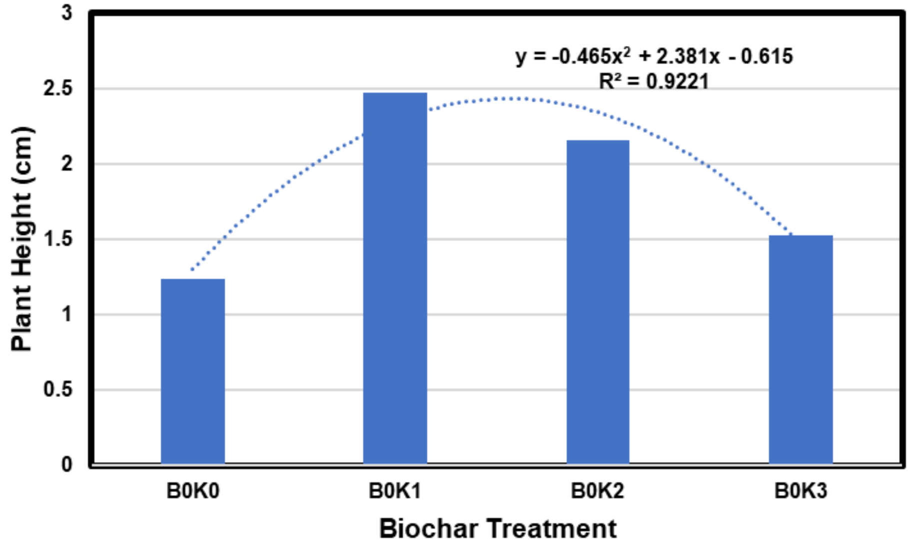
Fig. 2. Tomato growth performance on a growing medium composed of biochar and baglog compost, evaluated through plant height, number of leaves, leaf area, and stem diameter.

Tomato growth was significantly slower in the control media without biochar and baglog compost. The application of increasing doses of baglog compost alone resulted in improved plant growth. Notably, higher doses of biochar alone led to a rapid increase in tomato growth. However, when both biochar and baglog compost doses were increased simultaneously, tomato growth was inhibited.

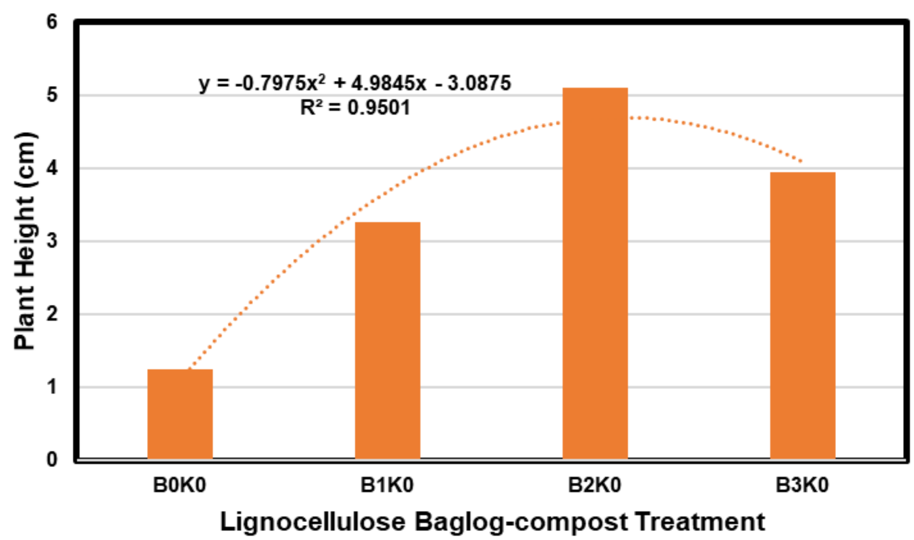
Figures 3a and 3b further illustrate tomato growth on media lacking both biochar and baglog compost. The difference that occurs in the two media can occur due to differences in composition, where the best media uses lignocellulose baglog compost while the worst media uses biochar. Biochar enhances soil structure but has a limited direct impact on soil fertility. This supports previous findings, which show that biochar can improve soil quality by improving soil structure and increasing water resistance (Ciptaningtyas *et al*. 2017).

Figure 3a illustrates the effect of biochar on tomato plant height at the age of 40 days after planting, showing that the best biochar dose is the second dose of 300 g/polybag (B0K1). Increasing the dose of biochar (B0K2 and B0K3) showed no increase in plant height. The equation of the chart shows Y=-07975X2+4.9845X-3.0875 and R2=0.9501. Figure 3b illustrates the effect of baglog compost treatment (B2K0) on tomato growth at the age of 40 days after planting. The results show that the best baglog compost treatment with the first dose is 250 g/polybag (B3K0). The increase in baglog compost application did not show an increase in plant height. The equation of the chart shows Y=-0.465X2+2.381X-0.615 and R2=0.9221. The graphs in both images show that the synergistic optimum dose for biochar is 300 g/5 kg polybag (6%), and the optimum dose for baglog compost is 250 g/5 kg polybag (5%).

Plants cannot grow with biochar alone without additional nutrients. Although biochar has benefits in improving soil quality, it generally does not provide essential nutrients needed by plants to grow optimally; therefore, the application of baglog compost can improve soil physical properties so that root growth becomes better (Prabowo *et al*. 2020). A well-developed root system will increase the rate of nutrient absorption by plants. Increased nutrient uptake can spur plant vegetative growth as indicated by the vegetative growth in terms of height and leaf production (Darwesh and Elshahawy 2023).



(a)



(b)

Fig. 3. The effect of (a) biochar treatment (K0, K1, K2, K3) and (b) lignocellulose baglog compost treatment (B0, B1, B2, B3) on plant height

The development of tomato plant cells for the process of plant height growth takes place continuously until the vegetative period ends, depending on hormones, assimilation results, favorable environmental factors, and other growth factors (Rahman 2014). The vegetative period ends, marked by the appearance of flowers on the plant. This is because the development of plant cells for vegetative growth has stopped and only focuses on generative growth (Xayitovna and Faxriddinovich 2023).

The height of the tomato plants increased every week. In the first and second week, there was no statistically significant variation observed in the height of tomato plants, while in the third week to the seventh week, there was a substantial difference in the height of tomato plants. This is because the availability of N nutrients can still be absorbed well by the roots (Ikram *et al*. 2024). During the first week, plant height showed minimal growth. From the second to the fifth week, a steady increase in plant height was observed, followed by a decline in growth from the sixth to the seventh week. This decrease in plant height occurred because the plants had flowered and had begun to enter the generative period (Suharjo *et al*. 2018).

For example, the application of baglog compost significantly enhanced the yield of several local purple sweet potato genotypes, with the optimal compost dosage determined to be 30 tons per hectare (Prasetyo *et al.* 2023). Besides solid organic fertilizers like baglog compost, liquid organic fertilizers derived from industrial waste, such as palm oil mill effluent (POME), tested with microalgae by Handayani *et al.* (2024), can also be utilized. Tomato plants can grow in areas with an altitude range of 1,000 to 1,250 meters above sea level, but there are LV and CLN varieties and even F1 gem varieties that can grow in the lowlands with a range of 0 to 400 meters above sea level (Narmanova *et al*. 2023). The optimal temperature range for tomato growth is 24 to 28 °C, which typically promotes uniform red pigmentation in the fruit. In contrast, temperatures exceeding 32 °C have been associated with the development of yellowish coloration. Tomatoes require loose soil, pH 5 to 6, soil containing little sand, and regular and sufficient irrigation. For optimal growth, tomato plants need a relative humidity of 80% and an average of 10 to 12 hours of sunlight per day (Malik *et al*. 2022).

Suitable rainfall for tomato plants is 750 to 1,250 mm/year; this is closely related to soil water availability, especially in areas where irrigation techniques are not available. High rainfall can also inhibit growth. Soil that contains a lot of organic matter will spur the vegetative growth of plants to increase crop yields (Ciptaningtyas *et al*. 2017). Tomato plant growth is determined by the interaction between genetic and environmental influences, which it experiences during growth and fruit formation (Mubarok *et al*. 2023).

Photosynthesis Rate

The photosynthetic rate of tomato plants was influenced by several environmental factors, including light intensity, CO_2 concentration, temperature, and humidity. The results showed that photosynthetic activity increased with rising light intensity up to a certain threshold, beyond which it plateaued, indicating light saturation. This is consistent with previous studies that report maximum photosynthetic efficiency in tomato plants occurring around 800 to 1000 μmol photons m^{-2} s^{-1}, after which the rate levels off due to the saturation of the photosystems. Zheng *et al.* (2023) found that under optimal greenhouse conditions, tomato plants had a net photosynthesis rate of 20 to 25 μmol CO_2 m^{-2} s^{-1}.

Additionally, elevated CO_2 concentrations enhanced the photosynthetic rate, as expected. CO_2 is a key substrate in the Calvin cycle, and increasing its availability accelerates carboxylation activity, thereby improving carbon assimilation. However, at very high concentrations, the increase in photosynthetic rate was marginal, suggesting a limitation due to other factors such as enzyme activity or stomatal conductance. Temperature also played a critical role (Moratiel *et al*. 2023). The optimal temperature range for tomato photosynthesis was 25 to 30 °C. At temperatures below or above this range, a decline in the photosynthetic rate was observed, likely due to the denaturation of photosynthetic enzymes and altered stomatal behavior (Villagran *et al*. 2025). Stomatal conductance correlated strongly with photosynthetic rate, indicating that gas exchange is a major regulatory factor. Under high humidity, stomata remained more open, promoting CO_2 uptake. Conversely, under lower humidity or water stress, stomatal closure limits gas exchange, reducing photosynthesis (Bertolino *et al*. 2019). Chlorophyll content was also positively correlated with photosynthetic performance. Plants with higher chlorophyll indices showed greater photosynthetic rates, supporting the importance of pigment density in light absorption efficiency (Yan *et al*. 2024).

This study showed a photosynthetic rate of 11.79-13.32 µmol CO_2 m^{-2} s^{-1} (Table 3). This figure is still too low for a good photosynthesis rate, because according to Xiaolong *et al.* (2018), optimum photosynthesis rate for a healthy, well-grown tomato plant typically falls within the range of 15 to 30 µmol CO_2 m^{-2} s^{-1}. Under these ideal conditions, tomato leaves can reach 25 to 30 µmol CO_2 m^{-2} s^{-1} during peak midday light. Lower rates occur in the early morning, on cloudy days, or under stressful water, nutrient, and temperature conditions. Overall, the findings of this study highlight the complex interplay between environmental factors in determining the photosynthetic performance of tomato plants. The results suggest that optimizing conditions such as light, temperature, and CO_2 levels can significantly enhance tomato productivity, especially in controlled environments like greenhouses.

Table 3. Chlorophyll a and b Content in Tomato Leaves (µg/mL)

Treatment	Chlorophyll Content (µg/mL)		Chlorophyll Total (µg/mL)	Nitrogen (%)	Photosynthesis rate (µmol CO_2 m^{-2} s^{-1})
	Chlorophyll a	Chlorophyll b			
B2K0	0.81101± 0.0001	0.32195 ± 0.0000158	1.11326 ± 0.0000192	1.5501 ± 0.0001581	13.13 ± 0.01581
B2K1	0.81071± 0.0000396	0.32141 ± 0.0000130	1.13185 ± 0.0000158	1.5509 ± 0.0001581	13.32 ± 0.02739
B3K0	0.71696 ± 0.0000158	0.26264 ± 0.0000209	0.97937 ± 0.0000234	1.5441 ± 0.0001916	11.79 ± 0.01483
B3K1	0.71742 ± 0.0000148	0.26182 ± 0.0000139	0.97901 ± 0.0000192	1.5441 ± 0.0001581	11.79 ± 0.02074

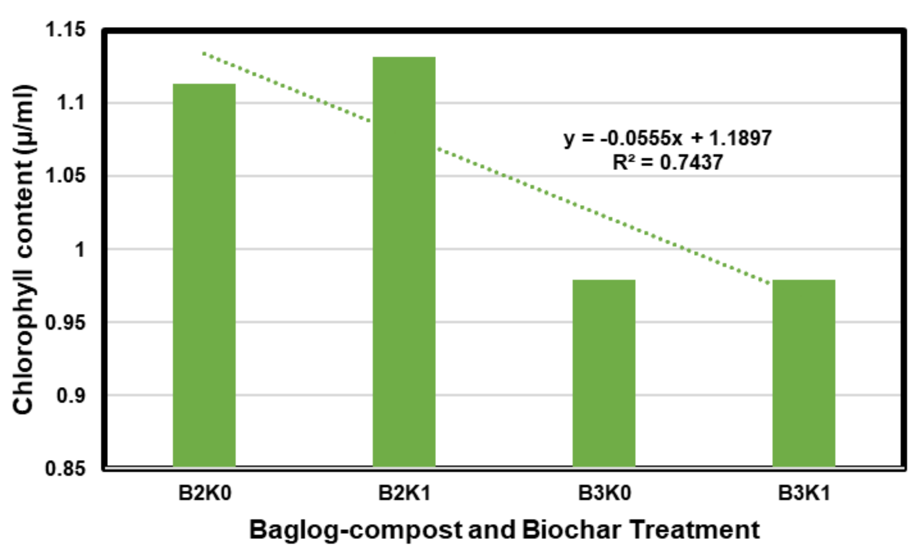


Fig. 4. Effect of lignocellulose baglog compost treatment on chlorophyll content

As shown in Table 2 and Fig. 4, chlorophyll content was higher in the B2K0 treatment compared to the B3K0 treatment. The difference in chlorophyll content in these plants is due to the presence of other pigment levels in the leaves that are more dominant or caused by adaptation factors in a plant. This can be seen in the color of the leaves of the B2K0 treatment being light green, so the chlorophyll content is higher than the B3K0 treatment. The surface area of the leaf will also maximize the capture of light energy for photosynthesis, normally in low light-intensity conditions (Hu *et al.* 2025).

The high photosynthesis process in tomato plants will produce a higher number of leaves. The highest photosynthetic rates were observed in the B2K1 treatment with the optimum doses of baglog compost (B2) 300 g/polybag (6%) and biochar (K1) 250 g/polybag (5%), the highest number of leaves, plant height, and stem diameter. Leaf characteristics are emphasized due to their direct role in chlorophyll production (Narmanova *et al.* 2023), which is critical for the photosynthetic process (Singh *et al.* 2023). The high and low leaf area produced is related to the intensity of sunlight that can be absorbed by plants. (Metsoviti *et al.* 2020).

Leaf area is one of the results of the photosynthesis process. The high photosynthesis process is affected by the content of the amount of chlorophyll in the leaves. The content of macro elements such as N, P, and K in plants is the main constituent factor of chlorophyll. If the chlorophyll content in the leaves is low, the photosynthesis process runs slowly, so the food reserves produced are small. The low food reserves produced from the photosynthesis process inhibit the process of cell division and elongation in the plant body, which causes the formation of plant organs, especially the leaf area, to be inhibited (Qian *et al*. 2021).

Factors that affect chlorophyll content in a plant are plant age, leaf morphology, and genetic factors (Arifin *et al*. 2022). Chlorophyll content is influenced by both leaf age and the plant's physiological stage (Xie *et al*. 2025). Each species of the same age has a different chemical content with a different number of genomes1. This results in different metabolisms related to the number of substrates and metabolic enzymes. Chlorophyll distribution in leaves varies, one of which is influenced by leaf color. The greener the leaf color, the higher the chlorophyll content (Calderón *et al.* 2015).

Inhibitory Factors Affecting Tomato Growth

The growth of tomato plants grown in media containing baglog compost and biochar appears slower than those grown in media containing only baglog compost. Figure 5 presents nutrient absorption by a tomato planted in medium based on biochar and compost baglog. The illustration demonstrates how the combined use of lignocellulosic baglog compost and biochar improves nutrient and soil structure availability in the root zone. However, not all nutrients were taken up by the plants, as biochar absorbed nutrients and water from the baglog compost. As a result, this study found that tomato plants did not grow well in media with excessively high doses of biochar. This supports healthier growth and more efficient use of soil amendments. To better understand the influence of substrate characteristics on tomato growth, a systematic analysis of soil physicochemical properties was conducted and is summarized in Tables 4 and 5.

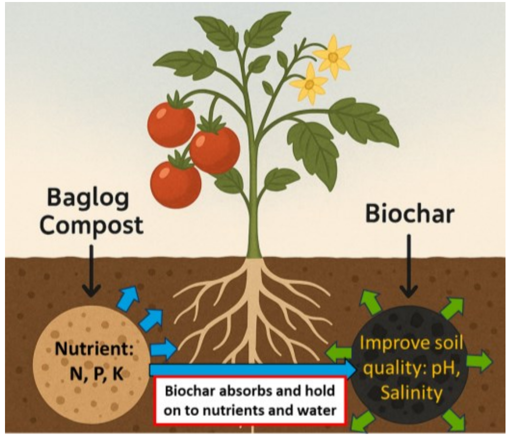


Fig. 5. The illustration of tomato plant growth using nutrients of lignocellulose baglog compost and the role of biochar in enhancing soil quality. However, not all nutrients were taken up by the plants, as biochar absorbed nutrients and water from the baglog compost

Table 4. Result of Growing Media Analysis

Sample	pH		Organic Materials		
	H_2O (%)	KCl (%)	C (%)	N (%)	C/N (%)
Sand	6.8	5.4	0.08	0.01	10
Soil	6.6	5.5	1.25	0.11	11
Baglog compost	9	7.5	47.70	1.59	30
B3K0	8.1	7.7	1.1	0.1	11
B0K3	8	7.2	16.67	0.57	29

The C/N contained in the compost illustrates the level of maturity of the compost; the higher the C/N, means that the compost has not decomposed completely or, in other words, is not mature. In the fermentation of baglog compost, the C/N is 31, which means that fermentation has not been completed because the minimum standard is <25. This is supported by Putri *et al.* (2022) that baglog compost is used to improve the physical properties of the soil, namely providing nutrients and reducing soil density and soil airspace. However, plant growth is still not optimal because some plants that use baglog compost do not thrive and even die. The failure factor of baglog waste compost can be caused by the incomplete fermentation process, which can cause plants to die because it contains harmful compounds or even pathogens (Gazali *et al*. 2022). The composting period of baglog waste takes 1 month. This is the main cause of the failure of the fermentation process because the process is only carried out for 14 days. Composting time affects the C/N ratio; the longer the composting process, the percentage of the C/N ratio in the compost. In addition, unbalanced nutrient composition, raw material size, and moisture content are factors in the success of the composting process (Hunaepi *et al*. 2018).

When the plants were 30 days after planting, the content of N nutrients in the soil began to decrease because N nutrients have been absorbed by tomato plants for the vegetative growth process, especially in the formation of stems, leaves, and the number of branches. This is the cause of the reduction of nitrogen elements in plants (Amalia and Fajri 2020).

Table 5. Macro and Micro Nutrients of Growing Media

Sample	HCL 25%		Totally (HNO_3)		
	P_2O_5 (%)	K_2O (%)	MgO (%)	Fe (%)	Zn (ppm)
Sand	44	13	0.08	1.16	18
Soil	246	9	0.1	8.67	136
Baglog compost	0.7	0.94	0.5	337.2	46.2
B3K0	164	47	0.14	3.84	126
B0K3	0.03	0.11	0.15	390.9	34.5

Phosphorus plays a role in root growth because it improves the root structure, so that the plant's absorption of nutrients becomes better. Plants that experience phosphorus deficiency have the characteristics of old leaves, brown leaf edges, small, growth-inhibited leaf growth, and abscission. The symptoms of the deficiency are in Fig. 1. This supports the results of the planting media analysis in Table 4. The sample with B0K3 contains 0.03% Phosphorus, which, according to the Indonesian Minister of Agriculture regulation, should be at least 2.21% (Table 5).

Excess phosphorus causes the absorption of other elements, such as iron (Fe) and zinc (Zn) to be impaired. However, the symptoms are not physically visible on the plant. The amount of phosphorus of B3K0 is 164% (Table 5), where the minimum standard is 2%. This affects the two elements, where each element, such as Fe, is 3.84% and Zn is 126%, because the minimum standard of the two elements is <15,000% in Fe and <5,000% in Zn (Paolo *et al*. 2018).

Potassium plays a role as a regulator of plant physiological processes such as photosynthesis, accumulation, translocation, and carbohydrate transportation. Potassium is closely related to magnesium. There is antagonism between the two elements. This causes the defeat of one element to be absorbed by plants if the composition is not balanced. Potassium is absorbed faster by plants than magnesium. In B3KO media, the potassium contained is 47% with a minimum standard of 2%, while in magnesium, it is 0.14% (Table 5). This causes disruption of absorption by magnesium. However, in B0K3 media, the potassium contained is only 0.11, where the plant experiences potassium deficiency, which is characterized by leaf characteristics such as burning to fall, leaves rolling down, and disease susceptibility (Xie *et al*. 2025).

Biochar derived from food waste and baglog compost is utilized for organic farming. The utilization of these wastes is a contribution to the low-carbon program. Evaluation of the current waste management system is focused on increasing reduction and recycling, which will improve the balance in achieving a recycling-oriented society and a low-carbon society (Chotimah *et al*. 2020).

Biochar from food waste in this study can improve the physical, chemical, and biological properties of soil to increase plant growth. The addition of biochar as a soil improver has promise—to support sustainable agriculture or improve the quality/productivity of land. Biochar has characteristics that are resistant to decomposition, unlike manure, chicken composting, and other composts, so that its availability in the soil is relatively longer. In making biochar, molasses is appropriate for use as a binder to maintain moisture (Duarte *et al*. 2020). Lignocellulose in baglog compost can significantly influence crop growth when used as an amendment. If biochar and baglog compost are not properly combined, tomato growth may suffer. One significant problem with biochar is that it tends to absorb and retain water and nutrients, which reduces their availability to plants, particularly when it is raw or uncharged.

Deficits, especially in nitrogen, which is necessary for tomato growth, may result from this nutrient immobilization (Calcan *et al.* 2022).

Furthermore, biochar has an alkaline pH, which might cause the growing medium's total pH to rise above what tomatoes prefer when added in significant quantities. Because tomatoes prefer slightly acidic to neutral environments (pH 5.5 to 6.8), this pH imbalance may hinder their ability to absorb important micronutrients, including phosphorus, manganese, and iron (Mwangi *et al*. 2024). If baglog compost has been incompletely broken down, it may still contain ammonia, phenolic chemicals, or other phytotoxins from the mushroom growing process. Certain compounds may harm tomato roots, particularly in early plants. Additionally, combining biochar with immature backlog compost may upset the soil's microbial equilibrium, favoring dangerous microorganisms while inhibiting good ones (Guo *et al*. 2021).

The tomato plant may become even more deficient in vital nutrients as a result of soil bacteria using up available nitrogen during decomposition due to the mix's high carbon-to-nitrogen (C/N) ratio. Finally, water may drain too quickly if the mix's physical texture is too porous (from too much biochar), creating dry conditions surrounding the roots (Sultana *et al*. 2024). Together, these factors, nutrient lock-up, pH imbalance, toxicity, microbial disruption, and poor water retention, can significantly inhibit root development and stunt tomato plant growth if the biochar and baglog compost are not properly prepared or balanced in the mix.

Recommendation

Agriculture is one of the important sectors in building food security that requires technological support to maximize its results. Various technological support is applied by many countries in every agricultural process, such as in the process of irrigation, seeding, fertilization, to harvesting. Biochar has an important role in the agricultural sector because of its ability to restore soil from critical soil, so it can be applied in smart farming programs (Ayundyahrini *et al*. 2023).

It is crucial to properly balance the usage of compost formed from mushroom substrate (baglog) waste with biochar to promote good tomato growth. Since raw biochar can lock up nutrients and raise soil pH, it should only be used in modest amounts, ideally no more than 300g/5kg (6%) of the whole growth medium by volume. Pre-treating or activating the biochar by soaking it in organic liquid fertilizer or composting it with other materials for a few weeks before use is the best way to prevent this. In contrast, 20 to 40% of the mix should consist of baglog compost. This compost must be well-aged and completely digested. It can produce toxic compounds like ammonia and upset the soil's microbial balance if it is utilized fresh or immature. Ensuring that it supplies advantageous nutrients and bacteria to the growing media requires letting it ferment or mature appropriately.

Good quality topsoil or garden soil should make up at least 50% of the medium. To help with drainage and moisture retention, it may be combined with sand, rice husk charcoal, or cocopeat. Make sure the mix's final pH is between 5.5 and 6.8, which is optimal for tomatoes, for the best outcomes. Early detection of any nutritional imbalances or deficiencies can be facilitated by routinely monitoring plant growth and leaf color. During the growing season, organic liquid fertilizers can be used to provide extra support if necessary.

Utilization of waste to increase agricultural production is a sustainable economic system. The ability of biochar to improve agricultural systems shows sustainability in handling environmental problems. Sustainable development refers to the ability to fulfill human needs through economic progress while minimizing environmental harm. In terms of production, this involves reducing the extraction of non-renewable resources and limiting waste discharge into nature, aiming for low-waste or zero-waste technologies, although achieving this within a single enterprise's production cycle can be challenging (Zhumadilova and Zhigitova 2023).

Carbon-enriched biochar promotes the growth of native microbes by neutralizing pH and providing nutritional support.

CONCLUSIONS

1. Based on the study's findings, the proposed hypothesis was not supported. The results can be concluded that the individual application of lignocellulosic baglog compost significantly enhanced tomato plant growth, in contrast to the application of biochar without baglog compost, which showed lower growth indices. Biochar improves soil structure but has a limited direct effect on soil fertility, as excessive application can suppress plant growth by adsorbing nutrients from baglog compost, thereby reducing their availability to plants.
2. Optimal tomato plant growth was achieved with the synergistic application (B2K1) of baglog compost (B2) at 300 g (5%) and biochar (K1) at 250 g (6%). This treatment shows a balanced dose, resulting in enhanced photosynthetic activity, which correlates with an increased number of leaves, plant height, and stem diameter, supporting optimal plant development.
3. The application of biochar and baglog compost has proven effective in improving soil quality and enhancing the vegetative growth of tomato plants in sub-optimal growing conditions when using optimal doses. The study demonstrated that lignocellulosic baglog compost significantly influenced key growth parameters, including plant height, number of leaves, stem diameter, and leaf area. These findings highlight the potential of integrating biochar and lignocellulosic baglog compost as a sustainable alternative to chemical fertilizers, contributing to increased agricultural productivity while supporting environmental preservation in Indonesia.

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