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Improving The Growth and Yield of Pak Choy (*Brassica chinensis* L.) Using Cacao Pod Husk Biochar

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Abstract—**This work aimed to assess the influence of cacao pod husk biochar treatments combined with the urea fertilizer addition on the growth and yield of pak choy (*Brassica chinensis* L.). The study used pot trials in a completely randomized design with two factors. The first was the addition of biochar from cacao pod husk, which consisted of 4 levels, namely 0, 62, 125, and 187 g/pot. The second factor was the dosage of urea addition with 4 levels, namely 0, 0.46, 0.93, and 1.40 g/pot. Pak choy was planted in triplicate polybags. Plant parameters included plant height, number of leaves, canopy cover area, fresh yield, water consumption, and water productivity. The results exhibited that adding biochar was significant in terms of parameters. Low dose biochar (62 g/pot) increased plant height, number of leaves, and water productivity, whereas high dose (125 to 187 g/pot) negatively affected pak choy growth and yield. The addition of urea is significant, except for pH and number of leaves. A fertilizer dose of up to 1.40 g/pot positively affected plant growth and yield of the pak choy. The most optimal interaction of the two factors occurred at a biochar dose of 62 g/pot and urea dose of 1.40 g/pot, which produced a maximum crop fresh yield of 111.83 g/plant. This research concluded that biochar from pyrolysis of cacao pod husk can be employed as soil amendment during pak choy cultivation but with controlled doses.**

Keywords—**Biochar; cacao pod husk; crop yield; pak choy; plant growth.**

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I. INTRODUCTION

Pak choy (*Brassica rapa* L. *chinensis*) is locally called *sawi pakcoy*. It is a healthy green mustard vegetable that is good for human health. In each 100 g eatable material, the nutritional value of Pak choy is 65 kJ of energy, 0.2% fat, 2.5% carbohydrates, 1.2% protein, 0.5% fiber, 4.9‰ Ca, 0.7 mg Fe, 38 mg vitamin C, 0.9 mg vitamin A, and 95 g water [1]. Pak choy is also rich in glucosinolates, precursor metabolites that can be anti-cancer [2]. Several types of mustard are currently quite popular and widely consumed, including green mustard, pak choy, and white mustard or chicory. Pak choy is characterized by a thicker stem and broader leaves, which makes this mustard used every so often in various processed dishes. Therefore, of the three types of mustard, pak choy is the most widely cultivated today. The market demand for vegetables in Indonesia, especially pak choy, constantly increases. This is reflected in the harvested area of pak choy, which continuously increased from 60,871 ha in 2019 to 71,085 ha in 2022, with production of 652,723 tons to 727,467 tons [3]. In the same period, the harvesting area of pak choy in Lampung Province slightly decreased from 1,329 ha in 2019 to 1,305 ha in 2021. However, the production increased by 11.8% from 9,095 tons in 2019 to 10,180 tons in 2021 [4].

In Southeast Asia, including Indonesia, pak choy can be well cultivated throughout the year [5], both in the highlands and lowlands. It is best cultured in areas with temperatures 18 – 20 C, although it can tolerate up to 35 °C [6]. Good soil for cultivating mustard plants is characterized by having a loose texture, rich in humus, fertile, and good drainage. The soil pH tends to be neutral, which is ideal for the optimum growth of pak choy [7]. Pak choy can be cultivated in large fields or narrow areas using pots, polybags, and hydroponic technology.

One of the obstacles to cultivating vegetables in Lampung is infertile, acidic ultisol soil. Some problems encountered in this soil are low soil pH (< 5), low organic matter content, high exchangeable Al, low level of essential macronutrients, some micronutrients in toxic amounts, low soil cation exchange capacity (CEC), and sensitivity to erosion [8].

Biochar is a good material for improving the quality of infertile soils, such as ultisol, which is widely spread in Lampung. Biochar is a previous material rich in organic carbon manufactured via the pyrolysis method under conditions of no or with minimal oxygen, which avoids combustion [9]. Pyrolysis converts biomass into a durable form of carbon (C), which can be employed as a soil conditioner [10]. Biochar has porous characteristics, a large specific surface area, and a remarkable ability to absorb nutrients, making it a good place for microorganisms to grow and multiply in the soil. Research on the usage of biochar for soil improvement has increased dramatically in the last few decades [11].

Materials commonly used to manufacture biochar are agricultural or forestry wastes, including wood chips, coconut shells, rice husks, cacao pods, oil palm bunches, wood residues, corn cobs, and other recycled organic materials. Unlike biomass materials, biochar consists of more stable carbon that is difficult to decompose [12] and vanishes in a very extended time in the soil [13], [14]. Geng (2022) revealed that using biochar in acid soils raises soil pH and declines exchangeable Al [15].

The properties of biochar are governed by the method of production and the raw materials used [15], such as wood, plantation, and animal wastes. As one of the world's third largest cacao (Theobroma cacao L.) producers, Indonesia is rich in cacao pod husk biomass that can be potentially explored as biochar feedstock. Cacao pod husk is the most significant part of the cacao fruit, comprising 60-76% of the wet pod, implying that every ton of dry cacao bean produces around 10-ton pod husk [16], [17], [18], [19]. So far, cacao pod husks have not been used optimally, and most of them are still handled minimally by only stockpiling in holes [20]. The waste becomes a severe problem, which causes significant inoculum disease when used as compost for plants [17], while the theobromine content is toxic when used as animal feed [21]. Better management should be applied to explore the economic potential of cacao pod waste [22]. Cacao pods have high minerals such as calcium and potassium so that they can be used as a source of K in the soil [23]. Consequently, it is essential to find a more efficient way of utilizing cacao pod husks by converting them into biochar. As far as authors know, the interaction of a cacao pod husk biochar and urea addition has not been studied extensively for pak choy cultivation. This study aims to assess the influences of cacao pod husk biochar and urea addition on the growth and yield of pak choy.

II. MATERIAL AND METHOD

A. Location and Materials

This research was carried out in a greenhouse facility of the Integrated Field Lab., Faculty of Agriculture, the University of Lampung (UNILA). Materials used in this study consisted of soil, biochar, and pak choy seeds. Infertile ultisol soil taken from the Integrated Field Lab. was collected from the subsoil layer after removing the topsoil. The use of low-fertility soil aimed to obtain a more real treatment effect. The soil was dried naturally for 5-7 days by spreading on the plastic mat and then ground and screened using a 5 mm soil sieve. Soil characteristics were analyzed at the Laboratory of Soil Science, Agricultural Faculty, UNILA. The soil properties have been reported in our previous work [24]. The soil used in this study had low nutrients (Table I) with N-total of 0.04% (very low), P-available of 11.85 ppm (low), exchangeable K of 0.09 (very low), C-organic 0.385% (very low), and soil pH of 5 (acid). This implied that the soil used as a growing medium is infertile.

TABLE I
CHARACTERISTICS OF ULTISOL SOIL USED IN THE STUDY [24]

Parameters	Unit	Value
N-Total	%	0.04
C-Organic	%	0.38
K-exchangeable	me/100g	0.09
P-available	ppm	11.85
pH	--	5

Biochar was made from dried cacao pods from a Central Lampung farmer. Cacao pods were pyrolyzed in a closed container heated for 1.5 hours. The resulting biochar has an ash content of 36.93% and an essential property with a pH of 9.7. The biochar was pulverized and then screened using a sieve of 0.9 mm (20 mesh). Fine biochar was mixed evenly with the soil. Pak choy seeds, purchased from the local farm kiosk, were seeded by spreading over a mixture of soil and compost for two weeks until 2-3 true leaves appeared. Good seedlings were selected and transferred into the prepared polybags sized 20×20 cm.

B. Experimental Design

This study was arranged in a factorial, completely randomized design with two factors and three replications. The first was biochar with four levels, namely B0 (without biochar), B1 (62 g/pot ≈ 2%), B2 (125 g/pot ≈ 4%), and B3 (187 g/pot ≈ 6%). The second factor was urea dosage with four levels, namely U0 (without fertilizer), U1 (0.46 g/pot), U2 (0.93 g/pot), and U3 (1,40 g/pot). Urea (46% N) was purchased from a local supplier. Pak choy planting was carried out in black polybags of 20×20 cm filled with 3000 g of prepared growing media.

C. Observation and Measurement

The ash content was quantified by burning biochar sample in a Muffle Furnace (FB 1410-M33) at 550 °C for two h. Ash content (AC) was calculated as the following:

$$AC = 100\% \times (Ash/dry\ sample) \quad (1)$$

The pH (biochar, initial soil, and soil after harvest) was measured using a pH meter indicator after the soil or biochar was mixed with distilled water. Consumption of irrigation water was measured every afternoon by weighing polybags containing plants, followed by giving irrigation water to return to initial conditions. Crop yield (*CY*) was measured at harvest (age 36 DAP). Water productivity (*WP*) was calculated from (*CY*) and total water consumption (*TWC*) as:

$$WP\ (g/L) = CY/TWC \quad (2)$$

Crop growth parameters, including number of leaves, plant height, and canopy area, were measured every four days. The canopy area was determined using an application, Canopy Cover Free, available on smartphones. The pot was equipped with a square frame of 60×60 $cm^{2,}$ which was installed at the level of the soil surface in the pot. The crop image was captured at such a height that the frame hit the edge of the smartphone screen. After the filtering process, the application automatically scans the picture, and the canopy area according to green leaf color will be displayed in % of the frame (Figure 1).

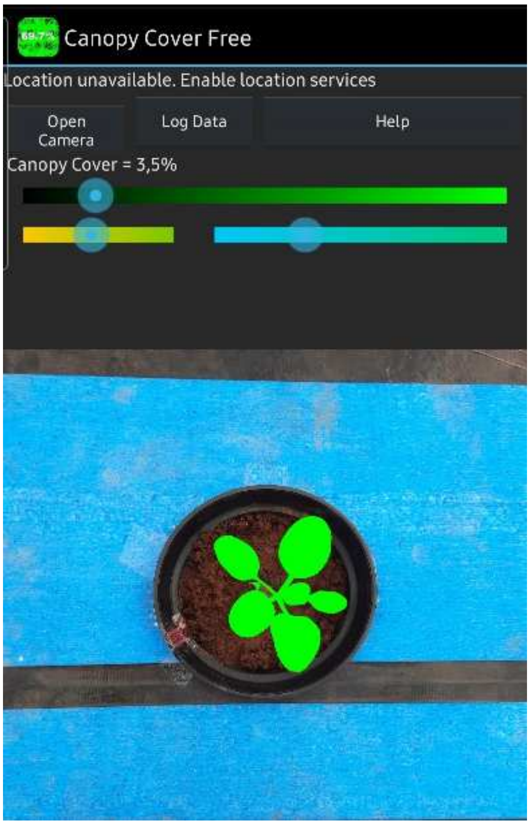

Fig. 1 Canopy Cover Free application to measure the canopy area

D. Data Analysis

Experiment data was analyzed using ANOVA to observe if the treatments were significant. The analysis was performed using SAS software version 9.13. If the treatment was significant ($p<0.05$), then the analysis was sustained with the LSD (least significant difference) test to see the differences among treatments at the level of $\alpha = 5\%$.

III. Results and Discussion

A. Ash Content of Biochar

Biochar mainly consists of carbon, so the main goal of biochar addition is to increase soil organic carbon. It was reported that cocoa pod husk biochar increased soil carbon by 215% for 7 days of incubation, from 1.12 (no treatment) to 3.53 mg/kg with an amendment rate of 80 g/kg [25]. Another essential characteristic of biochar about its function as a soil amendment is the ash content. Measurements show that cocoa pod husk biochar has a high ash content, reaching 36.93%. This is by the study of [26] that reported cacao pod husk biochar contains ash of 33.67%. Ash is the remaining part of the material from complete combustion. The ash component of biomass charcoal contains several minerals such as potassium, sodium, calcium, magnesium, etc. Therefore, the ash content of biochar is closely related to its pH. The measurement results show that the cocoa pod husk biochar is very alkaline, with a pH value of 9.70. Cacao pod has a near-neutral pH of 6.25 [22], but once converted to biochar, it becomes highly alkaline due to the high content of alkali (potassium) and alkaline earth (calcium) metals. Biochar from cacao pod husks pyrolyzed at 350 °C contained $CaCO_3$eq 10.1% and an acid-neutralizing capacity of 198.1 mmol/kg [25]. The high pH value agrees with the findings of other studies where the pH of cacao pod husk biochar was reported to be higher than 9 [25], [27]. Another study reported cacao pod husks pyrolyzed at 450 C have a pH value of 9.1, electrical conductivity (EC) of 998 (µS/cm), surface area of 0.18 m2/g, moisture of 4.83%, volatile matter of 23.11%, and fixed carbon 39.21% [26].

Our cocoa pod husk biochar has a relatively high-water content (12.41%, wet basis). This high-water content is related to the way it turns off the pyrolysis process, which is carried out by sprinkling (spraying) water. Biochar has a low bulk density, only 0.266 g/cm^3. The low bulk density causes biochar to have a strong tendency to float in the soil when watered.

B. Soil pH

Measurement of soil pH after harvest (Table II) showed a significant rise ($p = 0.000$) in soil alkalinity, especially in the treatment with the highest dose of biochar, namely 125 g/pot (B2) and 187 g/pot (B3). On the other hand, the dose of urea was not statistically significant in terms of soil pH. The dose of urea fertilizer was not statistically significant ($p = 0.102$) on the soil pH. Urea is a chemical fertilizer extensively used as a worthy source of nitrogen. With a chemical formula of $CO(NH_2)_2$, urea is a very slightly base fertilizer. In the soil, urea reacts to form bicarbonate and ammonium-N with a total effect that is just slightly acidifying. The continuous use of urea in the long term will result in the impact of soil acidification [28]. Recently, urea fertilizer application was reported to decrease soil pH in paddy fields [29]. The minor effect of urea on the soil pH in our study can result from the fact that the dose (0.49–1.40 g in 3000 g media) is substantially low as compared to the growing media (equivalent to 0.016–0.047%) and furthermore within the very short application.

The ultisol soil utilized in this trial was acidic and had a low pH of 5 (Table I). Meanwhile, cacao pod biochar had a pH of 9.7 (essential). Therefore, supplementing the biochar to ultisol soil (low pH) is the right step to increase soil pH value to neutral conditions. Vegetable crops like pak choy grow optimally with a soil pH of around 6.5 [30]. Measurement of soil pH after harvest (Table II) showed a significant increase in soil alkalinity, especially in the treatment with the high biochar dose (B3).

TABLE II
Effect of Cacao Pod Biochar and Urea on the Final Soil pH

Urea	Biochar				
	B0	**B1**	**B2**	**B3**	**Average**
U0	5.67	7.00	8.00	8.67	7.33
U1	6.33	6.33	9.33	10.33	8.08
U2	7.67	6.00	8.33	8.67	7.67
U3	5.67	6.67	8.00	8.33	7.17
Average	6.33^B	6.5^B	8.4^A	9^A	

Notes: Same letters mean no significant difference at $\alpha = 5\%$ of LSD test

The increase in soil pH due to the addition of cacao pod husk biochar is in line with other studies. Addition of cacao pod husk biochar pyrolyzed at 350 °C increased soil pH by

0.68, 1.27, 2.32 units respectively at doses of 20, 40, and 80 g/kg [25].

C. Plant Height

The application of biochar and urea fertilizer affects the development of pak choy plants. Figure 2 shows that the biochar implementation at 62 g/pot (B1) resulted in the best growth compared to other treatments. The results from ANOVA showed that the dose of cacao pod biochar affected significantly (p = 0.000) the plant height of pak choy at 8 DAP to 36 DAP. Cacao shell biochar utilization as soil amendment was reported to increase cayenne pepper grown in acid upland soil [31]. Application of other biochar as a soil amendment has been reported to positively improve yield in several crops, such as cauliflower [32], tomato [33], maize, okra and cassava [34], cowpea [35], cotton [36], lettuce [37], red chili [38], and corn [39]. Urea fertilizer dosage significantly affected ($p < 0.05$) on 28 DAP to 36 DAP. Meanwhile, the interaction of biochar dose and urea dose was not statistically different from the height of pak choy.

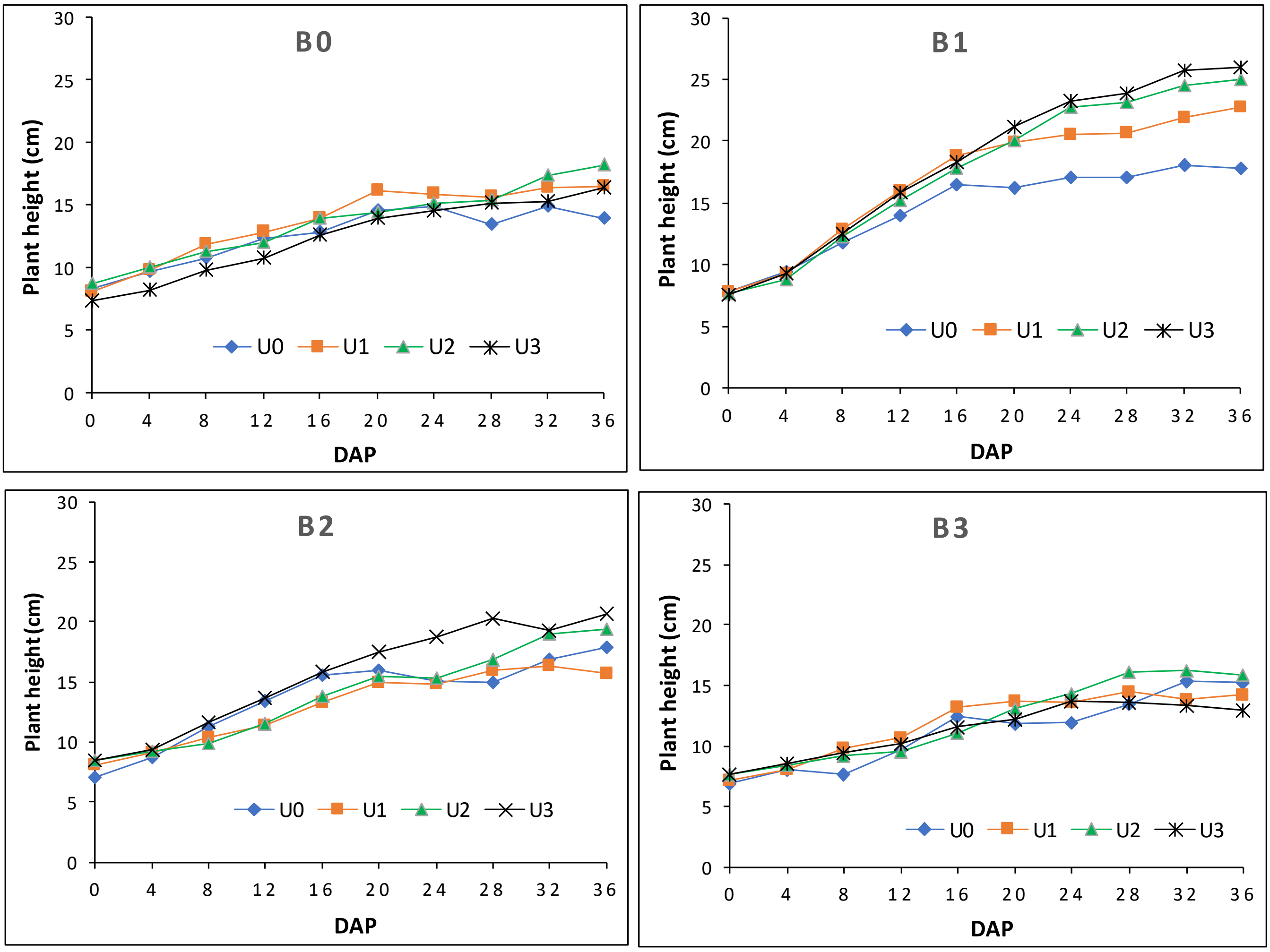

Fig. 2 Influence of biochar and urea dose on the plant height of pak choy up to 36 DAP. (Descriptions of B0 – B3 and U0 – U3 are in the Research Method)

Table III shows that treatment B1 (biochar 62 g/pot) resulted in an average plant height of 22.88 cm and was statistically higher than those of other doses (B2, B3, and B0). Increasing the dose of biochar to 125 g/pot (B2), however, resulted in a decrease in plant height (18.41 cm), and at a biochar dose of 187 g/pot (B3) resulted in the lowest plant growth (14.58 cm), which was lower than that of without biochar (16.23 cm) even though statistically are not different. This correlates to the increase in soil alkalinity caused by applying biochar, where the soil pH reached nine at high biochar doses, as shown in Table 2. The influence of biochar depends on the dose [40], and therefore, biochar must be applied in a correct dose to have an optimum effect on plant growth. This is by [41] where biochar application at 1% to 2% improves plant growth and suppresses Fusarium wilt, but at 3% increases disease in tomatoes. The negative effect of biochar at high doses can be attributed to the increase of soil pH, as mentioned. Based on these results, adding cacao pod biochar at a dose of 62 g/pot (2%) is recommended.

Table III also shows that urea fertilizer dose significantly ($p = 0.02$) increased plant height. At a dose of U1 (0.46 g/pot), the height of pak choy plants still did not show a significant increase compared to the treatment without urea fertilizer. A urea dose of U2 (0.93 g/pot) resulted in the highest plant height. This implies urea can meet the nutritional needs required during plant vegetative growth. This is to the findings of another study that applied 352 g N per plant, which resulted in the highest yield compared to higher N-dose treatments [42]. However, increasing the urea dose to 1.40

g/pot tends to decrease plant height, although it is not statistically different from a urea dose of 0.93 g/pot.

TABLE III
EFFECT OF BIOCHAR AND UREA ON PLANT HEIGHT (CM) AT 36 DAP

Urea	Biochar				
	B0	B1	B2	B3	Average
U0	13.90	17.77	17.93	15.23	16.21^{c}
U1	16.43	22.77	15.67	14.27	17.28^{bc}
U2	18.20	25.00	19.40	15.83	19.61^{a}
U3	16.40	26.00	20.63	13.00	19.01^{ab}
Average	16.23^{C}	22.88^{A}	18.41^{B}	14.58^{C}	

Notes: Same letters mean no significant difference at = 5% of the LSD test. Capital letters for rows (biochar) and lowercase for columns (urea dose).

D. *Number of Leaves*

The leaf development of pak choy is shown in Figure 3. We can see that applying biochar and urea fertilizer affects the development of pak choy leaves. Adding biochar at a dose of 62 g/pot (B2) resulted in the best growth compared to other doses. The number of leaves is closely related to the plant growth. Plants that experience instability in their development will produce fewer leaves than typical plants. Biochar and urea fertilizer should be applied in combination. The addition of urea without biochar did not make maximum effect. The application of biochar without urea fertilizer also resulted in suboptimal growth.

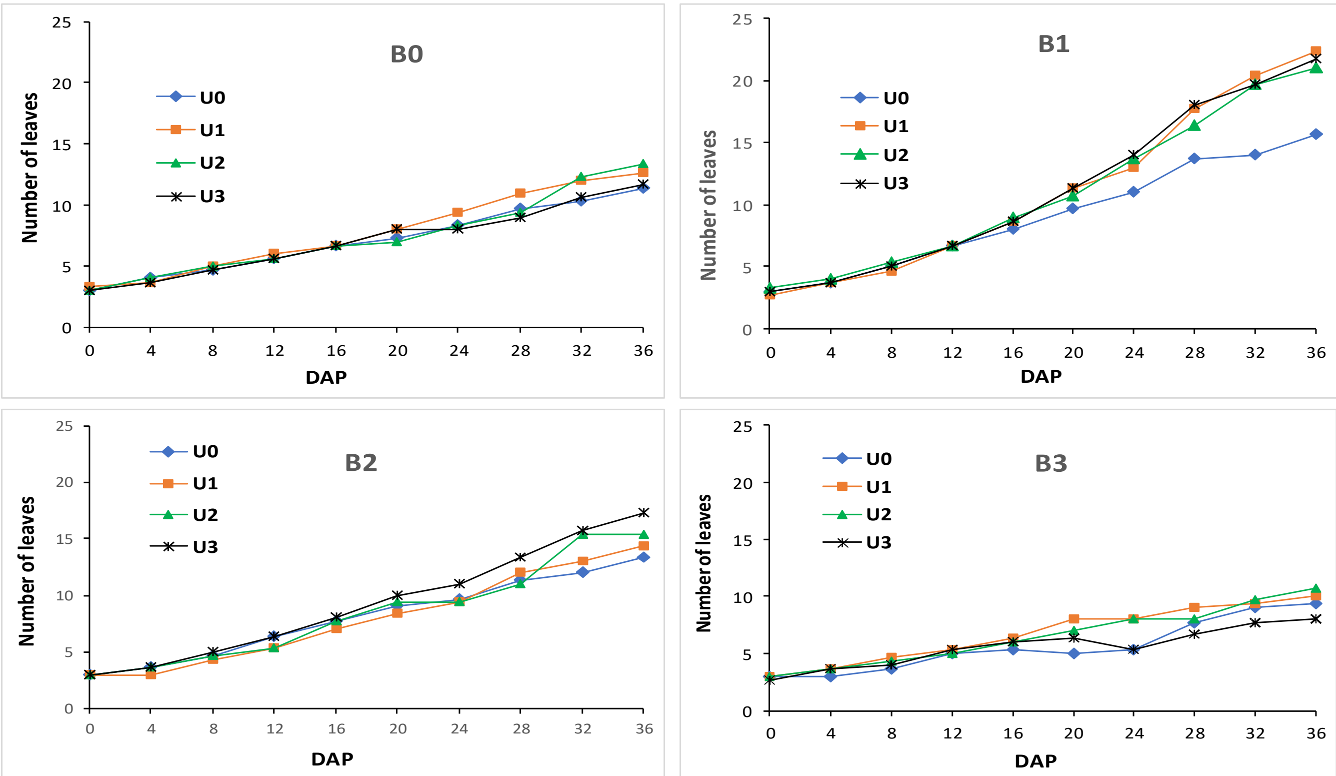

Fig. 3 Effect of biochar and urea fertilizer on the development of the number of leaves of pak choy up to 36 DAP. (Descriptions of B0 – B3 and U0 – U3 are in the Research Method)

Table IV shows the effect of treatment on the number of leaves of pak choy plants at 36 DAP. The application of cacao pod husk biochar with a dose of 62 g/pot (B1) provided the best growth of plants with the number of leaves significantly highest (p = 0.000) with an average of 20.17. Meanwhile, in treatment B3 (187 g/pot), the growth was stunted from the beginning of planting to harvesting, reflected by the lowest number of leaves.

TABLE IV
EFFECT OF BIOCHAR AND UREA ON NUMBER OF LEAVES AT 36 DAP

Urea	Biochar				
	B0	B1	B2	B3	Average
U0	11.33	15.67	13.33	9.33	12.42
U1	12.67	22.33	14.33	10.00	14.83
U2	13.33	21.00	15.33	10.67	15.08
U3	11.67	21.67	17.33	8.00	14.67
Average	12.25^{C}	20.17^{A}	15.08^{B}	9.50^{D}	

Notes: Same letters mean no significant difference at = 5% of the LSD test.

E. *Canopy Area*

The canopy area closely relates to plant growth and crop yields. The low canopy area indicates that the plant is experiencing disturbances, disrupting its growth. This is because the canopy area determines the photosynthesis intensity, ultimately determining the growth rate and yield of plants [43]. A good canopy area reflects optimal plant growth. Figure 4 shows the development of the canopy area of the pak choy plant up to 36 DAP. The development of the canopy area at 0–12 DAP is still the same for all treatment combinations. Significant differences started at 20–36 DAP. Based on the development of the canopy area, the B1 treatment revealed the best growth. In contrast, the B3 treatment (187 g/pot) produced stunting crops from the beginning of planting to harvesting so that the resulting canopy area was much smaller than the other treatments, even with the plants from untreated soil media.

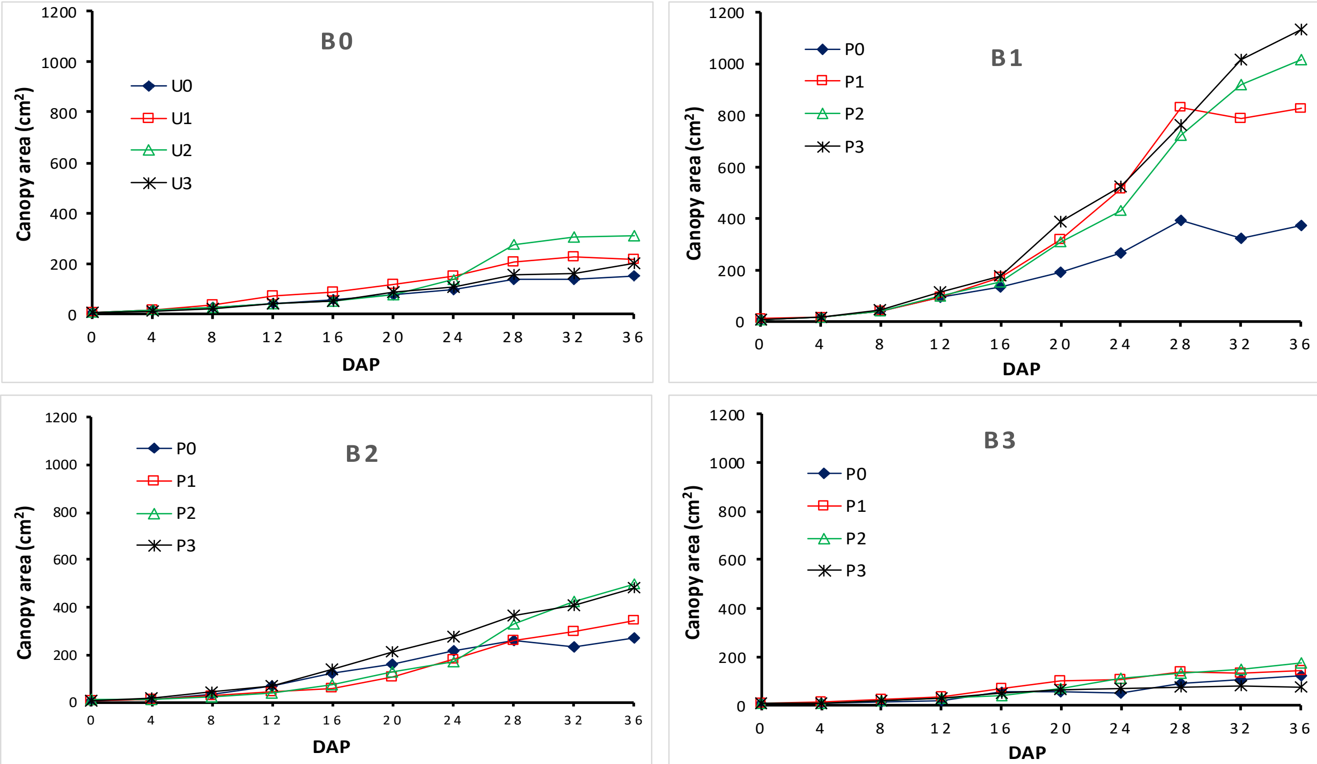

Fig. 4 Effect of biochar and urea fertilizer on the development of the canopy area of pak choy up to 36 DAP. (Descriptions of B0 – B3 and U0 – U3 are in the Research Method).

The ANOVA results indicated that the interaction of biochar dose and urea dose significantly affected ($p = 0.014$) the canopy area of the pak choy plant (Table V). Without the application of Urea (U0), adding biochar (especially at low doses) could increase the canopy area, but it was not statistically significant. Likewise, in the treatment without biochar (B0), the application of urea fertilizer alone could not significantly increase the canopy area. Table V shows that the addition of biochar at 62 g/pot in combination with urea at a dose of 0.93 g/pot (B1U2) or 1.40 g/pot (B1U3 produced pak choy plants with the uppermost canopy area. This confirms that adding biochar with the correct dose will affect the effectiveness of urea in increasing the canopy cover area and, ultimately, plant growth.

TABLE V

EFFECT OF BIOCHAR AND UREA ON CANOPY AREA (CM^2) AT 36 DAP

Urea	Biochar			
	B0	B1	B2	B3
U0	150.00^{de}	373.20^{cd}	272.40^{cde}	124.80^{de}
U1	218.40^{de}	825.60^{b}	346.80^{cd}	142.80^{de}
U2	309.60^{cde}	1015.20^{ab}	501.60^{c}	174.00^{de}
U3	200.40^{de}	1130.40^{a}	482.40^{c}	78.00^{e}

Notes: Same letters mean no significant difference at = 5% of the LSD test.

F. *Pak Choy Yield*

Pak choy plant is a green vegetable so the fresh weight of the plant's top portion (shoot) is used as a parameter of fresh yield. The previously discussed pak choy growth parameters (plant height, number of leaves, and canopy area) show extensive data from stunted to normal plant conditions. This is also reflected in the production of pak choy resulting from this research. Figure 5 shows an example of pak choy resulting from the highest urea dose (1.4 g/pot). An excessive dose of biochar (187 g/pot) resulted in stunted plants despite being given a high fertilizer.

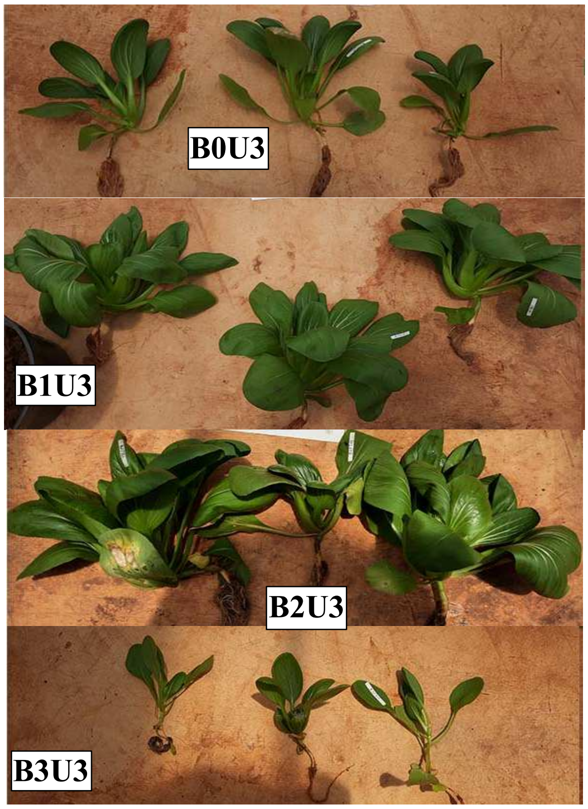

Fig. 5 Pak choy plants produced from treatment with a dose of urea fertilizer of 1.4 g/pot (U3) at various doses of biochar (B0 = 0; B1 = 62 g/pot; B2 = 125 g/pot; B3 = 187 g/pot).

TABLE VI
EFFECT OF BIOCHAR AND UREA ON PAK CHOY FRESH YIELD (G/PLANT)

Urea	Biochar			
	B0	B1	B2	B3
U0	8.96^{de}	28.30^{cd}	20.18^{cde}	3.04^{e}
U1	15.36^{de}	87.57^{b}	23.36^{cde}	9.61^{de}
U2	21.67^{cde}	94.76^{ab}	38.20^{c}	12.94^{de}
U3	11.44^{de}	111.83^{a}	42.26^{c}	3.55^{e}

Notes: Same letters mean no significant difference at = 5% of the LSD test.

A study by [44] reported a similar finding that the positive effect of biochar on pak choy crop yields occurred at specific doses (10-30%). Further addition of biochar significantly reduced the yield of pak choy plants. Table VI shows the effect of adding cacao pod biochar and urea fertilizer on the production of pak choy plants. The interaction between biochar and urea fertilizer has a significant impact ($p = 0.001$) on the yield of pak choy. Without biochar (B0), the application of urea fertilizer increased the fresh weight of pak choy plants, but statistically, it was not significant. The positive effect of cocoa pod husk biochar was recently reported on the growth and yield of okra. Treatment of low-dose biochar (5 t/ha) and NPK 60 kg/ha resulted in the highest plant height, number of leaves, and yield of okra [45].

Similarly, without urea, the addition of biochar failed to increase the yield of pak choy significantly. Even at a dose of 187 g/pot, it caused the plants to become underdeveloped with considerably lower yields than the control. The dosage of biochar applied in this research was based on [46] where for acid-dry land in Lampung, the application of biochar at a dose of 5-10 tons/ha gives stable results up to three consecutive growing seasons without the addition of biochar in the second and third growing seasons. The dose also referred to the work of [47], who used biochar of 2% (low), 5% (medium), and 10% (high).

Our results reinforce the previous statement that adding biochar must be combined with urea fertilizer in the right amount. In general, the fresh product of pak choy in this study was not optimal, with the highest yield of 111.83 g/pot obtained from the B1U2 treatment. Assuming a spacing of 20cm x 25cm, the best results in this study could reach 22.37 t/ha. This result is higher than that reported by [24], where the pak choy with corncob biochar achieved the best yield of 35.6 g/plant, and that was of [48] with a yield of around 70 g/m^2 at plant spacing of 40cm x 40 cm. However, these results are still far from those reported by [49], where the fresh weight of pak choy reached 246.84 g/plant.

The low yield of pak choy in our research can be a result of infertile growing media (ultisol soil). Ultisol is an acid soil that has undergone heavy leaching, so it has a low fertility level. Typical constraints on Ultisol soils are low pH, low N and P elements, lack of Ca, Mg, K, and Mo elements, excess Mn and Fe content, and high Al solubility, which become the main obstacles for plant growth. [8]In our case, the situation became worse due to the excessive addition of cacao pod biochar, which boosted the soil pH beyond the limit that is not in accordance with plant needs, resulting in stunted plants, as happened in the combination of B3 treatment with various doses of urea fertilizer application (U0, U1, U2, and U3).

G. Water Consumption and Water Productivity

Water consumption in plants is closely related to plants' water needs, namely for the process of plant photosynthesis. Plants with an excellent vegetative growth period will need a lot of water to help the growth process. Whereas stunted plants only need a little water to grow. This study used water supply (irrigation) to replace water lost through evaporation and transpiration of pak choy plants. Therefore, there is a reciprocal relationship between water consumption and plant growth. Sufficient water is needed to ensure good plant growth. On the other hand, good plants will also evaporate more water.

The results from the variance analysis showed that the interaction of biochar cacao pod and urea fertilizer application had a significant effect on the total water consumption of pak choy plants (Table VII). Pak choy plants showed the highest water consumption under the biochar treatment with doses of 125 g/pot and urea application of 1.4 g/pot. Based on the LSD test, the interaction of the two factors showed that the B1U1, B1U3, and B2U3 treatments consumed the highest irrigation water and were significantly different ($p = 0.014$) from other treatments. This implies that giving biochar and urea fertilizer with the correct dose will determine the optimal conditions for plant growth. Cocoa pod husk biochar application in excessive doses can cause detrimental effects on plants and soil. The soil becomes highly alkaline, so plant roots will find it difficult to absorb water and their growth will be stunted.

Analysis of variance showed that both the application of cacao pod biochar and urea fertilizer and their interaction had a significant effect ($p = 0.000$) on the water productivity of the pak choy. From Table VIII, we can see that fertilizer has increased water productivity by 113.5% from 7.41 g/L (without fertilizer) to 15.82 g/L at a dose of U2 fertilizer (0.93 g/pot). Applying biochar gave a more significant effect in increasing the water productivity of pak choy plants, namely 272.6% at a dose of B1 (62 g/pot). This reveals that the role of biochar in increasing water productivity is more dominant than the role of urea fertilizer.

TABLE VII
EFFECT OF BIOCHAR AND UREA ON IRRIGATION WATER CONSUMPTION (ML)

Urea	Biochar			
	B0	B1	B2	B3
U0	513.67^{cd}	523.33^{cd}	512^{cd}	906^{bcd}
U1	525^{cd}	1317^{ab}	585^{cd}	331.33^{d}
U2	528.67^{bcd}	1061.67^{bcd}	707^{bcd}	472^{cd}
U3	511^{cd}	1123.33^{abc}	1449^{a}	406.33^{cd}

Notes: Same letters mean no significant difference at = 5% of the LSD test.

TABLE VII
EFFECT OF BIOCHAR AND UREA ON WATER PRODUCTIVITY (G/L)

Urea	Biochar				
	B0	B1	B2	B3	Average
U0	4.49	14.07	9.82	1.25	7.41^{b}
U1	8.32	25.83	10.08	6.14	12.59^{a}
U2	10.29	32.02	15.01	5.97	15.82^{a}
U3	5.93	36.29	13.88	1.99	14.52^{a}
Average	7.26^{C}	27.05^{A}	12.20^{B}	3.84^{C}	

Notes: Same letters mean no significant difference at = 5% of the LSD test.

IV. Conclusions

The addition of biochar and urea showed a significant effect on the growth and yield of pak choy. The interaction of biochar and urea dose showed substantial differences in the parameters of plant height, crop fresh yield, and water consumption. The effects of single-factor biochar dose are significant for final soil pH, plant height, and a number of leaves. Meanwhile, the single factor of urea addition showed substantial differences in plant height and water productivity. Based on the plant's vegetative growth and pak choy yield, the best interaction is cacao pod biochar of 62 g/pot with urea fertilizer of 1.40 g/pot. Within this condition, the pak choy produces 111.83 g/plant of fresh vegetables.

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References

[1] J. S. Siemonsma and K. Piluek, *Plant Resources of South-East Asia No 8: Vegetables*. Wageningen, The Netherlands: Pudoc Scientific Publishers, 1993.

[2] J.-E. Park, J. Kim, E. Purevdorj, Y.-J. Son, C. W. Nho, and G. Yoo, "Effects of long light exposure and drought stress on plant growth and glucosinolate production in pak choi (*Brassica rapa* subsp. Chinensis)," *Food Chem*, vol. 340, p. 128167, 2021, doi:10.1016/j.foodchem.2020.128167.

[3] Badan Pusat Statistik, *Statistical Yearbook of Indonesia 2023*. Jakarta: Badan Pusat Statistik, 2023.

[4] Badan Pusat Statistik, *Lampung Province in Figures 2023*. Bandar Lampung: BPS Provinsi Lampung, 2023.

[5] D. D. M. Hamdan, M. A. M. Nizam, K. Seow, N. Z. Zahari, and S. A. Rahim, "Trace elements uptake in *Brassica rapa* Chinensis cultivated in ultrabasic (oxisol) and ultisol soils, North Borneo," *J Phys Conf Ser*, vol. 2314, no. 1, p. 012026, 2022, doi: 10.1088/1742-6596/2314/1/012026.

[6] G. Niu, J. Masabni, T. Hooks, D. Leskovar, and J. Jifon, "The performance of representative asian vegetables in different production systems in Texas," *Agronomy*, vol. 11, no. 9, p. 1874, 2021, doi:10.3390/agronomy11091874.

[7] Y.-G. Kang *et al.*, "Effects of varying rates of nitrogen and biochar pH on NH_3 emissions and agronomic performance of Chinese cabbage (*Brassica rapa* ssp. Pekinensis)," *Agronomy*, vol. 12, no. 1, p. 61, 2021, doi: 10.3390/agronomy12010061.

[8] Septiyana, Husnain, L. R. Widowati, A. F. Siregar, and A. Samsun, "The use of soil ameliorants and fertilizers to increase the yields of rice and maize in ultisols Lampung, Indonesia," *IOP Conf Ser Earth Environ Sci*, vol. 648, no. 1, p. 012198, 2021, doi: 10.1088/1755-1315/648/1/012198.

[9] J. W. Gabhane, V. P. Bhange, P. D. Patil, S. T. Bankar, and S. Kumar, "Recent trends in biochar production methods and its application as a soil health conditioner: a review," *SN Applied Sciences*, vol. 2, no. 7. Springer Nature, Jul. 01, 2020. doi: 10.1007/s42452-020-3121-5.

[10] A. Haryanto *et al.*, "Valorization of Indonesian wood wastes through pyrolysis: A review," *Energies (Basel)*, vol. 14, no. 5, p. 1407, 2021, doi: 10.3390/en14051407.

[11] Y. Gao, G. Shao, J. Lu, K. Zhang, S. Wu, and Z. Wang, "Effects of biochar application on crop water use efficiency depend on experimental conditions: A meta-analysis," *Field Crops Res*, vol. 249, Apr. 2020, doi: 10.1016/j.fcr.2020.107763.

[12] I. Criscuoli *et al.*, "Stability of woodchips biochar and impact on soil carbon stocks: Results from a two-year field experiment," *Forests*, vol. 12, no. 10, Oct. 2021, doi: 10.3390/f12101350.

[13] A. Gross, T. Bromm, and B. Glaser, "Soil organic carbon sequestration after biochar application: A global meta-analysis," *Agronomy*, vol. 11, no. 12. MDPI, Dec. 01, 2021. doi: 10.3390/agronomy11122474.

[14] N. Nayak, R. Mehrotra, and S. Mehrotra, "Carbon biosequestration strategies: a review," *Carbon Capture Science and Technology*, vol. 4. Elsevier Ltd, Sep. 01, 2022. doi: 10.1016/j.ccst.2022.100065.

[15] N. Geng *et al.*, "Biochar mitigation of soil acidification and carbon sequestration is influenced by materials and temperature," *Ecotoxicol Environ Saf*, vol. 232, p. 113241, 2022, doi:10.1016/j.ecoenv.2022.113241.

[16] M. Vergara-Mendoza, G. R. Martínez, C. Blanco-Tirado, and M. Y. Combariza, "Mass balance and compositional analysis of biomass outputs from cacao fruits," *Molecules*, vol. 27, no. 12, p. 3717, 2022, doi: 10.3390/molecules27123717.

[17] M. F. Baidoo *et al.*, "Conventional and unconventional transformation of cocoa pod husks into value-added products," in *Biomass, Biorefineries and Bioeconomy*, M. Samer, Ed., IntechOpen, 2022. [Online]. Available: https://www.intechopen.com/chapters/80493

[18] L. Y. Ouattara *et al.*, "Cocoa pod husks as potential sources of renewable high-value-added products: A review of current valorizations and future prospects," *Bioresources*, vol. 16, no. 1, pp. 1988–2020, 2021, doi: https://doi.org/10.15376/biores.16.1.Ouattara.

[19] W.-T. Tsai, C.-H. Hsu, Y.-Q. Lin, C.-H. Tsai, W.-S. Chen, and Y.-T. Chang, "Enhancing the Pore Properties and Adsorption Performance of Cocoa Pod Husk (CPH)-Derived Biochars via Post-Acid Treatment," *Processes*, vol. 8, no. 2, p. 144, 2020, doi: 10.3390/pr8020144.

[20] F. Picchioni *et al.*, "Valorisation of natural resources and the need for economic and sustainability assessment: The case of cocoa pod husk in Indonesia," *Sustainability (Switzerland)*, vol. 12, no. 21, pp. 1–16, Nov. 2020, doi: 10.3390/su12218962.

[21] D. Oduro-Mensah, A. Ocloo, T. Nortey, S. Antwi, L. K. Okine, and N. A. Adamafio, "Nutritional value and safety of animal feed supplemented with Talaromyces verruculosus-treated cocoa pod husks," *Sci Rep*, vol. 10, no. 1, p. 13163, 2020, doi: 10.1038/s41598-020-69763-9.

[22] D. C. Meza-Sepúlveda, A. M. Castro, A. Zamora, J. W. Arboleda, A. M. Gallego, and A. V Camargo-Rodríguez, "Bio-based value chains potential in the management of cacao pod waste in Colombia, a case study," *Agronomy*, vol. 11, no. 4, p. 693, 2021, doi:10.3390/agronomy11040693.

[23] D.-G. J. M. Hougni, A. G. T. Schut, L. S. Woittiez, B. Vanlauwe, and K. E. Giller, "How nutrient rich are decaying cocoa pod husks? The kinetics of nutrient leaching," *Plant Soil*, vol. 463, no. 1, pp. 155–170, 2021, doi: 10.1007/s11104-021-04885-1.

[24] A. Haryanto *et al.*, "Use of corncob biochar and urea for pakchoi (Brassica rapa L.) cultivation: Short-term impact of pyrolysis temperature and fertiliser dose on plant growth and yield," *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, vol. 123, no. 2, pp. 251–257, 2022.

[25] G. P. Ngalani, F. D. Kagho, N. N. C. Peguy, P. Prudent, J. A. Ondo, and E. Ngameni, "Effects of coffee husk and cocoa pods biochar on the chemical properties of an acid soil from West Cameroon," *Arch Agron Soil Sci*, vol. 0, no. 0, pp. 1–15, 2022, doi:10.1080/03650340.2022.2033733.

[26] J. O. Eduah, S. W. Henriksen, E. K. Nartey, M. K. Abekoe, and M. N. Andersen, "Nonlinear sorption of phosphorus onto plant biomass-derived biochars at different pyrolysis temperatures," *Environ Technol Innov*, vol. 19, p. 100808, 2020, doi: 10.1016/j.eti.2020.100808.

[27] K. O. Iwuozor *et al.*, "Unlocking the hidden value of pods: A review of thermochemical conversion processes for biochar production," *Bioresour Technol Rep*, vol. 22, p. 101488, 2023, doi:10.1016/j.biteb.2023.101488.

[28] N. A. Daba *et al.*, "Long-term fertilization and lime-induced soil ph changes affect nitrogen use efficiency and grain yields in acidic soil under wheat-maize rotation," *Agronomy*, vol. 11, no. 10, p. 2069, 2021, doi: 10.3390/agronomy11102069.

[29] Y. Zhang *et al.*, "The effects of long-term application of stabilized and coated urea on soil chemical properties, microbial community structure, and functional genes in paddy fields," *Agronomy*, vol. 13, no. 9, p. 2190, 2023, doi: 10.3390/agronomy13092190.

[30] J.-E. Lee *et al.*, "Effects of soil pH on nutritional and functional components of Chinese cabbage (*Brassica rapa* ssp. campestris)," *Korean Journal of Horticultural Science and Technology*, vol. 28, no. 3, pp. 353–362, 2010.

[31] R. Ariani, N. L. Nurida, and A. Dariah, "Utilization of cacao shell biochar and compost to improve cayenne pepper (*Capsicum frutescens* L.) in acid upland," *IOP Conf Ser Earth Environ Sci*, vol. 648, no. 1, p. 012182, 2021, doi: 10.1088/1755-1315/648/1/012182.

[32] D. Losacco *et al.*, "Use of biochar to improve the sustainable crop production of cauliflower (*Brassica oleracea* L.)," *Plants*, vol. 11, no. 9, p. 1182, 2022, doi: 10.3390/plants11091182.

[33] A. Obadi, A. Alharbi, A. Alomran, A. G. Alghamdi, I. Louki, and A. Alkhasha, "Effect of biochar application on morpho-physiological

traits, yield, and water use efficiency of tomato crop under water quality and drought stress," *Plants*, vol. 12, no. 12, p. 2355, 2023, doi:10.3390/plants12122355.

[34] K. A. Frimpong, C. A. Phares, I. Boateng, E. Abban-Baidoo, and L. Apuri, "One-time application of biochar influenced crop yield across three cropping cycles on tropical sandy loam soil in Ghana," *Heliyon*, vol. 7, no. 2, p. e06267, 2021, doi: 10.1016/j.heliyon.2021.e06267.

[35] E. Yeboah, G. Asamoah, P. Ofori, B. Amoah, and K. O. A. Agyeman, "Method of biochar application affects growth, yield and nutrient uptake of cowpea," *Open Agric*, vol. 5, no. 1, pp. 352–360, 2020, doi:10.1515/opag-2020-0040.

[36] S. R. Pinnamaneni, I. Lima, S. A. Boone, S. S. Anapalli, and K. N. Reddy, "Effect of continuous sugarcane bagasse-derived biochar application on rainfed cotton (*Gossypium hirsutum* L.) growth, yield and lint quality in the humid Mississippi delta," *Sci Rep*, vol. 13, no. 1, p. 10941, 2023, doi: 10.1038/s41598-023-37820-8.

[37] S. Yin *et al.*, "Effect of biochar and hydrochar from cow manure and reed straw on lettuce growth in an acidified soil," *Chemosphere*, vol. 298, p. 134191, 2022, doi: 10.1016/j.chemosphere.2022.134191.

[38] Y. P. Situmeang, I. D. N. Sudita, and M. Suarta, "Application of compost and biochar from cow, goat, and chicken manure to restore soil fertility and yield of red chili," *Int J Adv Sci Eng Inf Technol*, vol. 11, no. 5, pp. 2008–2015, 2021.

[39] C. Knoblauch, S. H. R. Priyadarshani, S. M. Haefele, N. Schröder, and E. Pfeiffer, "Impact of biochar on nutrient supply, crop yield and microbial respiration on sandy soils of northern Germany," *Eur J Soil Sci*, vol. 72, no. 4, pp. 1885–1901, 2021, doi: 10.1111/ejss.13088.

[40] T. Simms, H. Chen, and G. Mahato, "Dose-dependent effect of biochar as soil amendment on reducing copper phytotoxicity and mobility," *Int J Environ Res*, vol. 14, no. 6, pp. 751–759, 2020, doi: 10.1007/s41742-020-00293-y.

[41] X. Jin, X. Zhou, F. Wu, W. Xiang, and K. Pan, "Biochar amendment suppressed fusarium wilt and altered the rhizosphere microbial composition of tomatoes," *Agronomy*, vol. 13, no. 7, p. 1811, 2023, doi: 10.3390/agronomy13071811.

[42] J. Sun *et al.*, "Effect of different rates of nitrogen fertilization on crop yield, soil properties and leaf physiological attributes in banana under subtropical regions of China," *Front Plant Sci*, vol. 11, 2020, doi:10.3389/fpls.2020.613760.

[43] T. C. Jayalath and M. W. Van Iersel, "Canopy size and light use efficiency explain growth differences between lettuce and mizuna in vertical farms," *Plants*, vol. 10, no. 4, p. 704, 2021, doi:10.3390/plants10040704.

[44] Y. Shen *et al.*, "Impacts of biochar concentration on the growth performance of a leafy vegetable in a tropical city and its global warming potential," *J Clean Prod*, vol. 264, p. 121678, 2020, doi:10.1016/j.jclepro.2020.121678.

[45] A. K. Oluleye, M. O. Ogunlade, and O. B. Adewoyin, "Response of okra, *Abelmoschus esculentus* (L.) Moench, to biochar derived from cocoa pod husk and NPK fertiliser," *Tropical Agriculture*, vol. 100, no. 1, pp. 11–19, 2023.

[46] Balai Penelitian Tanah, "Laporan Akhir Penelitian Formulasi Pembenahan Tanah Berbahan Baku Biochar untuk Meningkatkan Kualitas Tanah, Retensi Air, dan Produktivitas Tanaman >25% pada Lahan Kering Terdegradasi," Jakarta, 2009.

[47] P. Campos, H. Knicker, R. López, and J. M. De la Rosa, "Application of biochar produced from crop residues on trace elements contaminated soils: Effects on soil properties, enzymatic activities and *Brassica rapa* growth," *Agronomy*, vol. 11, no. 7, Jul. 2021, doi:10.3390/agronomy11071394.

[48] M. B. Yunindanova, S. Pramono, and M. H. Ibrahim, "Nutrient uptake, partitioning, and production of two subspecies of brassica using different solution concentrates in floating hydroponics systems," *Buletin Agroteknologi*, vol. 1, no. 2, pp. 86–97, 2020, doi:10.32663/ba.v1i2.1810.

[49] M. Silitonga *et al.*, "The effect of biochar dose and NPK fertilizer on the production and growth of pak choi plant," in *IOP Conference Series: Earth and Environmental Science*, Institute of Physics Publishing, Dec. 2018. doi: 10.1088/1755-1315/205/1/012028.