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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

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Abstract

This study aimed to evaluate the effect of pyrolysis temperature of corncob biochar as a soil amendment and urea fertiliser on the growth and yield of pakchoi. Pakchoi was cultivated in pots (13 cm height, 19 cm upper diameter, and 13.5 cm bottom diameter). Two factors including pyrolysis temperature of biochar and urea dose were combined with four levels each. Pyrolysis temperature factor consisted of B0 (no biochar), B1 (250 °C), B2 (300 °C), and B3 (350 °C). Urea dose consisted of F0 (no urea), F1 (0.6 g pot^{-1}, F2 (1.2 g pot^{-1}), and F3 (1.8 g pot^{-1}). All treatment combinations were randomly designed in triplicates. The amount of biochar was 90 g with total growing media of 3000 g. The results showed that pyrolysis temperature influenced significantly ($\alpha = 0.05$) growth parameters, fresh yield, and water productivity. Pyrolysis temperature of 350 °C resulted in the highest growth and production with average yield of 30.6 g pot^{-1}, water productivity of 10.09 g cm^{-3}, and fertiliser productivity of 27.59-53.39 g g^{-1} depending on the dose. In order to have optimal benefits, biochar application should be combined with fertiliser application.

Keywords: biochar, canopy, crop yield, number of leaves, water productivity

1 Introduction

Developed in China, pakchoi (*Brassica rapa* L.) is a leafy, green vegetable now consumed nearly all over the world and an economically valuable commodity in many countries. In Indonesia, pakchoi is one of the favorite vegetables and increasingly popular because of its short cultivation period with a harvesting time of 40-45 days after sowing or 25-35 days after transplanting (DAT). Pakchoi production in Lampung Province increased 15.5 % from 7872 t (2018) to 9095 t (2019) (BPS, 2020). Pakchoi productivity in Lampung Province (6.84 t ha^{-1}) is significantly lower than the national level (10.7 t ha^{-1}) due to inefficient cultivation techniques and infertile soils. Lampung has a wide expanse of suboptimal dry upland of ultisol soils characterised by low cation exchange capacity (CEC), low organic matter, low water holding capacity, and high aluminium (Al) and P fixation (Cornelissen *et al*, 2018). Therefore, increasing soil fertility by applying soil amendment materials such as compost and biochar are of great importance.

Biochar is a porous, carbon-rich organic material produced through pyrolysis under no oxygen. Pyrolysis converts biomass to a stable carbon (C) form that is important not only as source for renewable fuel, but also for soil amendment applications (Haryanto *et al.*, 2021). The application of biochar as a soil amendment has sharply increased during the last decade. In soil, biochar acts as a sponge-like material with a high specific surface area (SSA) that enhances water holding capacity. The ash in biochar provides a liming effect that alleviate soil acidity (Cornelissen *et al.*, 2018). Biochar facilitates a good home for soil microorganisms that improves microbial activity and increases nutrient availability (Jabborova *et al.*, 2021). Interaction of these properties climaxes in the increase of soil productivity and

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plant yield. For example, a combination of corncob biochar and low rate fertiliser (25 % of recommended dose) in the humid season in Tanzania increased dry biomass yield by 83 % and was comparable to that of full dose (Kiobia *et al*., 2019).

The application of biochar for pakchoi has been reported significantly increased pakchoi yield for five seasons regardless of nitrogen application in acidic soil (Yu *et al*., 2015). Similarly, application of rice husk biochar at medium (5 % w/w) and high (10 % w/w) dose increased aerial biomass yield of *Brassica rapa* L. in contaminated soils (Campos *et al*., 2021). The effects of biochar depend on feedstock type and pyrolysis conditions such as reaction time, temperature, and heating speed. Feedstock type dictates mineral composition, total organic carbon, and fixed carbon of biochar, while pyrolysis temperature determines pH and surface area of biochar. For example, using a top-lit updraft stove at high temperature are better for soil amendment due to their adsorption capacities and chemical stability as compared to those of low-temperature anaerobic charring using a retort (Kaal *et al*., 2017). This paper, therefore, aims to provide information about the effect of the pyrolysis temperature of corncob biochar and its application on the growth and yield of pakchoi.

2 Materials and methods

Research was conducted in a greenhouse of the University of Lampung, Indonesia (5°22′7″ S, 105°14′33″ E) from November 2020 to February 2021. Corncob was chosen as feedstock for biochar because of its abundant availability in Lampung as Indonesia's top three corn-producing regions. The dry corncob was pyrolysed at three different temperatures of 250, 300 and 350 °C using a covered drum externally heated by an LPG stove. Pyrolysis temperature was maintained by controlling flame intensity through the gas flow adjustment knob. The biochar was ground and sieved using a 20 mesh (0,9 mm) screen. Ultisol soil from subsoil layer within the University's field laboratory had a composition of 29 % sand, 30 % silt, and 42 % clay. It was sieved using a 3-mm soil screen and then mixed thoroughly with biochar at a ratio of 90 g biochar with 2910 g soil to make a total 3000 g growing medium. Table 1 presented properties of the soil and corncob biochar. The growing media was filled into pots (13 cm height, 19 cm upper diameter, and 13.5 cm bottom diameter) and watered with pre-measured quantity to have a field capacity condition. Pakchoi seed purchased from local farm shop was seeded for two weeks. Seedlings with a good vigour were transplanted into the prepared media. The pots were watered daily to replace the evapotranspiration loss as measured by weighing method. Fertilisation was applied at 14 DAT and 21 DAT with half a dose for each application. The plants were harvested at 32 DAT.

Table 1: *Properties of soil and biochar used in the experiment*

Soil properties	*Value*	*Criteria*	
N-total (%)	0.04	Very low	
P-available (ppm)	11.85	Low	
C-organic (%)	0.38	Very low	
K-dd (mg/100 gr)	0.09	Very low	
pH (initial)	4.5-5.5	Acid/medium	
pH (after harvesting)	6.0-8.0	Neutral	
Biochar properties	250 °C	300 °C	350 °C
pH	9	10	10
Density (g cm^{-3})	0.228	0.328	0.209

2.1 *Experimental design*

The pot trial was arranged in a Completely Randomised Design with two factors, namely pyrolysis temperature consisting of B0 (no biochar), B1 (250 °C), B2 (300 °C), and B3 (350 °C) and urea (46 % N) dose consisting of F0 (no fertiliser), F1 (0.6 g pot^{-1}, F2 (1.2 g pot^{-1}), and F3 (1.8 g pot^{-1}). All treatment combinations were performed with three replications.

2.2 *Analysis and measurements*

Water consumption, plant growth, canopy cover, and crop yield (fresh and dry basis) were monitored during plant growth. After harvesting, soil pH and water productivity were observed. The canopy cover was measured using the Canopy Cover Free application available freely on android (https://play.google.com/store/apps/details?id=com.heaslon.canopycover). In this case, a styrofoam square of 60 cm side was used as a guide frame. The image was taken from such height that the guide frame is fully covered in the smartphone screen. The canopy was presented as a percentage of the guide frame area. Water productivity (WP) was calculated as fresh yield over water consumption.

2.3 *Statistical analysis*

Analysis of variance and the least significant difference were performed using the SAS program version. 9.13 to see the effect of treatment on the dependent variables at $\alpha = 5$ %.

3 Results

Number of leaves of pakchoi grows almost linearly for all treatment combinations and media without biochar amendment (B0) always lowest regardless urea dose (Figure 1).

However, after 16 AND plant height showed slow development for all treatment combinations (Figure 2). We can observe from Figure 1 and 2 that the growth of pakchoi on media without biochar amendment (B0) was always lower than those of plants grown on biochar-amended media for all urea doses.

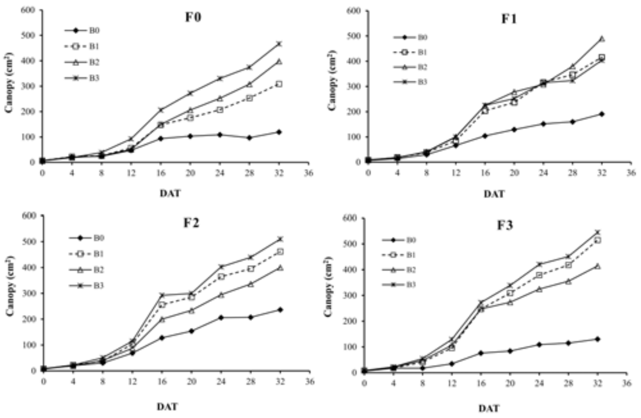

Fig. 1: *Number of leaves of pakchoi for different treatments.*
B0 (no biochar); B1 (250 °C); B2 (300 °C); B3 (350 °C) and F0 (no urea); F1 (urea 0.6 g pot^{-1}); F2 (urea 1.2 g pot^{-1}); F3 (urea 1.8 g pot^{-1})

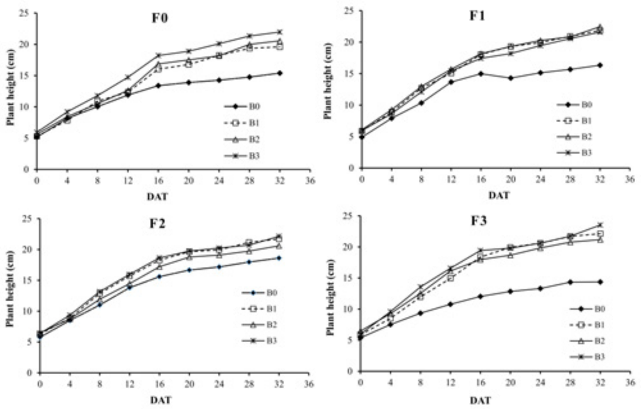

Fig. 2: *Plant height of pakchoi for different treatments.*
Note: B0 (no biochar); B1 (250 °C); B2 (300 °C); B3 (350 °C) and F0 (no urea); F1 (urea 0.6 g pot^{-1}); F2 (urea 1.2 g pot^{-1}); F3 (urea 1.8 g pot^{-1}).

Observations before and at harvest time (32 DAT) as presented in Table 2 showed that the addition of biochar significantly affected all plant growth parameters (leaf number, plant height, leaf width, and canopy area) as well as crop yield and water productivity. The application of urea had no significant effect on the number of leaves and plant height, but had a significant effect on other parameters (leaf width, canopy area, crop yield, and water productivity). There is no significant interaction between urea dose and biochar. Furthermore, Table 2 also shows that the pyrolysis temperature did not statistically result in differences in plant height, leaf width, and water productivity. The pyrolysis temperature significantly increased the number of leaves, canopy area and plant yields.

More detailed observations showed that when the two treatment factors showed significant effects on growth parameters, then the effect of biochar was superior to the effect of adding urea. Treatments without fertiliser (F0) can still produce comparable pakchoi growth in terms of plant height and number of leaves as long as biochar was amended to the soil. Urea application increased number of leaves by average 9 % but it was not statistically different. Biochar application, however, increased significantly number of leaves by 49 % to 68 % from 10.3 (B0) to 15.4 to 17.4 depending on pyrolysis temperature. While urea dose did not affect plant height, biochar application significantly improved plant height by average 33 % from 16.3 cm (B0) to (21.3-21.5 cm) with biochar. Urea dose increased leaf width significantly by average 10 % from 6.71 cm (F0) to 7.41 (with urea, regardless dose). On the other hand, biochar application increased leaf width by average 51 % from 5.23 cm (B0) to average 7.91 cm (with biochar) regardless pyrolysis temperature. Similarly, higher doses of urea (1.2 and 1.8 g pot^{-1}) increased significantly plant canopy area by only 20 % in average, considerably lower than the increment due to biochar application ranged from 148 – 181 %. Pyrolysis temperature influenced significantly on canopy cover with the highest effect occurred at 350 °C.

The effect of treatment on crop yield was similar to its effect on canopy cover. At low dose (0.6 g pot^{-1}) the effect of urea on crop yield was not significant. At higher doses (1.2 and 1.8 g pot^{-1}) the crop yield significantly increased by average 35 % when compared to that of without urea application. Without biochar (B0), crop yield was in average 9.3 g plant^{-1} and increased significantly by 169 % to 229 % due to biochar application with the highest of 30.6 produced from media amended with biochar produced at 350 °C. Pyrolysis temperature from 250 to 350 °C statistically increased crop yield (Table 3), while the effect of urea dose from 1.2 to 1.8 g pot^{-1} was not significant. The superiority of urea over biochar can be seen in the effectiveness of using irrigation water where the application of urea has resulted in much higher water productivity, reaching an average of 143 % at urea doses 0.6 – 1.2 g pot^{-1} to 212 % at 1.8 g pot^{-1}. In this case, the addition of biochar was only able to increase water productivity by 46 – 58 % (an average of 52 %) and the pyrolysis temperature had no significant effect. Table 3 shows that the effect of biochar on fertiliser productivity was not consistent. For example, at a dose of urea 0.6 g pot^{-1}, the pyrolysis temperature significantly affected the productivity

Table 2: *Effect of treatments on plant growth parameters at 32 days after transplanting (DAT).*

*Factor**	*F0*	*F1*	*F2*	*F3*	*Average*†
Plant height (cm)					
B0	15.7	16.3	18.6	14.4	16.3[b]
B1	20.3	21.9	21.7	22.1	21.5[a]
B2	20.9	22.5	20.6	21.2	21.3[a]
B3	22.0	21.6	22.1	23.5	22.3[a]
Average†	19.7[A]	20.6[A]	20.8[A]	20.3[A]	
Number of leaves					
B0	9,3	10,7	12,3	9,0	10.33[c]
B1	14,7	15,3	14,7	17,0	15.4[bc]
B2	15,0	17,3	16,0	17,0	16.3[ab]
B3	16,7	16,7	18,3	18,0	17.4[a]
Average†	13.9[A]	15.0[A]	15.1[A]	15.3[A]	
Leaf width (cm)					
B0	4.53	5.67	5.93	4.77	5.23[b]
B1	7.17	7.93	7.87	8.33	7.83[a]
B2	7.57	8.23	7.30	7.80	7.73[a]
B3	7.57	8.40	8.23	8.47	8.17[a]
Average†	6.71[B]	7.56[A]	7.33[A]	7.34[A]	
Canopy cover (cm^2)					
B0	119.6	190.6	236.8	130.2	169.3[c]
B1	309.0	415.6	461.8	511.5	424.5[ab]
B2	397.8	478.4	400.2	406.1	420.6[b]
B3	466.5	403.8	510.3	522.2	475.7[a]
Average†	323.2[B]	372.1[AB]	402.3[A]	392.5[A]	

Note: * B0 (no biochar); B1 (250 °C); B2 (300 °C); B3 (350 °C) and F0 (no urea); F1 (urea 0.6 g pot^{-1}); F2 (urea 1.2 g pot^{-1}); F3 (urea 1.8 g pot^{-1}).
† Numbers followed by the same letter are not statistically different at $\alpha = 5$ %: lowercases are for column (biochar treatment), uppercases are for row (urea dose).

of fertiliser with the highest value obtained in the treatment of biochar which was pyrolysed at a temperature of 300 °C. But, at doses of 1.2 and 1.8 g pot^{-1} the effect of pyrolysis temperature on fertiliser productivity was not significant.

It is worthy to note that temperature in the greenhouse was on average 32.3 °C with a range of 26.7 to 43.1 °C and a standard deviation (SD) of 3.7 °C. This was higher than that of outside greenhouse at normal situation. This condition, accompanied by low relative humidity (RH) at an average value of 58.4 % with a range of minimum of 34 % to maximum of 83 % and SD of 10 %, was an unfavorable environment for good plant growth. Yunindanova *et al. (2020)* reported similar condition where greenhouse temperature ranged 32.9–41.8 °C and RH was 41–69 %.

4 Discussion

4.1 Plant growth

In the current experiment, pakchoi was transplanted when the seedlings had three true leaves. Without biochar, number of leaves increased by an average of 7.33 meaning a leaf appearance of 0.23 d^{-1}. Using biochar number of leaves growth by 12.42–14.42 or leaf appearances of 0.39–0.45 d^{-1}. This result is higher than those reported by Gunawan & Susylowati (2013) with number of leaves between 8 and 10. Our results are close to Yunindanova *et al.* (2020) with 14.5 ± 3.1 leaves after four weeks for pakchoi grown hydroponically. However, the results are slightly lower than the work of Cho & Son (2007) with appearance rate of 0.542 d^{-1}. Pakchoi is a leafy vegetable, so an increase in the number of leaves will have implications for an increase in production. Although pyrolysis temperatures did not significantly affect on the leaf width, the addition of biochar improved

Table 3: *Effect of treatments on plant yield and productivity at 32 days after transplanting (DAT).*

*Factor**	*F0*	*F1*	*F2*	*F3*	*Average†*
Crop yield (g pot^{-1})					
B0	7.4	9.8	13.7	6.2	9.3^{c}
B1	16.3	23.4	28.3	33.2	25.3^{ab}
B2	21.3	29.4	23.4	25.9	25.0^{b}
B3	26.4	26.8	33.5	35.7	30.6^{a}
Average†	17.8^{B}	22.3^{AB}	24.7^{A}	25.2^{A}	
Water productivity (g L^{-1})					
B0	2.77	5.62	6.98	10.23	6.40^{b}
B1	4.37	9.49	12.74	10.90	9.37^{a}
B2	6.06	10.95	8.85	13.28	9.78^{a}
B3	2.69	13.56	8.94	15.16	10.09^{a}
Average†	3.97^{C}	9.90^{B}	9.37^{B}	12.39^{A}	
Fertiliser productivity (g g^{-1})					
B0	-	21.60^{cde}	15.48^{ef}	4.62^{f}	
B1	-	53.32^{b}	31.43^{cd}	25.42^{cde}	
B2	-	73.79^{a}	24.78^{cde}	18.63^{def}	
B3	-	53.39^{b}	35.87^{c}	27.59^{cde}	

Note: *B0 (no biochar); B1 (250 °C); B2 (300 °C); B3 (350 °C) and F0 (no urea); F1 (urea 0.6 g pot^{-1}); F2 (urea 1.2 g pot^{-1}); F3 (urea 1.8 g pot^{-1}).
†Numbers followed by the same letter are not statistically different at α= 5 %: lowercases are for column (biochar treatment), uppercases for row (urea dose).

it by average 51 % as compared to media without biochar amendment. This is in accordance with the report of Jabborova *et al.* (2021) on basil and Milla *et al.* (2013) on spinach.

Our study revealed that urea addition results in much lower effect (20 %) on plant canopy area as compared to the effect of biochar (148–181 %). According to Massignam *et al.* (2011), availability of N correlated with photosynthesis by leaves, and leaf area index decrease under limited N due to lower rates of leaf area development and increased leaf senescence. It was also reported that the leaf area index of maize cultivated in soils amended with biochar was significantly larger than that of the control (no biochar addition) treatment (Njoku *et al.*, 2015). Even, residual effects of a combination of biochar and NPK fertiliser was still able to increase plant canopy by 23.5 % for collard plant (*Brassica oleracea*) (Apori *et al.*, 2021). The effect of biochar and fertiliser treatment on plant height was in contrast to the report by Silitonga *et al.* (2018) where the effect of NPK fertiliser was significant, while the effect of biochar was not significant. Plant height of our research is in general lower that may be due to infertile soil combined with hot greenhouse conditions and low RH.

4.2 Plant yield

The highest pakchoi yield was 35.57 g plant^{-1} from treatment combination of urea 1.8 g pot^{-1} and biochar pyrolysed at 350 °C. Assuming plant spacing of 20×25 cm, the maximum yield was 6.12 t ha^{-1}, much lower than found in study of Wiangsamut & Koolpluksee (2020) with a yield of 18.76 t ha^{-1}. However, it is close to the productivity of pakchoi in Lampung which is 6.8 t ha^{-1} (BPS, 2020). The combination of acidic-infertile ultisol soil coupled with high temperature and low RH is likely to have caused the low production of pakchoi. Although temperature elevation from 28 to 32 °C causes insignificant effect on yield, but leaf length and leaf area are significantly affected and may have a negative impact on leaf nutrients (Huang *et al.*, 2021). In our case, high temperatures (> 33 °C) occurred seven times when plants were in the age of 4 – 16 DAT and during day 25 – 31 DAT the temperature exceeded 33 °C with three times reaching extreme points (39.2, 42.3, and 43.1 °C). High temperatures impede the growth of pakchoi and between 35 – 40 °C the plants are highly stressed (Okimura & Hanada, 1993).

Pyrolysis temperature had a significant positive effect on crop yields with highest yield (30.6 g) was obtained at 350 °C. Some studies revealed robust effects of pyrolysis temperature on biochar physico-chemical properties valuable for agronomic applications. Increasing slow pyrolysis temperature up to 550 °C is reported to improve SSA and water holding capacity, increase pH, macronutrients availability, and nitrogen absorption in the soil (Cheng *et al.*, 2018). These properties are beneficial for biochar as a soil amendment. Increasing pyrolysis temperature up to 500–600 °C should product which is beneficial for agronomic applications (Huang *et al.*, 2021).

4.3 Water and fertiliser productivity

Water productivity is the ratio of the crop yield to the total evapotranspiration which is equal to water supplied to the plant. Although the effects of nutrient shortages are worse than that of water shortages, in dry areas water availability is a limiting input so that efficient water use has to be managed properly. An increased water productivity due to urea dose is in accordance with Nangia *et al.* (2008) statement where water productivity can be improved by increasing factor inputs provision such as fertiliser. Biochar addition also increased water productivity of pakchoi although at a lower degree. Biochar utilisation as soil amendment for maize improved soil physico-chemical properties, water use efficiency, growth, and yield under deficit irrigation (Faloye *et al.*, 2019). A meta-analysis from a total of 284 data pairs discloses that biochar application increased water use efficiency by 18.8 % (Gao *et al.*, 2020). It can be concluded from Table 3 that higher urea doses combined with biochar application produce higher water productivity.

Fertiliser productivity tends to increase due to the increase in pyrolysis temperature. However, there is a consistent pattern where increasing the dose of fertiliser results in a decrease in fertiliser productivity in each biochar treatment. This means that the increase in pakchoi yield is lower than the rate of increase in fertiliser. Therefore, the application of biochar and chemical fertilisers must be carried out in an integrated manner.

5 Conclusion

Using corncob biochar as a soil enhancer significantly benefits pakchoi cultivation in terms of plant growth and yield as well as water productivity. Increasing pyrolysis temperature significantly improved the parameters of plant height, leaf width, number of leaves, canopy area, and crop yields. Furthermore, biochar application should be combined with chemical fertiliser for the best benefits. The results of this work support other previous studies and enrich the body of knowledge on applying biochar as a soil enhancer. The dose of corncob biochar is believed to donate to the agronomic effects. Therefore, it is necessary to further investigate the effect of the biochar application rate.

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Conflict of interest

The authors declare no potential of competing interest.

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