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The Impact of Pelletized Biochar Soil Application on Sweetcorn Growth and Productivity

Nazri, Ahmad A.Z.[1,5]; Adrian, Marie M.[1]; Adibah, Amin M.[1]; Mahmud, Khairil[2,4]; Ali, Miratul H.M.[6] & Sulaiman, Muhammad F.[1,3]*

[1]*Department of Land Management, Faculty of Agriculture, UPM, Selangor, Malaysia*
[2]*Department of Crop Science, Faculty of Agriculture, UPM, Selangor, Malaysia*
[3]*Laboratory for Climate-Smart Food Production, Institute of Tropical Agriculture and Food Security, UPM, 43400 Serdang, Selangor, Malaysia*
[4]*Biodiversity Unit, Institute of Bioscience, UPM, Selangor, Malaysia*
[5]*Department of Agriculture Malaysia, Level 7-17, Wisma Tani, No. 30 Persiaran Perdana, Presint 4, Pusat Pentadbiran Kerajaan Persekutuan, 62624 Putrajaya, Malaysia*
[6]*Elite Scientific Instruments Sdn. Bhd., B-07-02, Block B,*
Serdang Perdana Selatan, 43300 Seri Kembangan, Selangor, Malaysia

**Corresponding author: muhdfirdaus@upm.edu.my*

ABSTRACT

Biochar application to soil improves soil health, recycles biomass waste, and sequesters carbon. However, biochar's small size and dusty character make it a health hazard when applied. Pelletized biochar has the potential to overcome this issue but, its reduced surface area may affect its effectiveness as a soil amendment. The present study compared the impacts of applying pelletized biochar with unpelletized biochar on the physical and physiological characteristics of sweetcorn, as well as the chemical properties of the soil. The study consisted of five treatments arranged in a randomized complete block design (RCBD): i) unpelletized bamboo biochar (UBB), ii) pelletized bamboo biochar (PBB), iii) pelletized rice husk biochar (PRHB), iv) unpelletized rice husk biochar (URHB), and v) a control group with no biochar application. The application rate for all biochar treatments was 6 Mg ha $^{-1}$*. The study found that the pelletized biochar did not significantly differ from unpelletized biochar for both bamboo and rice husk in terms of soil physical and chemical characteristics. There were no significant differences in plant height, plant leaf area, total leaf area, photosynthetic rate, final biomass, and corn yield between pelletized biochar and unpelletized biochar treatments. The present study demonstrated that compressing biochar into pellets did not render its quality inferior to unpelletized biochar, thus potentially solving its health hazard issue without compromising its efficacy, potentially increasing the widespread use of biochar as a soil conditioner.*

Keywords: rice husk biochar, bamboo biochar, biochar pellet, soil amendment

INTRODUCTION

The application of biochar, a carbon-rich material produced through the pyrolysis of organic matter, has gained significant attention in the agricultural community due to its potential to improve soil properties and enhance crop productivity. Research indicates that the incorporation of biochar into agricultural soils can lead to various benefits, such as improved nutrient retention, increased water-holding capacity, and enhanced soil fertility, although results regarding crop yield remain inconsistent due to factors like biochar type, application rate, and soil characteristics (Mukome *et al*., 2013).

Malaysia being the second largest producer of oil palm generates huge amounts of biomass wastes such as empty fruit bunch, palm mesocarp fiber, palm kernel shell and oil palm trunk (Ooi *et al*., 2017). As such, these wastes have great potential to be converted into biochar. The efficacy of oil palm-based biochar as a soil amendment have been widely studied and discussed (Hwong *et al*., 2022; Gan *et al*., 2023). Nevertheless, oil palm is not the only abundant biomass waste produced in Malaysia. Rice husk, one of the byproducts of rice milling is also abundant and is suitable to be converted into biochar. Rice husk has adsorptive capability, nutrient retention capacity, and high silica content making it suitable to be converted to biochar (Singh Karam *et al*., 2022), besides being a low-cost and renewable resource *(Li et al*., 2023). Other important rice husk properties that make it a suitable feedstock for biochar production are its high carbon content, allowing greater soil carbon sequestration *(Munda et al*., 2018; Linam *et al*., 2023), and its high alkalinity, making it a good soil acidity neutralizer (Prakongkep *et al*., 2013).

While rice husk is mostly available within the vicinity of rice mills, bamboo, another abundant biomass, grows almost everywhere in Malaysia. With an estimated total growing area of 6.7×10^5 ha translating to an annual production of 2×10^6 t, bamboo has great potential to be turned into biochar due to its widespread availability. Furthermore, bamboo in Malaysia is largely underutilized and is mainly processed into small-scale products such as furniture, chopsticks, and handicrafts. Bamboo biochar generally has a high surface area and porosity due to its fibrous structure. This allows it to retain more water and nutrients, improving its ability to enhance soil moisture and nutrient retention. Though rice husk biochar also possess high surface area characteristics, its high silica content may reduce its ability to absorb nutrients compare to bamboo biochar. However unlike rice husk, bamboo in Malaysia faces challenges of ensuring a steady supply of bamboo support large-scale biochar production. For bamboo to become a viable biomass source of biochar feedstock however, sustainable cultivation practices has to be developed.

Nevertheless, despite its beneficial chemical properties, physically biochar is fine, light and has low density. Direct application of biochar to soil poses a great potential health hazard to workers. The 'dusty' state of biochar can cause serious lung damage to workers if inhaled (Amran *et al*., 2021). One of the solutions for solving the field application issue with the dusty nature of biochar is by modifying its physical form into a form that is easier to handle and apply in the field. One way of doing so is by solidifying the dusty constituents of biochar to form pellets (Lau *et al*., 2019). Pelletizing involves extruding the materials under pressure over a dies of fixed diameter holes. The extrusion, with the help of a suitable binder will compress the dusty materials into evenly shaped pellets of similar lengths and will have higher density which improves field application either manually or mechanically. However, biochar pellet will now have reduced surface area as compared to its original state, which will potentially hinder its decomposition and efficacy as a soil amendment (Wystalska *et al*., 2023). The pellets now will have to rely on abiotic factors to hasten its disintegration and subsequent decomposition.

The question however remains on the effectiveness of the pelletized biochar as compared to if they were applied as is in their original form. Future research should explore the rate of disintegration and decomposition of pelletized biochar in soil and determine whether these processes occur rapidly enough to effectively condition the soil and promote the growth of annual crops. The present study was therefore carried out to compare the efficacy of pelletized rice husk and bamboo biochar against their original raw form. The comparison was made at a commercial sweetcorn farm using sweetcorn as the test crop. The hypothesis set out for the present study was that pelletized biochar will have the same effect on soil and the growth and production of sweetcorn as the biochar in their original raw form.

MATERIALS AND METHODS

Preparation of materials

Two types of biochar were used in the study: bamboo biochar and rice husk biochar. Both types were used as is in their original form and they were also pressed to form pellets. The bamboo biochar was obtained from a commercial bamboo biochar producer, Tadom Eco Hills Sdn. Bhd. located in Banting, Selangor, Malaysia. The rice husk biochar was acquired from Sendi Enterprise, a commercial producer of rice husk biochar based in Sekinchan, Selangor, Malaysia. The bamboo biochar and rice husk biochar were heated in an oxygen-deprived kiln at 600℃ for 6 hours and at 400℃ for approximately two hours, respectively. Both variants of biochar were pulverized to pass through a 2 mm sieve using a cutting mill (MF 10 Basic, IKA-Werke GmbH & Co. KG, Staufen, Germany) to ensure uniformity in size. The ground biochar was subsequently examined for their overall carbon (C) and total nitrogen (N) levels using the Dumas method (TruMac CNS, LECO Corp., MI, USA).

The pelletizing process of the rice husk and bamboo biochar involved combining the pulverized biochar with shredded cassava, which served as the binding agent (Gumban et al., 2024; Lubwama et al., 2024). The cassava was shredded using a mechanized coconut grater. The pellets for both biochar types used a biochar to cassava mixing ratio of 3:2. The mixture was compressed and shaped into pellets using a mechanical feed pelletizer attached to a 3 mm circular die. The roller inside the pelletizer compressed the mixtures and extruded the mixture through the die. The extruded pellets were then air-dried before storage in a moisture-free container. The pellets formed from both rice husk and bamboo biochar were ground using a cutting mill and were analyzed for their total carbon and nitrogen content using the Dumas method (TruMac CNS, LECO Corp, MI, USA).

Field Experiment

The field trial for the study was conducted at Mascorn Sdn Bhd, a commercial sweetcorn farm located in Bestari Jaya, Rawang, Selangor, Malaysia (3.3821° N, 101.4554° E). The soil at the site is of the Bungor series (fine, kaolinitic, isohyperthermic, Typic Paleudults). The climate at the research site is categorized as equatorial (Af) based on the Köppen–Geiger climate classification. The measured air temperature fluctuated between 22°C and 35°C, with an average temperature of 27°C. The total precipitation during the experiment was 886.6 mm.

The experimental treatments assigned in this study are listed in **Table 1**. All biochar treatments were applied to the soil at a rate of 6 Mg ha^{-1}. The treatments were surface-broadcasted 14 days before planting and were incorporated into the soil using a hoe. Each treatment has four replications, resulting in 20 experimental units. All experimental units were arranged in a randomized complete block design (RCBD).

Table 1: Treatment label and their description

Treatment	Description
UBB	Unpelletized bamboo biochar + normal fertilization
PBB	Pelletized bamboo biochar + normal fertilization
PRHB	Pelletized rice husk biochar + normal fertilization
URHB	Unpelletized rice husk biochar + normal fertilization
CONTROL	Only normal fertilization without any biochar application to the soil

Sweetcorn (*Zea mays*) was used as the test crop in this study. Each experimental unit consisted of 10 test plants, with two plants in the front and back of each experimental unit acting as buffers. Sweetcorn was planted on September 2, 2023 and harvested on November 4, 2023, 63 days after planting. The plot size used was 1.1 m × 1.5 m (width × length). Agronomic practices were carried out according to the standard procedure practiced by the farm. Compound fertilizer N-P-K (12:12:17:2) was applied in each experimental plot at the rate of 10 g plant^{-1}. The compound fertilizer N-P-K green was applied at 14 days after transplanting, while N-P-K blue was applied at 28 days after transplanting.

Soil chemical properties

Soil samples were collected during pre-planting, during the reproductive stage, and harvest. Soil samples were collected using an Edelman auger from the 0-15 cm layer. Collected soil samples were air-dried, crushed using a pestle and mortar, and sieved to pass through a 2 mm sieve. The soil pH level was determined using a pH meter (SevenCompact S213, METTLER-TOLEDO Inc., Columbus, OH, USA), using a soil-to-water ratio of 1:2.5 (weight/volume basis). The soil cation exchange capacity (CEC) and concentration of basic cations were determined using the leaching method using 1N ammonium acetate (NH_4OAc) buffered at pH 7.0. Soil available phosphorus (P) was determined using the Bray and Kurtz II method. The concentration of basic cations was determined using an atomic absorption spectrometer (PinAAcle 500, Perkin-Elmer Inc., Waltham, MA, USA) while the concentrations of ammonium (NH_4^+) and P were determined using an auto-analyzer (AA500 AutoAnalyzer, SEAL Analytical Ltd., Wrexham, UK).

Plant physical and physiological measurement

The plant height was measured from the base of the stem to the top of the uppermost leaf every two weeks from transplant until the maturing stage. Total plant leaf area was determined using a portable leaf area meter (LI-3000C, LI-COR Biosciences Inc., Lincoln, NE, USA), where the scanning head was placed over the leaf near the petiole and the encoding cord was pulled over the leaf until the apex. Three plants from each experimental unit were selected for measurement with all leaves from the selected plants measured for their area.

Leaf photosynthesis rate was measured using a portable photosynthesis system with an integrated fluorescence chamber head of 6 cm^2 (LI-6800, LI-COR Biosciences Inc., Lincoln, NE, USA). The most fully expanded leaf was selected (one leaf) for measurements from three plants from each experimental unit. The survey mode setup was used during measurement. The CO_2 concentration was supplied to the chamber at 400 $\mu mol\ mol^{-1}$ and the light intensity (Q) was set at 1200 $\mu mol\ m^{-2}\ s^{-1}$. Chamber temperature and relative humidity were set at 27°C and 60%, respectively. The leaf photosynthesis rates were measured on 28, 41, and 60 DAT.

Measurements of leaf chlorophyll content were made using a portable chlorophyll meter (SPAD-502Plus Konica Minolta Inc., Tokyo, Japan). Similar to leaf photosynthesis rate measurement, the most fully expanded leaf was selected for measurements from three plants from each experimental unit for measurement using the leaf chlorophyll meter. However, unlike leaf photosynthesis rate measurement, leaf chlorophyll content measurements were carried out every two weeks throughout the study.

Plant yield and biomass

The corn was harvested at 63 DAT. At harvest, plant biomass was sampled from each experimental unit cutting the corn plant as close as possible to the soil surface. The corn plant was immediately separated into its cob, stalk, and leaves. All plant parts were measured for fresh weight on-site using a field scale. Subsamples of the leaves and stalk were brought back and oven-dried at 60°C until constant weight for the determination of moisture content and subsequent processing for elemental content analysis.

Plant tissue elemental analysis

The elemental content of corn biomass samples was determined using the dry ashing method Jones (2001). Oven-dried plant tissues were ground to pass through a 1 mm sieve, and 0.5 g of the sample was ashed at 500°C for 8 hours. After cooling, the ash was treated with distilled water, 5 ml of HCl, and 10 ml of HNO_3, then diluted to 100 ml. The solution was filtered and analyzed using an atomic absorption spectrometer (PinAAcle 500, Perkin-Elmer Inc., Waltham, MA, USA).

Statistical analysis

All measurements were analyzed using a one-way analysis of variance (ANOVA). The separation of means between treatments was determined using the Least Significant Difference (LSD) using R ver. 4.3.2 (R Core Team, 2021). A significance level of $P<0.05$ was used.

RESULTS AND DISCUSSION

Effects of biochar forms on soil chemical properties

The chemical properties of the soil sampled at harvest, 63 days after transplant (DAT) are listed in **Table 2**. Overall, the pelletized and unpelletized biochar treatments were observed to have no significant difference between each other in almost all the soil chemical properties. There were no significant differences ($p<0.05$) between treatments for soil pH, CEC, Ca, and Mg. There were however differences between the biochar treatments compared to the control treatment. The pelletized biochar (UBB) showed significantly higher soil exchangeable potassium compared to the control while for total nitrogen, only UBB was significantly higher than the control and pelletized rice husk biochar (URHB). One possibility is that nitrogen may be increased due to the ability of biochar to retain nitrate which is easily leached. This is supported by Pathak *et al.* (2022), who observed higher levels of nitrogen in soil because of decreased nitrogen leaching from the soil. Meanwhile, for soil-available phosphorus (P), only bamboo biochar in both forms, unpelletized (UBB) and pelletized (PBB) showed a significant difference to the control.

Soil pH observations in this study diverged from those of Ichsan et al. (2023), who reported an increase in soil pH from 4.57 to 5.03 following the application of 10 t ha^{-1} of biochar. Similarly, Rodríguez-Vila *et al.* (2022) found that the application of corn cob biochar to acidic soil elevated soil pH from 4.89 to 6.92, whereas rice husk biochar reduced pH in acidic soils. This phenomenon is consistent with observations made by (Zhang, 2021), who suggested that biochar’s large surface area, having numerous functional groups, facilitates the release of OH^- ions, contributing to the rise of soil pH. Conversely, Chathurika *et al*. (2016) noted that in alkaline soils (pH > 7.5), increasing biochar application can adversely affect soil by reducing nutrient availability and microbial activity. In the present study, soil pH was slightly above neutral, ranging from 7.37 to 7.49, potentially explaining the limited interaction between biochar and soil. This observation aligns with Wang *et al.* (2022), who highlighted the negative impact of biochar addition on pH and liming effects in alkaline soils.

The lack of significant results between the biochar treatments and the control treatment observed in this study may be attributed to the relatively low application rate of biochar, which could require higher rates, as much as 30 Mg ha^{-1} as suggested by previous studies (Feng *et al*., 2021). Nevertheless, the practical application of large quantities of biochar may pose logistical challenges, including increased transportation costs, potentially limiting its feasibility. Although no significant differences were observed between pelletized and unpelletized biochar in terms of carbon content across treatments, the carbon content in the biochar-amended soils increased compared to the control. This suggests that biochar contributes to enhanced carbon sequestration, as it reduces atmospheric carbon dioxide and enhances soil carbon storage. This finding aligns with Xu *et al.* (2015) who demonstrated that biochar increased soil carbon through the addition of recalcitrant carbon.

Table 2: Chemical properties of soil sampled during harvest

Treatment	**pH**	**C (%)**	**N (%)**	**CEC (cmol$_c$ kg^{-1})**	**P (cmol$_c$ kg^{-1})**	**K (cmol$_c$ kg^{-1})**	**Ca (cmol$_c$ kg^{-1})**	**Mg (cmol$_c$ kg^{-1})**
UBB	7.44a±0.03	2.17ab±0.11	0.21a ± 0.11	13.11a±2.39	0.38a± 0.15	1.98a±0.10	8.14a±3.71	3.65a±0.05
PBB	7.49a±0.08	2.57a±0.58	0.19ab±0.58	14.09a±1.46	0.38a±0.14	1.80ab 0.12	9.84a±2.99	3.19a±0.13
PRHB	7.37a±0.07	2.42a±0.23	0.19ab±0.23	12.51a±1.67	0.32ab±0.11	1.73ab±0.06	12.64a±4.89	3.24a±0.08
URHB	7.38a±0.05	2.34a±0.24	0.17b±0.24	13.03a±0.84	0.31ab±0.07	1.68ab±0.18	10.32a±3.31	3.28a±0.22
CONTROL	7.41a±0.06	1.48b±0.05	0.17b±0.05	11.32a±0.75	0.25b±0.08	1.48b±0.12	10.30a±3.28	3.53a±0.33

Note: Means within the same column followed by the same letter are not significantly different among treatments at $p < 0.05$; (LSD test). The column presents the mean values ± standard error. UBB = pelletized bamboo biochar, PBB = Unpelletized bamboo biochar, PRHB = Unpelletized Rice Husk biochar, URHB = Pelletized Rice Husk biochar, CONTROL = Control

Effects of biochar source and form on the physical and physiological characteristics of sweetcorn

The impact of biochar treatments on the leaf chlorophyll content (LCC) and the photosynthetic rate of sweetcorn is presented in **Tables 3** and **4**. **Table 3** illustrates the effects of pelletized and unpelletized biochar on chlorophyll content, revealing no statistically significant differences between the forms of biochar and against the control treatment throughout the growing season. Similarly, as shown in Table 4, there were no significant differences in the photosynthetic rate of sweetcorn plants between the two biochar treatments.

Table 3: Leaf chlorophyll content measured on days 14, 28, and 41 after transplant

Treatment	**Days after transplant**		
	14	**28**	**41**
UBB	43.09a ± 2.49	50.62a ± 0.75	49.07a ± 0.97
PBB	40.34a ± 3.80	50.75a ± 0.64	48.20a ± 1.13
PRHB	44.93a ± 1.85	49.91a ± 0.75	50.08a ± 1.06
URHB	43.67a ± 2.94	49.74a ± 0.25	47.49a ± 2.35
CONTROL	42.35a ± 1.01	48.02a ± 2.42	47.37a ± 0.57

Note: Means within the same column followed by the same letter are not significantly different among treatments at $p < 0.05$; (LSD test). The column presents the mean values ± standard error. UBB = pelletized bamboo biochar, PBB = Unpelletized bamboo biochar, PRHB = Unpelletized Rice Husk biochar, URHB = Pelletized Rice Husk biochar, CONTROL = Control

Table 4: Leaf photosynthesis rate (μmol CO_2 m^{-2} s^{-1}) on days 28 and 41 after transplant

Treatment	**Days after transplant**	
	28	**41**
UBB	61.35a ± 4.90	49.86a ± 4.10
PBB	59.12a ± 3.61	52.18a ± 5.18
PRHB	63.88a ± 4.66	43.16a ± 5.73
URHB	58.91a ± 4.47	50.62a ± 3.57
CONTROL	64.43a ± 4.98	49.51a ± 2.91

Note: Means within the same column followed by the same letter are not significantly different among treatments at $p < 0.05$; (LSD test). The column presents the mean values ± standard error. UBB = pelletized bamboo biochar, PBB = Unpelletized bamboo biochar, PRHB = Unpelletized Rice Husk biochar, URHB = Pelletized Rice Husk biochar, CONTROL = Control

The results for the total leaf area of sweetcorn are presented in **Table 5**. At 14 DAT, analysis of variance revealed a significant difference between treatments, with PBB showing significantly lower total leaf area compared to UBB, PRHB, and the control. However, no significant differences in total leaf area were observed between treatments when measured at 28 DAT.

The plant height of sweetcorn under different treatments is detailed in **Table 6**. At both 14 and 28 DAT, analysis of variance revealed no significant differences among the treatments. However, by 41 DAT, the tallest plants were observed in treatment PRHB, while the shortest was recorded in the control treatment. At this stage, the analysis of variance indicated significant differences in plant height between the treatments.

Table 5: Total leaf area (cm^2) of sweetcorn on days 28 and 41 after transplant

Treatments	**Days after transplant**	
	14	**28**
UBB	258.10ab ± 48.34	3773.84a ± 465.57
PBB	110.98c ± 45.03	3364.10a ± 350.74
PRHB	237.29ab ± 28.36	3826.85a ± 282.18
URHB	161.93bc ± 27.36	3574.53a ± 122.38
CONTROL	336.19ab ± 52.52	4359.80a ± 194.27

Note: Means within the same column followed by the same letter are not significantly different among treatments at $p < 0.05$; (LSD test). The column presents the mean values ± standard error. UBB = pelletized bamboo biochar, PBB = Unpelletized bamboo biochar, PRHB = Unpelletized Rice Husk biochar, URHB = Pelletized Rice Husk biochar, CONTROL = Control

Table 6: Plant height (cm) measured on 14, 28, and 41 DAT

Treatment	**Days after transplant**		
	14	**28**	**41**
UBB	24.29a ± 1.38	83.82ab ± 6.49	184.54ab ± 3.26
PBB	21.57a ± 1.80	76.19b ± 3.86	174.50bc ± 4.54
PRHB	24.44a ± 1.70	85.15a ± 4.65	185.88a ± 4.01
URHB	21.56a ± 1.41	78.63ab ± 6.45	181.65ab ± 3.19
CONTROL	23.00a ± 1.23	83.82ab ± 7.98	170.54c ± 7.07

Note: The means with the same letters above the bars are not significantly different among treatments at $p < 0.05$; (LSD Test). The standard error of 4 replications is shown by bar errors. UBB = pelletized bamboo biochar, PBB = Unpelletized bamboo biochar, PRHB = Unpelletized Rice Husk biochar, URHB = Pelletized Rice Husk biochar, CONTROL = Control

Plant tissue elemental content

The elemental content in plant tissue taken during harvest is reported in **Table 7**. The one-way analysis of variance showed that there were no significant differences between the treatments at $p < 0.05$.

Table 7: Elemental content of plant tissue sampled during harvest

Treatment	**Element (%)**			
	P	**K**	**Ca**	**Mg**
UBB	0.14a ± 0.01	1.44a ± 0.06	0.20b ± 0.01	0.13a ± 0.01
PBB	0.15a ± 0.01	1.38a ± 0.05	0.21ab ± 0.01	0.13a ± 0.01
PRHB	0.15a ± 0.01	1.51a ± 0.05	0.21ab ± 0.01	0.13a ± 0.00
URHB	0.15a ± 0.01	1.36a ± 0.08	0.22ab ± 0.01	0.12a ± 0.01
CONTROL	0.16a ± 0.00	1.45a ± 0.08	0.22a ± 0.01	0.13a ± 0.01

Note: The means with the same letters above the bars are not significantly different among treatments at $p < 0.05$; (LSD Test). The standard error of 4 replications is shown by bar errors. UBB = pelletized bamboo biochar, PBB = Unpelletized bamboo biochar, PRHB = Unpelletized Rice Husk biochar, URHB = Pelletized Rice Husk biochar, CONTROL = Control

Plant yield and plant biomass

The corn yield and plant biomass for each experimental unit are presented in **Table 8**. Corn yield ranged from 3934.60 kg ha^{-1} to 5706.83 kg ha^{-1} while plant biomass ranged from 3690.69 kg ha^{-1} to 4223.98 kg ha^{-1}. The one-way analysis of variance shows there were no significant differences at $p < 0.05$ between treatments on corn yield and plant biomass.

Table 8: Corn yield and plant biomass (dry matter) at harvest

Treatment	**Yield (kg ha^{-1})**	**Biomass (kg ha^{-1})**
UBB	5238.74a ± 186.54	3690.69a ± 172.53
PBB	5494.23a ± 1423.53	3878.06a ± 219.79
PRHB	3934.60a ± 308.48	3856.52a ± 337.41
URHB	5476.62a ± 479.75	3428.53a ± 374.94
CONTROL	5706.84a ± 854.78	4223.98a ± 316.67

Note: The means with the same letters above the bars are not significantly different among treatments at $p < 0.05$; (LSD Test). The standard error of 4 replications is shown by bar errors. UBB = pelletized bamboo biochar, PBB = Unpelletized bamboo biochar, PRHB = Unpelletized Rice Husk biochar, URHB = Pelletized Rice Husk biochar, CONTROL = Control

Overall, the application of pelletized and unpelletized biochar treatments did not significantly affect plant morphological characteristics. This contradicted the findings of Khan *et al*. (2022) who reported that biochar positively influences the plant height, stem diameter, leaf area index (LAI), leaves, stem, root, and crop growth rate (CGR), and dry weight of plants. According to Khan *et al.* (2022), applying biochar can improve the soil's physical condition, which further helps in the decomposition of organic carbon in the soil, thus increasing the organic matter and higher nutrient availability in the soil, which improves the crop's growth and plant height. Similar observations were also made by Ndor *et al.* (2016) who found that biochar, when used as a soil amendment, positively affects plant growth and serves as a carbon sink in the soil.

For total leaf area, however, the study by Wan *et al*. (2023) found that applying biochar decreases the leaf area in maize plants; similar to the findings of the present study. They also found that having a small leaf area will increase the nitrogen concentration in the leaf. However, the same observation was not observed in the present study, biochar application neither increased nitrogen concentration in the leaf nor increased SPAD value.

The leaf photosynthesis rate and chlorophyll content in the present study showed no significant differences between the treatments contrasted with the findings of Ren *et al*. (2021). In their study, the reason why there is an increase in total leaf area, SPAD value, and photosynthesis rate is that the biochar itself is good for the microorganisms in the soil, which will also enhance the soil fertility and root growth. Good root growth will increase uptake of plant nutrients by crops, which will lead to a positive result in the plant's physiological parameter. Wang *et al*. (2021) further support this by stating that biochar application increases plant nitrogen accumulation, correlating linearly with the photosynthesis rate. The contradicting findings of the present study with previous literatures may suggest that the duration after application of biochar, regardless of its form, in the present study may be too short exert any effects to the soil, hence the lack significant changes on plant morphology.

CONCLUSION

In conclusion, the application of biochar did not show significant differences between the treatments when applied to the soil for sweetcorn production. There were no differences in soil pH, soil electrical conductivity, soil nutrient, total leaf area, photosynthesis rate, chlorophyll content of corn, plant nutrients as well as plant height and plant yield and biomass. Thus, the there is no significant difference between pelletized and unpelletized biochar on soil quality and plant development. Though the beneficial effects of soil application of biochar were not observed, the present study demonstrated that forming biochar into pellets were not different than if it is applied in its original dusty form. Thus, pelletizing biochar may help to reduce its health hazard risk without compromising its efficacy. Nevertheless, biochar application to soil did show an increase of soil carbon content compared to the control soil (2.38% vs. 1.48%). The contradictory findings of this study, however, may be due to the brief duration of the experiment for the biochar to show its effectiveness as a soil amendment. Future research work could explore more on extending the time frame to further investigate the potential impacts of biochar on plant growth and soil parameters.

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REFERENCES

Amran, M., G. Murali, R. Fediuk, N. Vatin, Y. Vasilev, et al. 2021. Palm oil fuel ash-based eco-efficient concrete: A critical review of the short-term properties. *Materials* 14(2): 332.

Chathurika, J.A.S., D. Kumaragamage, F. Zvomuya, O.O. Akinremi, D.N. Flaten, et al. 2016. Woodchip biochar with or without synthetic fertilizers affects soil properties and available phosphorus in two alkaline, chernozemic soils. *Can. J. Soil Sci.* 96(4): 472–484.

Feng, W., F. Yang, R. Cen, J. Liu, Z. Qu, et al. 2021. Effects of straw biochar application on soil temperature, available nitrogen and growth of corn. *J. Environ. Manage*. 277: 111331.

Gan, S., R.S. Chen, F.N.M. Padzil, S. Moosavi, A.T. Mou'ad, et al. 2023. Potential valorization of oil palm fiber in versatile applications towards sustainability: A review. Ind. Crops Prod. 199: 116763.

Gumban, M.M., L.J. Manuel, R. Bawar, and J. Elauria. 2024. Effects of varying binder proportions to the mechanical, physico-chemical and combustion properties of Banana (*Musa acuminata* x *balbisiana*) leaves-derived biochar briquettes. *Philipp. J. Agric. Biosyst. Eng*. 20(1).

Hwong, C.N., S.F. Sim, L.K. Kho, Y. Teh, L. David, et al. 2022. Effects of biochar from oil palm biomass on soil properties and growth performance of oil palm seedlings. *J. Sustain. Sci. Manag*. 17(4): 183–200.

Ichsan, C.N., W.S. Mahfira, A. Halim, and J. Juliawati. 2023. Mitigation of drought disaster in sorghum (*Sorghum bicolor* l. Moench) in Ultisol soil with application of soil amendments and NPK for diversification and improvement of food security. *IOP Conf. Ser. Earth Environ. Sci*. 1183(1): 012076.

Jones, J.B. 2001. Laboratory guide for conducting soil tests and plant analysis. CRC Press.

Khan, I., B. Iqbal, A.A. Khan, Inamullah, A. Rehman, et al. 2022. The interactive impact of straw mulch and biochar application positively enhanced the growth indexes of maize (*Zea mays* L.) *Crop. Agronomy* 12(10): 2584.

Lau, S.Y., S.L. Phuan, M.K. Danquah, and C. Acquah. 2019. Sustainable palm oil refining using pelletized and surface-modified oil palm boiler ash (OPBA) biosorbent. *J. Clean. Prod*. 230: 527–535.

Li, Z., Z. Zheng, H. Li, D. Xu, X. Li, et al. 2023. Review on rice husk biochar as an adsorbent for soil and water remediation. *Plants* 12(7): 1524.

Linam, F., M.A. Limmer, A.M. Ebling, and A.L. Seyfferth. 2023. Rice husk and husk biochar soil amendments store soil carbon while water management controls dissolved organic matter chemistry in well-weathered soil. *J. Environ. Manage*. 339: 117936.

Lubwama, M., A. Birungi, A. Nuwamanya, and V.A. Yiga. 2024. Characteristics of rice husk biochar briquettes with municipal solid waste cassava, sweet potato and matooke peelings as binders. Mater. Renew. Sustain. *Energy* 13(2): 243–254.

Mukome, F.N.D., X. Zhang, L.C.R. Silva, J. Six, and S.J. Parikh. 2013. Use of chemical and physical characteristics to investigate trends in biochar feedstocks. *J. Agric. Food Chem.* 61(9): 2196–2204.

Munda, S., D. Bhaduri, S. Mohanty, D. Chatterjee, R. Tripathi, et al. 2018. Dynamics of soil organic carbon mineralization and C fractions in paddy soil on application of rice husk biochar. *Biomass Bioenergy* 115: 1–9.

Ndor, E., J.O. Jayeoba, C. Asadu, and E. Iheshiulo. 2016. Growth, nutrient uptake and dry matter yield of maize (*Zea mays* L) grown in soil amended with rice husk and sawdust biochar. *Int. J. Sci. Res. Agric. Sci*. 3: 99–103.

Ooi, Z.X., Y.P. Teoh, B. Kunasundari, and S.H. Shuit. 2017. Oil palm frond as a sustainable and promising biomass source in Malaysia: A review. *Environ. Prog. Sustain. Energy* 36(6): 1864–1874.

Prakongkep, N., R. Gilkes, W. Wiriyakitnateekul, A. Duangchan, and T. Darunsontaya. 2013. The effects of pyrolysis conditions on the chemical and physical properties of rice husk biochar. *IJMSCI* 3: 98–103.

R Core Team. 2021. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Ren, T., H. Wang, Y. Yuan, H. Feng, B. Wang, et al. 2021. Effects of Biochar on Root System Development and Leaf Photosynthetic Characteristics of Flue-cured Tobacco by the Three-years Located Experiment. Under review. https://doi.org/10.21203/rs.3.rs-278676/v1

Rodríguez-Vila, A., L. Atuah, A.H. Abubakari, D.W. Atorqui, A. Abdul-Karim, et al. 2022. Effect of biochar on micronutrient availability and uptake into leafy greens in two urban tropical soils with contrasting soil pH. F*ront. Sustain. Food Syst.* 6. https://www.frontiersin.org/articles/10.3389/fsufs.2022.821397 (accessed 11 January 2024).

Singh Karam, D., P. Nagabovanalli, K. Sundara Rajoo, C. Fauziah Ishak, A. Abdu, et al. 2022. An overview on the preparation of rice husk biochar, factors affecting its properties, and its agriculture application. *J. Saudi Soc. Agric. Sci.* 21(3): 149–159.

Wan, H., X. Liu, Q. Shi, Y. Chen, M. Jiang, et al. 2023. Biochar amendment alters root morphology of maize plant: Its implications in enhancing nutrient uptake and shoot growth under reduced irrigation regimes. *Front. Plant Sci*. 14: 1122742.

Wang, Z., J.-L. Cheng, Y. Bian, C.-L. Zheng, W. Wang, et al. 2022. Effect of aging on stabilization of Cd^{2+} through biochar use in alkaline soil of Bayan Obo Mining Area. *Huan Jing Ke Xue Huanjing Kexue* 43(11): 5205–5213.

Wang, S., J. Zheng, Y. Wang, Q. Yang, T. Chen, et al. 2021. Photosynthesis, chlorophyll fluorescence, and yield of peanut in response to biochar application. *Front. Plant Sci*. 12: 650432.

Wystalska, K., A. Kwarciak-Kozłowska, and R. Włodarczyk. 2023. Influence of technical parameters of the pyrolysis process on the surface area, porosity, and hydrophobicity of biochar from sunflower husk pellet. *Sustainability* 15(1).

Xu, G., X. Yang, and L. Spinosa. 2015. Development of sludge-based adsorbents: Preparation, characterization, utilization and its feasibility assessment. *J. Environ. Manage*. 151: 221–232.

Zhang, Z. 2021. Characteristics of biochar and its role in the remediation of heavy metals in soil. *IOP Conf. Ser. Earth Environ. Sci*. 687(1): 012023.