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Research Article

Impact of Biochar on Growth and Productivity of Broccoli in Coastal areas

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ABSTRACT

Agricultural practices in coastal regions face significant challenges due to poor soil quality and limited nutrient availability. This study investigates the impact of maize straw biochar on the growth and yield of broccoli (*Brassica oleracea*) in Bangladesh's coastal region, aiming to improve crop performance while reducing dependence on conventional fertilizers. Biochar is expected to enhance soil quality by improving water retention, nutrient availability and microbial activity, making it a promising soil amendment in challenging agricultural conditions. From December 2021 to March 2022, five biochar treatments (0, 2, 4, 6 and 8 tons/ha) were utilized in the field experiment. Each treatment was duplicated three times using a Randomized Complete Block Design (RCBD). The results suggested that biochar greatly enhanced a number of growth parameters, such as leaf length, leaf breadth, dry curd weight and chlorophyll content. The highest yield (5.35 tons/ha) and primary curd weight were achieved with 8 tons/ha of biochar. However, no significant differences were observed in plant height, leaf number or primary curd diameter across treatments. These findings suggest that biochar, particularly at 8 tons/ha, is a promising soil amendment for enhancing broccoli productivity in coastal regions. Further research is recommended to explore the long-term impacts of biochar and its interactions with environmental factors and soil properties to optimize its use in agricultural systems.

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Introduction

Broccoli (*Brassica oleracea*, Italica cultivar group) is an edible green vegetable renowned for its health benefits, including cancer risk reduction and enhanced immune function (Ravikumar, 2015; Drewnowski, 2013). This cool-season crop is primarily cultivated in Asia during winter, particularly in regions with less precipitation and elevated evapotranspiration (Hussain et al., 2016). Despite its nutritional advantages, broccoli is not widely grown in the coastal areas of Bangladesh. Interest in its cultivation has surged markedly owing to its capacity to improve health outcomes, as it is rich in bioactive compounds, vitamins and minerals (Wu et al., 2013; Kelly et al., 1985; Owis, 2015).

Soil fertility poses a significant challenge to vegetable production, especially in coastal regions where salinity and nutrient depletion are prevalent. Traditional farming practices often rely on synthetic fertilizers, which can degrade soil quality over time. While organic fertilizers have been examined as a sustainable alternative, they may sometimes lead to reduced agricultural production. Biochar, a carbon-rich byproduct of biomass pyrolysis, offers a feasible remedy to these challenges (Montoya et al., 2022). Commonly referred to as "Black Gold," biochar is produced in low-oxygen conditions, transforming agricultural waste into a stable carbon form that enhances soil quality (Oni et al., 2019). Various waste biomasses, including rice husks, sawdust and sugarcane residues, are frequently utilized in the production of biochar (Baquy et al., 2022).

Incorporating biochar into broccoli cultivation can enhance soil fertility by improving nutrient retention and availability, which are critical for broccoli's growth and yield. Research suggests that biochar can assist in the mitigation of salinity stress by enhancing moisture retention, fostering beneficial microbial activity and improving soil structure (Montoya et al., 2022). These factors contribute to improved overall crop productivity, increased nutrient absorption and healthier broccoli plants. Biochar's utilization in this

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investigation is intended to establish a more favorable growing environment for broccoli in the coastal regions of Bangladesh, as broccoli is susceptible to saline conditions.

In Bangladesh, the degradation of soil due to improper biomass management is a pressing concern. Biochar has the potential to address these obstacles by increasing soil fertility, improving water retention, and sequestering carbon (Lehmann et al., 2006). The treatment promotes sustainable agricultural practices by improving the physical, chemical, and biological qualities of the soil (Awad et al., 2018). Biochar is a desirable supplement for coastal saline agriculture due to its immediate advantages, which include sustained improvements in soil health and increased crop yield (Lin et al., 2015).

The potential of biochar to enhance soil quality is particularly relevant for broccoli cultivation in Bangladesh's coastal regions. Research suggests that the development, production, and nutritional content of numerous Brassica crops can be significantly improved through the use of biochar (Boersma et al., 2017). Biochar enhances soil structure and nutrient availability, which may mitigate broccoli's susceptibility to salinity stress (Zhang et al., 2019). Additionally, the formation of stable soil aggregates, which are essential for the retention of moisture and nutrients in coastal soils, may be facilitated by biochar (Sun et al., 2022).

Despite the promising results from global studies, there remains a lack of research specifically focusing on biochar's effectiveness in enhancing broccoli production in Bangladesh's coastal environments. In order to promote sustainable agricultural practices in the region, it is crucial to address the gaps in the current literature regarding the application of biochar, particularly in saline soils. The objective of this investigation is to assess the impact of biochar on the cultivation of broccoli and soil fertility in the coastal regions of Bangladesh. We seek to explicitly understand how biochar can mitigate salinity stress, improve crop productivity and ultimately enhance the livelihoods of local farmers. By investigating these aspects, this research will contribute to the broader goal of sustainable agriculture in Bangladesh's southern coastal regions.

Materials and Methods

Experimental site

The experiment was conducted at the Agriculture Field of Noakhali Science and Technology University, Sonapur, Noakhali, from December 2021 to March 2022. The site is located at 22.79187°N latitude and 91.10073°E longitude. The site is part of the 18th agro-ecological region, the "Young Meghna Estuarine Floodplain," featuring medium-high land. This region, influenced by the Meghna estuary, experiences continuous deposition and erosion. The soil is stratified, mildly calcareous silt, with variable salinity during the dry season. Seasonal flooding is typically shallow, influenced by rainfall, river inflows, and occasionally by saltwater during high tides and cyclones.

Climatic condition

The site has a tropical climate (Köppen-Geiger classification: Aw), characterized by wetter summers and drier winters. The average annual temperature is 25.2°C (77.3°F), with 2218 mm (87.3 inches) of annual precipitation. During the experimental period, the maximum temperature ranged from 25.4°C to 32°C, and the minimum ranged from 12.6°C to 20.3°C. Meteorological data were sourced from Climate-Data.org.

Soil characteristics

The soil of the experimental site was sandy loam in texture, medium high land.

Table 1. Physio-chemical properties of soil tested by SRDI (December, 2021) prior to conduct this experiment

Sl. No.	Test parameters	Unit	Test results	Interpretation
01	pH	-	7.42	Mildly alkaline
02	Moisture	%	1.56	Moderate Dry
03	Electrical conductivity	µS/cm	111	Low level of salinity
04	Total Organic carbon	%	1.37	Medium
05	Total Organic matter	%	2.36	Medium

Experimental materials

“Barbara” a cultivar of broccoli (*Brassica oleracea var. italica* L) was cultivated as experimental material.

Experimental treatments

We preferred five treatments of maize straw biochar. Five treatments are respectively T_0 = 0 ton/ha, T_1 = 2 ton/ha, T_2 = 4 ton/ha, T_3 = 6 ton/ha, T_4 = 8 ton/ha. These were produced by CCDB Biochar Project of Shibalaya, Manikgonj. While biochar derived from wood is frequently utilized in agricultural research, we opted for biochar produced from maize straw to explore its distinct impact on broccoli development. The maize straw biochar was generated through the pyrolysis process, which entails the thermal decomposition of organic material at elevated temperatures in an oxygen-limiting environment. This method usually stabilizes the biomass's carbon content and improves its soil-amending qualities, turning it into biochar. Pyrolysis is a process that produces biochar while preserving its advantageous properties, like higher porosity and nutrient retention, which makes it appropriate for use in agriculture. This was accomplished with the assistance of the CCDB Biochar Project.

Experimental design and layout

A Randomized Complete Block Design (RCBD) with three replications was used to set up the experimental treatments. The experimental field was divided into three blocks, each containing five 1.36 m^2 (0.96 m × 1.42 m) unit plots. The space kept between two unit plots was 0.25 meters while the space between blocks was 0.50 meters. Each plot received 6 seedlings, making the total number of plants in the experiment 6 × 15 = 90. Five biochar treatments (0, 2, 4, 6 and 8 tons per hectare) were utilized in the field experiment.

The randomization of biochar treatments to different blocks was conducted using a systematic method to guarantee impartial treatment distribution. This approach effectively mitigates any bias from environmental gradients and ensures accurate implementation of randomization at both the block and plot levels.

The chosen biochar treatment levels were to investigate various potential effects on soil quality and broccoli cultivation. The lower rates (2 and 4 tons per hectare) were selected to represent feasible levels for local farmers, while higher rates (6 and 8 tons per hectare) were incorporated to evaluate potential diminishing returns or adverse impacts associated with increased biochar applications. The 0-ton treatment functioned as a control to establish a baseline for comparison. This method facilitated the assessment of incremental variations in growth and production, as well as the determination of the optimal usage rate.

Crop husbandry

Raising seedling

Seedlings were raised using a mixture of 50% cocodust, 40% vermicompost, 5% biodarma powder and 5% gypsum in a seedling tray on December 2, 2021. The seeds were kept in a shaded area after sprouting to protect them from direct sunlight, with light watering as needed. Seed germination began on December 8, 2021, and on January 13, 2022, healthy 35-day-old seedlings were transplanted into the experimental field.

Land preparation

It began on January 3, 2022, with ploughing and cross-ploughing, followed by laddering to break up large soil clods. Weeds and stubbles were removed and the experimental plots were prepared according to the specified method before applying biochar.

Fertilizer and amendments

Dose of applied fertilizers

We used regular and recommended dose of NPK fertilizers with Boron in broccoli cultivation. The recommended dose was N (120kg/ha), P (60kg/ha),K (40kg/ha),B (15kg/ha) (Chand, 2017). These were applied during soil preparation.

Transplanting and after care

Healthy 35-day-old seedlings were transplanted on January 13, 2022, in the afternoon. Each seedling received light watering for better establishment. To protect the seedlings from the morning sun, banana leaf sheaths were used as shade, which were removed before sundown daily until the seedlings were established. Additional seedlings were planted around the perimeter of the experimental plots for gap filling.

Intercultural operation

Weeding was done for 3 times and gap filling was done just after 10 DAT. Irrigtion were given 2-3 days interval as the temperature was increasing day by day. The regular watering was essential for the soil to maintain optimal moisture levels, particularly in light of the biochar's known water retention properties, which may have impacted the overall irrigation requirements.

Pest and disease control

Throughout the season, we faced considerable difficulties concerning pest and disease management. Aphids significantly affected the plants around 30 days after transplanting, and Alternaria leaf spot disease proliferated rapidly after an unexpected rain event that intensified pathogenic activity. We applied Carbendazim to mitigate the problem and monitored the plants closely for pest outbreaks. Ladybug beetles were observed in the field, serving as natural predators of aphids and may have contributed to reducing their populations.

Harvesting

Harvesting occurred between February 22 and March 20, 2022, as curd initiation and maturation varied among plants, likely due to different biochar dosages. Only compact, mature curds were harvested. While secondary shoots were expected to produce smaller curds after harvesting the primary curd, disease severity and the end of the season reduced the likelihood of their development. Compact curds were collected before the flower buds opened, following the method of Thompson and Kelly (1985).

Data collection

Data were recorded from three randomly selected plants per unit plot, except for curd yield, which was measured on a per-plot basis. The random selection of plants was performed by selecting plants from different areas of each plot to ensure a representative sample. Growth parameters were collected at 15, 35, and 60 days post-transplanting, while development parameters were documented at harvest. Random selection ensured that the data were representative of each plot, providing insights into plant growth, development, health and productivity.

Plant height (cm)

Plant height was measured from the base to the tip of the main stem on three randomly selected plants per unit plot. Measurements were taken in centimeters at 15, 35, and 60 days after transplanting (DAT) to monitor growth over time. Average heights were calculated from these measurements.

Number of leaves per plant

The number of leaves on three randomly selected plants per unit plot was counted, and the average was calculated. Counts were recorded at 15, 35, and 60 DAT to track leaf growth.

Leaf length (cm)

Leaf length was measured from the base of the petiole to the tip of the leaf using a meter scale. Measurements were taken on leaves from three randomly selected plants at 15, 35, and 60 DAT, ensuring only mature leaves were measured.

Leaf breadth (cm)

Leaf breadth was measured at the widest part of the lamina using a meter scale. Measurements were taken from three randomly selected plants at harvest and at 15, 45, and 60 days after sowing (DAS), with an emphasis on mature leaves and excluding the smallest immature ones. Average breadth was calculated from these measurements.

Stem diameter (cm)

At final harvest, the stem diameter was measured using a meter scale at multiple points around the circumference to ensure accuracy. The average diameter, recorded in centimeters (cm), was calculated from these measurements.

Diameter of primary curd (cm)

The diameter of the primary curd was measured with a meter scale at final harvest, taking measurements from various directions to cover the entire surface. The average diameter, recorded in centimeters (cm), was calculated from these measurements.

Weight of primary curd (g)

To determine the weight of the central curd, we carefully excluded the weight of all secondary marketable curds and recorded the value in grams (g).

Percent dry matter of curd

To determine the dry matter of the curd, a 100 g sample was first sun-dried for 72 hours to remove excess moisture, then oven-dried at 70°C for 3 days. The dry weight was recorded using an electric balance. The following formula was used to compute the percentage of dry matter:

Percent dry matter = (Weight of dry matter/Fresh weight) × 100

Percent dry matter of leaf

For leaf dry matter, a 100 g sample was sun-dried for 72 hours, followed by oven-drying at 70°C for 3 days. The following formula was used to compute the percentage of dry matter:

Percent dry matter = (Weight of dry matter/Fresh weight) × 100

Chlorophyll content (µmol m^{-2})

Chlorophyll content was measured using a SPAD meter, which provides a SPAD unit reading. This reading was recorded and used to estimate chlorophyll content in µmol m^{-2}.

Yield per plant (g)

Due to it being the off-season and the absence of secondary curds, each plant produced only one curd. The yield per plant was recorded as the weight of the curd in grams (g).

Yield per plot (kg)

The weight of all the plant curds from each unit plot was added to get the yield per unit plot which was represented in kilograms (kg).

Total yield (ton/ha)

By converting the curd weight per plot and recording it in tons per hectare, the yield of curd per hectare was determined.

Statistical analysis

Data were analyzed using IBM SPSS Statistics, where descriptive statistics and one-way ANOVA were conducted to assess differences in broccoli growth and productivity. Graphs illustrating the results were generated in Microsoft Excel 2016. The general linear model was applied to assess the impact of treatments and varieties on the variables. Significant differences between treatments and varieties were identified using Tukey's HSD post-hoc analysis. Statistical significance was evaluated at the 5% level, with numerical data presented as means ± standard error of the mean (SEM).

Results

Plant height

The effect of biochar on broccoli plant height was assessed at three intervals: 15, 35, and 60 days after transplanting (DAT). Although ANOVA results indicated that the treatments did not produce statistically significant differences in plant height at any time point (F-values: 0.982, 1.981, and 0.291 at 15, 35, and 60 DAT, respectively; p-values > 0.05), descriptive data showed some variations. At 15 DAT, the tallest plants were in the T_1 group (11.47 cm), while T_4 had the shortest (9.49 cm). By 35 DAT, T_3 had the greatest mean height of 16.47 cm. At 60 DAT, both the control (T_0) and T_3 exhibited the tallest plants with mean heights of 20.24 cm and 20.89 cm, respectively (Figure 1). Despite these numerical differences, none of the height variations between treatments were statistically significant at the 0.05 alpha level.

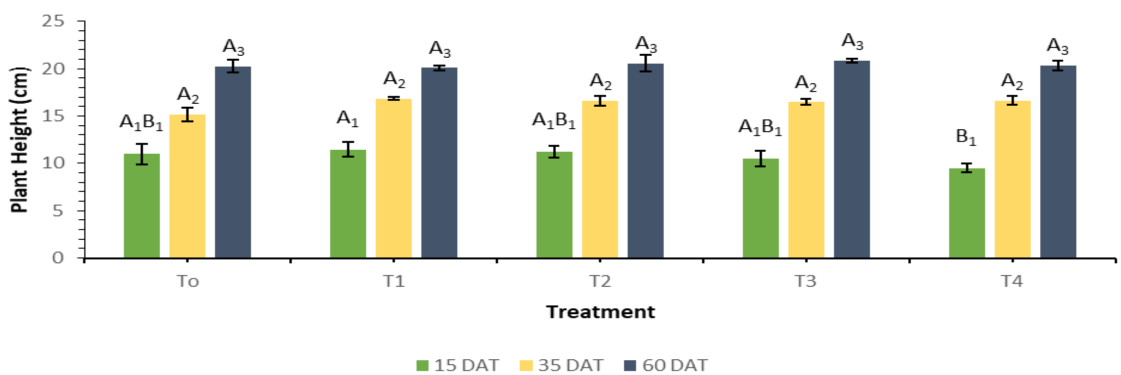

Figure 1. Effect of corn (maize straw) biochar doses on plant height at 15, 35 and 60 DAT. T_o = Control, T_1 = 2 ton/ha, T_2 = 4 ton/ha,T_3 = 6 ton/ha,T_4 = 8 ton/ha. Data are the averages of three replicates ± SEM (standard error mean). The values with different characters eg. A_1, B_1 indicate significancy (*p<0.05) over control.

Leaf number per plant

ANOVA results showed no statistically significant effect of biochar on the number of leaves per plant at 15, 35, or 60 DAT (p-values > 0.05). The F-values were 2.406, 0.631, and 0.322 at 15, 35, and 60 DAT, respectively. However, the average number of leaves increased over time across all treatments. At 15 DAT, the mean number of leaves ranged from 5.78 (T_4) to 6.89 (T_1). By 60 DAT, leaf counts had increased, ranging from 14.33 in T_4 to 15.33 in T_2 and T_3 (Figure 2). Despite these variations in leaf numbers, no significant differences between treatments were observed.

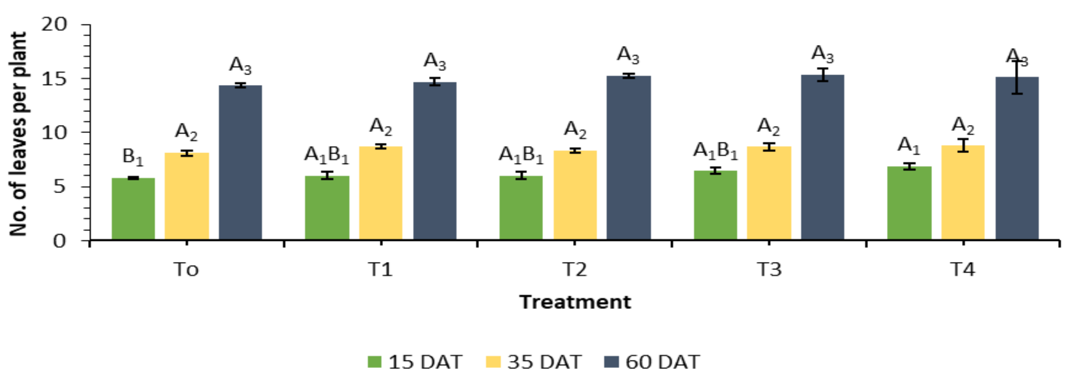

Figure 2. Effect of corn (maize straw) biochar doses on leaf no. at 15,35 and 60 DAT.T_o = Control,T_1 = 2 ton/ha,T_2 = 4 ton/ha,T_3 = 6 ton/ha,T_4 = 8 ton/ha.Data are the averages of three replicates ± SEM (standard error mean). The values with different characters eg. A_1, B_1 indicate significancy (*p<0.05) over control.

Leaf breadth

Biochar had a significant effect on leaf breadth at both 15 and 60 DAT, as indicated by ANOVA results (F-values: 4.663, p = 0.022 at 15 DAT; F = 10.901, p = 0.001 at 60 DAT). At 15 DAT, T_4 exhibited the widest leaves (4.38 cm), while the control (T_0) had the narrowest (3.48 cm). Similar trends were observed at 35 and 60 DAT, with T_4 consistently showing the largest leaf breadth (16.72 cm at 35 DAT and 18.89 cm at 60 DAT) compared to T_0 (15.24 cm and 17.00 cm, respectively). The increase in leaf breadth over time was observed in all treatments (Figure 3), with significant differences between groups at key time points.

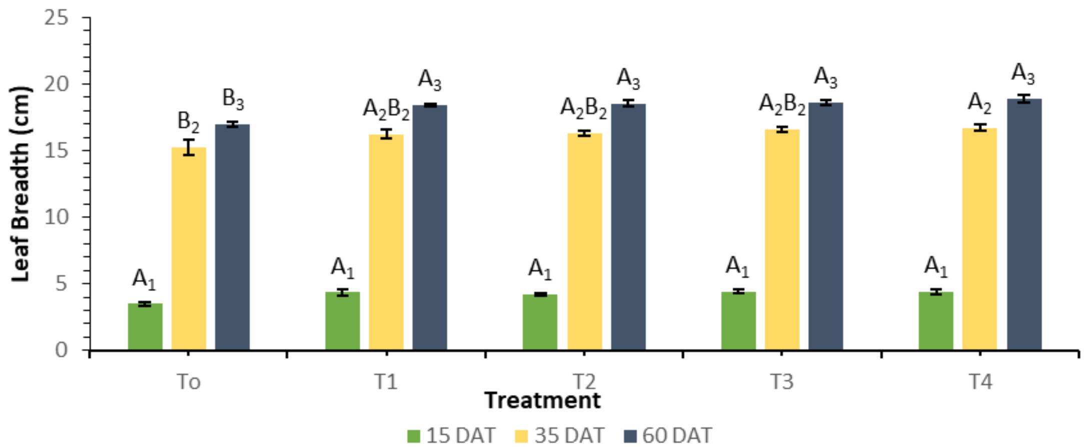

Figure 3. Effect of corn (maize straw) biochar doses on leaf breadth at 15,35 and 60 DAT.T_o = Control,T_1 = 2 ton/ha,T_2 = 4 ton/ha,T_3 = 6 ton/ha,T_4 = 8 ton/ha.Data are the averages of three replicates ± SEM (standard error mean). The values with different characters eg. A_2,B_2 indicate significancy (*p<0.05) over control.

Leaf length

Leaf length varied significantly between treatments at 15 and 35 DAT, as confirmed by ANOVA results (F = 5.315, p = 0.015 at 15 DAT; F = 5.792, p = 0.011 at 35 DAT). At 15 DAT, the longest leaves were recorded in T_1 (7.90 cm), followed by T_3 (7.72 cm), while T_4 had the shortest leaves (7.14 cm). This trend continued at 35 DAT, where T_1 again had the longest leaves (24.55 cm), and T_0 the shortest (21.51 cm). Despite these significant differences, no significant variations in leaf length were observed at 60 DAT (F = 0.970, p = 0.465) (Figure 4).

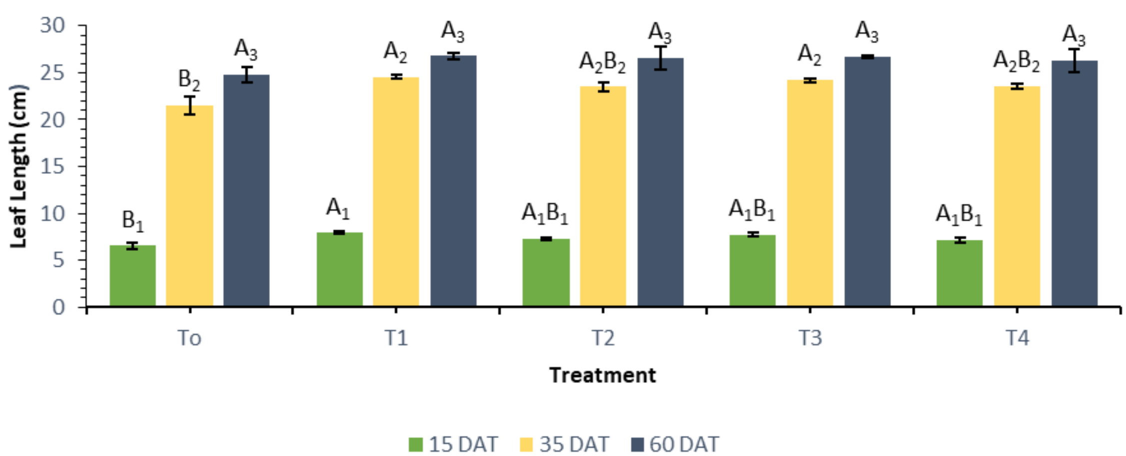

Figure 4. Effect of corn (maize straw) biochar doses on leaf length at 15,35 and 60 DAT.T_o = Control,T_1 = 2 ton/ha,T_2 = 4 ton/ha,T_3 = 6 ton/ha,T_4 = 8 ton/ha.Data are the averages of three replicates ± SEM (standard error mean). The values with different characters eg. A_1, B_1 and A_2,B_2 indicate significancy (*p<0.05) over control.

Primary curd weight

The primary curd weight showed a highly significant response to biochar treatments (F = 46.07, p = 0.00). T_4 produced the heaviest curds (110.11 g), followed by T_3 (105.79 g), T_2 (93.35 g), and T_1 (87.28 g), while the control (T_0) had the lowest curd weight at 81.25 g. The significance level between T_0 and T_4 was particularly strong ($p < 0.05$), indicating that biochar, particularly in the T_4 treatment, contributed significantly to increased curd weight. However, no significant differences were observed between T_0 and T_1 ($p = 0.199$) or between T_1 and T_2 ($p = 0.196$), showing that the lower biochar doses did not have a substantial impact (Figure 5).

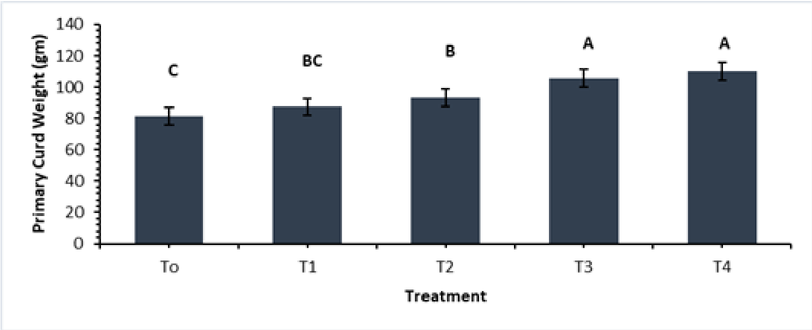

Figure 5. Effect of corn (maize straw) biochar doses on primary curd weight.T_o = Control,T_1 = 2 ton/ha,T_2 = 4 ton/ha,T_3 = 6 ton/ha,T_4 = 8 ton/ha.Data are the averages of three replicates ± SEM (standard error mean). The values with different characters eg. A,B,C indicate significancy (*p<0.05) over control.

Stem diameter

Biochar treatments significantly affected stem diameter ($F = 4.94$, $p = 0.018$). T_4 had the largest mean stem diameter (3.13 cm), while the control (T_0) had the smallest (2.63 cm). The other treatments showed intermediate stem diameters, with T_3 and T_1 at 2.75 cm and 2.79 cm, respectively, and T_2 at 2.85 cm. The difference between T_0 and T_4 was significant, though close to the threshold ($p = 0.054$), indicating a potential relationship between biochar dosage and stem growth (Figure 6).

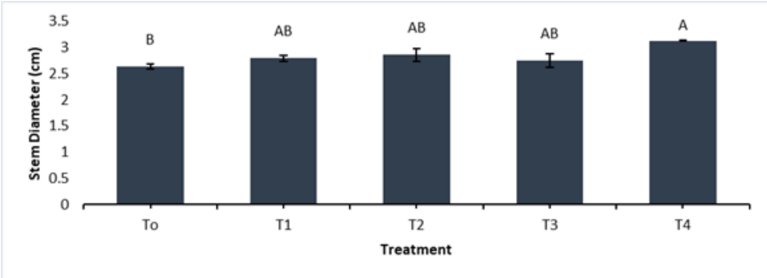

Figure 6. Effect of corn (maize straw) biochar doses on stem diameter.T_o = Control,T_1 = 2 ton/ha,T_2 = 4 ton/ha,T_3 = 6 ton/ha,T_4 = 8 ton/ha.Data are the averages of three replicates ± SEM (standard error mean). The values with different characters e.g. A,B indicate significancy (*p<0.05) over control.

Primary curd diameter

ANOVA results indicated no significant effect of treatments on primary curd diameter ($F = 2.36$, $p = 0.123$). While T_4 exhibited the largest mean curd diameter (23.34 cm), followed by T_3 (22.15 cm), T_2 (22.19 cm), T_0 (21.27 cm), and T_1 (20.53 cm), these differences were not statistically significant ($p > 0.05$) (Figure 7).

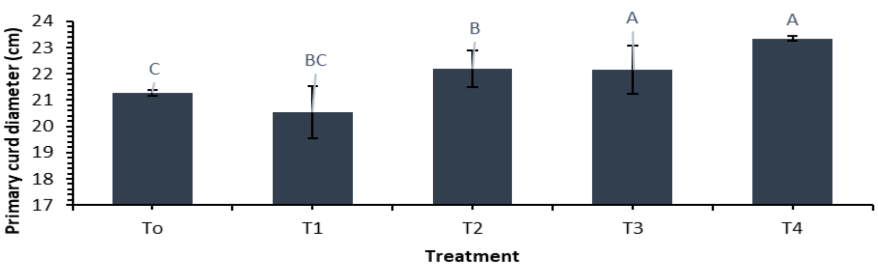

Figure 7. Effect of corn (maize straw) biochar doses on primary curd diameter.T_o = Control,T_1 = 2 ton/ha,T_2 = 4 ton/ha,T_3 = 6 ton/ha,T_4 = 8 ton/ha.Data are the averages of three replicates ± SEM (standard error mean). The values with different characters eg. A,B,C indicate significancy (*p<0.05) over control.

Dry weight of curd

Biochar significantly influenced the dry weight of broccoli curds ($F = 48.84$, $p = 0.00$). T_4 produced the heaviest dry curds, followed by T_3 and T_2, while the control had the lowest dry weight. Differences between T_1 and T_3 ($p = 0.118$) and T_1 and T_4 ($p = 0.136$) were also significant, indicating that higher biochar levels positively affected curd dry weight (Figure 8).

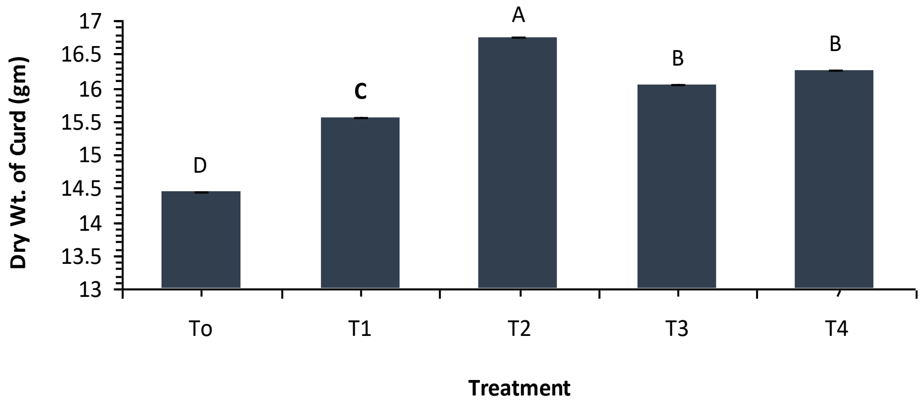

Figure 8. Effect of corn (maize straw) biochar doses on dry weight of curd.T_o = Control,T_1 = 2 ton/ha,T_2 = 4 ton/ha,T_3 = 6 ton/ha,T_4 = 8 ton/ha.Data are the averages of three replicates ± SEM (standard error mean). The values with different characters eg. A,B,C,D indicate significancy (*$p<0.05$) over control.

Dry weight of leaves

The dry weight of leaves showed a significant response to biochar treatments ($F = 76.70$, $p = 0.00$). T_3 and T_4 produced the highest leaf dry weights, with T_2 recording the maximum mean value. In contrast, the control (T_0) had the lowest leaf dry weight. The results suggest a positive correlation between biochar application and increased leaf biomass (Figure 9).

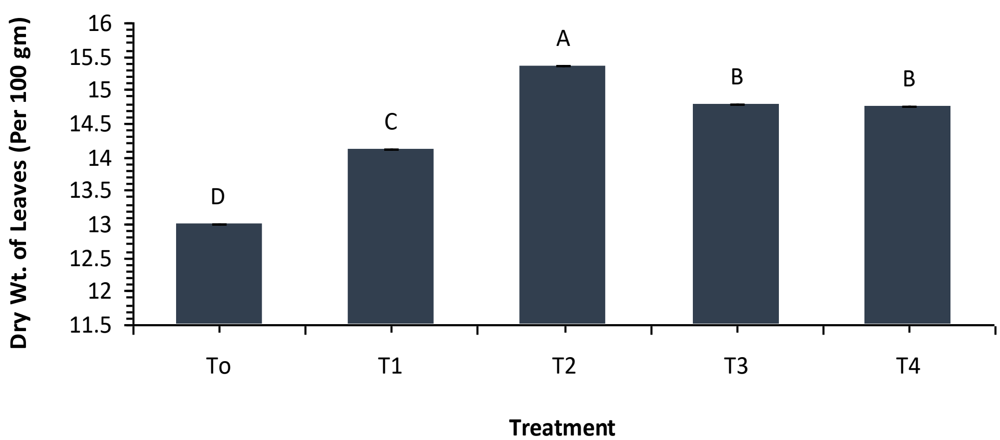

Figure 9. Effect of corn (maize straw) biochar doses on dry weight of leaves.T_o = Control,T_1 = 2 ton/ha,T_2 = 4 ton/ha,T_3 = 6 ton/ha,T_4 = 8 ton/ha.Data are the averages of three replicates ± SEM (standard error mean). The values with different characters eg. A,B,C,D indicate significancy (*$p<0.05$) over control.

Chlorophyll content (µmol m^{-2})

Chlorophyll content was significantly affected by biochar treatments ($F = 127.68$, $p = 0.00$). There were notable differences in chlorophyll content between the treatment groups, with T_2 showing a particularly high level of chlorophyll. Significant differences were observed between the control (T_0) and T_2 ($p = 0.999$), as well as between the other treatment pairs (T_1 vs. T_2, T_3 vs. T_2, and T_4 vs. T_2), highlighting the impact of biochar on chlorophyll accumulation (Figure 10).

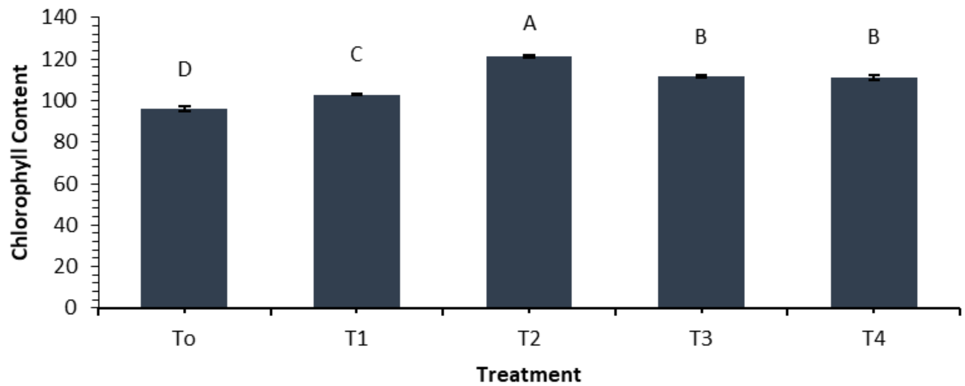

Figure 10. Effect of corn (maize straw) biochar doses on chlorophyll content.T_o = Control,T_1 = 2 ton/ha,T_2 = 4 ton/ha,T_3 = 6 ton/ha,T_4 = 8 ton/ha.Data are the averages of three replicates ± SEM (standard error mean). The values with different characters eg. A,B,C,D indicate significancy (*p<0.05) over control.

Total yield (ton/ha)

The total yield of broccoli also showed a significant response to biochar treatments ($F = 46.07$, $p = 0.00$). T_1 was significantly different from T_3 and T_4 at the 0.05 level, with T_3 and T_4 showing higher yields. However, no significant difference was found between the control and T_1, or between T_3 and T_4 (Figure 11). This indicates that higher biochar levels contributed to increased yield, but the impact plateaued between the two highest treatments.

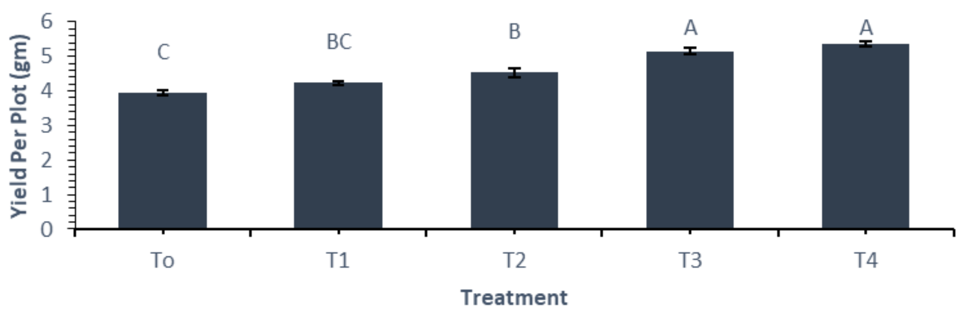

Figure 11. Effect of corn (maize straw) biochar doses on total yield. To = Control,T1 = 2 ton/ha,T2 = 4 ton/ha,T3 = 6 ton/ha,T4 = 8 ton/ha.Data are the averages of three replicates ± SEM (standard error mean). The values with different characters eg. A,B,C,D indicate significancy (*p<0.05) over control.

Discussion

This experiment aimed to evaluate the effects of maize straw biochar on the growth properties of broccoli, specifically the "Barbara" variety. The use of biochar did not considerably enhance plant height or leaf number, while some differences were evident. Previous studies suggested that biochar positively affected these characteristics; however, our findings demonstrate the contrary. Consider the study by Silva Gonzaga et al. (2019) on *Brassica juncea*, which shown significant impacts on plant height and growth-related characteristics. Conversely, Jabborova et al. (2021) noted significant enhancements in the growth properties of tomato and spinach. Our research revealed considerable variations in leaf breadth at 35 and 60 days after transplanting (DAT), especially with T_0 demonstrating notable variances in comparison to T_4. Moreover, significant changes in leaf length were recorded at 15 and 35 DAT, however no significant changes were found at 60 days after transplanting. This discovery contradicts earlier research demonstrating significant impacts of biochar on the dimensions of spinach leaves (Jabborova et al., 2021).

Additionally, significant variations in primary curd weight and stem diameter have been observed by us, which is consistent with the results of Rahman et al. (2022) who reported a 1262 g increase in cabbage head weight as a result of using biochar. Notably, whereas biochar markedly influenced the dry weight of curd and leaves, its impacts on curd width were found to be insignificant, contradicting the positive outcomes reported by Rahman et al. (2022). The chlorophyll content in broccoli leaves was significantly impacted by biochar, supporting the findings of Sun et al. (2020), which indicated fluctuations in chlorophyll contents in tomato seedlings. Our investigation revealed a significant increase in total output, with T_4 treatment attaining the maximum yield of 5.35 tons/ha. This result corresponds with the findings of Zhao et al. (2022), which indicated that biochar can improve yield relative to conventional fertilization alone. The discrepancies between our results and those of prior studies may arise from variances in experimental settings, encompassing differences in biochar content, soil types, and environmental factors. These disparities necessitate additional research to clarify the mechanisms by which biochar influences plant growth, including modifications in soil structure and microbial communities.

Conclusion and Recommendations

This study explored an innovative approach that reduces dependence on conventional fertilizers while enhancing environmental sustainability in broccoli farming. The results suggest that several treatments of maize straw biochar affected broccoli development characteristics to differing extents. T_4 had the most favorable results, attaining the highest total yield of 5.35 tons/ha, as well as notable enhancements in primary curd weight and stem diameter. T_2 treatment yielded the most significant results for dry weight of curd, leaves and chlorophyll content. Significant differences were also observed in leaf breadth at 35 and 60 days after transplanting (DAT) and in leaf length at 15 and 35 DAT. The highest leaf breadth was recorded at 35 DAT and 60 DAT due to T_3 treatment, while the longest leaf lengths were noted at 7.72 cm (T_3 at 15 DAT) and 24.209 cm (T_1 at 35 DAT).

Despite these positive findings, plant height, leaf number per plant and primary curd diameter exhibited no significant changes following biochar application. These non-significant results may be attributed to factors such as the small sample size, limited experimental area, potential pest impacts and unstable climatic conditions. In order to fully understand the cause-and-effect relationships between biochar and broccoli growth, it is imperative to conduct additional experiments with larger sample sizes and controlled environments, despite the significant efforts that were made to ensure the accuracy of this study. This study suggests that T_4 treatment of maize straw biochar should be considered for optimal broccoli cultivation, since it yielded the most favorable results overall. Subsequent research should include a conventional wood biochar treatment as a comparative benchmark to elucidate the relative benefits of maize straw biochar in contrast to typical wood biochar.

Additionally, the impact of microclimatic fluctuations, pest infestations and disease occurrences must be considered, particularly during essential growth phases. Implementing effective pest and disease management measures during the growing season will enable a thorough assessment of biochar treatments on broccoli growth and yield. Furthermore, executing experiments throughout several growing seasons will yield insights into the impact of biochar applications on both short-term and long-term crop performance under diverse environmental conditions. This study's shortcomings must be recognized, especially the lack of secondary characteristics, including soil properties and climatic circumstances, which are essential for comprehending biochar's comprehensive effects in agricultural systems. Future research ought to examine these secondary parameters to augment our comprehension of the connections between biochar treatments and environmental conditions, hence improving the efficacy of biochar in enhancing crop performance.

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