



A Comparative Analysis of Biochar Amendment in Enhancing Late-Season Growth and Yield of Cruciferous Vegetables in Coastal Bangladesh

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Abstract

Coastal areas of Bangladesh face significant agricultural challenges due to saline soils, nutrient deficiencies, and environmental stressors, particularly during the late growing season. This study evaluates the comparative effects of biochar application on the growth and yield of cauliflower (*Brassica oleracea* var. *botrytis*) and broccoli (*Brassica oleracea* var. *italica*) under these conditions. Biochar, a carbon-rich soil amendment, has been shown to improve soil fertility, water retention, and decrease soil salinity, making it a promising solution for sustainable crop production. The study examined the impact of biochar amendment at four rates (2, 4, 6 and 8 tons/ha) on key growth parameters, including plant height, leaf size, curd weight, and yield. Results revealed that while biochar significantly improved growth metrics across both crops, cauliflower demonstrated a more pronounced response in terms of yield and curd weight. Early-stage growth (15 days) showed improvements in leaf number, while leaf size and curd weight benefits persisted throughout the season. Interaction effects between crop type and biochar amendment were crop-specific, highlighting the need for tailored application strategies. This research underscores biochar's potential to enhance late-season growth and yield in coastal regions, offering critical insights for optimizing agricultural practices in resource-constrained environments.

Keywords: Biochar, Broccoli, Cauliflower, Coastal Agriculture, Crop Yield

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Introduction

Agriculture in coastal Bangladesh faces numerous challenges due to the prevalence of saline soils, nutrient deficiencies and climatic stresses (Haque, 2006). Cruciferous vegetables like cauliflower (*Brassica oleracea* var. botrytis) and broccoli (*Brassica oleracea* var. italica) are important crops due to their nutritional value and market demand (Shinali et al., 2024). In coastal Bangladesh, cauliflower and broccoli are mainly grown during the winter season (November–January), but many farmers extend cultivation into the late season (February–March) to increase cropping intensity and benefit from higher market prices. During this period, rising soil salinity, reduced soil moisture, and nutrient imbalance severely limit crop growth and yield (AZM et al., 2018). Therefore, improving soil resilience during the late season is critical for sustainable vegetable production in coastal areas. To address these challenges, biochar, a carbon-rich product created from the pyrolysis of organic materials, has emerged as a promising soil amendment (Chakradhar & Dattatray Chougale, 2024). Biochar is known for its potential to enhance soil fertility, improve water retention, and decrease soil salinity, thus promoting better growth and productivity in crops (Khan et al., 2024).

The positive effects of biochar amendment on soil properties have been well-documented in various studies. Karim et al. (2020) demonstrated that biochar could significantly improve soil health by enhancing soil fertility, increasing cation exchange capacity, and promoting better soil structure. These benefits are especially crucial in coastal Bangladesh, where soil degradation, salinity, and poor nutrient retention hinder agricultural production. In this context, the application of biochar could play a pivotal role in improving the growth and yield of crops like cauliflower and broccoli (Boersma et al., 2017).

While much research has been conducted on the general benefits of biochar for soil improvement, less attention has been paid to its specific impact on late season growth and yield of cruciferous vegetables, particularly in coastal areas of Bangladesh. Studies like those by Ahmed and Ali (2013) highlighted the nutritional benefits of cauliflower, suggesting that improved cultivation practices, such as biochar application, could further enhance these benefits. However, the optimal use of biochar in late season cultivation of these vegetables remains an under-explored area.

One critical gap in current research is the comparative evaluation of biochar amendment on both cauliflower and broccoli, which are similar in their growth requirements but may respond differently to biochar application. Previous studies have shown that biochar can improve plant growth (Nayem et al., 2024), but its effectiveness varies depending on crop type and the soil conditions. For example, Haque et al., 2019 found that biochar application improved cauliflower yield in specific regions, while the benefits for other cruciferous crops, like broccoli, were less clearly defined. Moreover, the impact of biochar on late season growth, when environmental stressors are most significant, has not been adequately explored for these crops in the coastal regions of Bangladesh.

The primary objective of this research is to evaluate the comparative impact of biochar on the late season growth and yield of cauliflower and broccoli in coastal Bangladesh. Specifically, this study aims to determine which of the two crops responds better to biochar application in the coastal region. The findings could be helpful to farmers' decision making regarding the use of this soil amendment to maximize productivity during the late season when crop growth

Materials and methods

Experimental site

The experiment was conducted in 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.

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. The field experiment was conducted during the late winter cropping period, when soil salinity and environmental stress are typically higher in coastal Bangladesh.

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 prior to conduct this experiment

Sl. No.	Test parameters	Unit	Test results	Interpretation
1	pH	-	7.42	Mildly alkaline
2	Moisture	%	1.56	Moderate Dry
3	Electrical conductivity	μS/cm	111	Low level of salinity
4	Total Organic carbon	%	1.37	Medium
5	Total Organic matter	%	2.36	Medium

Experimental materials

Broccoli

The cultivar used for this study was “Barbara,” a variety of broccoli (*Brassica oleracea* var. *italica* L), known for its yield potential and adaptability to various environmental conditions.

Cauliflower

For cauliflower, the “Snow White” variety was selected. This variety is characterized by its pure white heads and mild flavor, and it is recognized for its early maturation, typically ready for harvest 55-65 days post-transplanting.

Experimental treatments

Both crops were subjected to five maize-straw biochar treatments: $T_0 = 0 \text{ t ha}^{-1}$ (control), $T_1 = 2 \text{ t ha}^{-1}$, $T_2 = 4 \text{ t ha}^{-1}$, $T_3 = 6 \text{ t ha}^{-1}$, and $T_4 = 8 \text{ t ha}^{-1}$. These rates were selected to represent a gradient from low to high application levels based on commonly reported biochar doses in tropical and saline soils and to identify an agronomically and economically feasible optimum for smallholder farmers. Lower rates ($2\text{--}4 \text{ t ha}^{-1}$) reflect financially realistic farmer inputs, while higher rates ($6\text{--}8 \text{ t ha}^{-1}$) were included to evaluate whether additional benefits justify increased application costs. The biochar was supplied by the CCDB Biochar Project, Shibalaya, Manikganj.

Experimental design and layout

A Randomized Complete Block Design (RCBD) with three replications was employed for both crops. The experimental field was divided into three blocks, each containing five-unit plots of 1.36 m^2 for broccoli ($0.96 \text{ m} \times 1.2 \text{ m}$) and 1.92 m^2 for cauliflower ($1.65 \text{ m} \times 1.2 \text{ m}$). Each plot contained six seedlings, resulting in a total of 90 plants across the experiment. The planting layout is summarized below: space:

Parameter	Broccoli (m)	Cauliflower (m)
Plot size	0.96×1.2	1.65×1.2
Plant spacing	0.46×0.46	0.45×0.50
Spacing between blocks	0.50	0.50
Spacing between plots	0.25	0.25

Crop husbandry

Seedling preparation:

Seedlings for broccoli were raised using a mixture of 50% cocodust, 40% vermicompost, 5% biodarma powder and 5% gypsum. They were sown on December 2, 2021, and transplanted 35 days later on January 13, 2022, after germination began on December 8, 2021. For cauliflower, seedlings were collected from a local nursery and transplanted at 20 days of age.

Land preparation:

Land preparation for both crops commenced on January 3, 2022, involving ploughing and cross-ploughing to break up soil clods and remove weeds and stubbles. The final plot preparation occurred on January 13, 2022, to maintain soil fertility.

Fertilization and biochar application:

The recommended dose (Chand, 2017) of NPK fertilizers (N: 120 kg/ha, P: 60 kg/ha, K: 40 kg/ha, and B: 15 kg/ha) was applied during soil preparation for broccoli. Biochar treatments were mixed into the soil according to the treatment plan on January 25, 2022, eight days before transplanting.

Transplanting and aftercare:

Seedlings were transplanted in the afternoon, with initial watering to aid establishment. Banana leaf sheaths were used for shading during the first days after transplanting. For cauliflower, the same watering practices and care were followed, ensuring the soil remained moist.

Intercultural operations:

Weeding was conducted thrice for both crops, with gap filling done shortly after 10 days of transplanting (DAT). Irrigation was provided every 2-3 days as temperatures increased.

Pest and disease control:

Both broccoli and cauliflower faced significant pest and disease challenges during the growing season. For broccoli, severe aphid infestations occurred around 30 days after transplanting (DAT), which were managed through biological control methods, including the help of beneficial insects like ladybugs, along with fungicide applications to combat *Alternaria* leaf spot disease exacerbated by humid conditions. In contrast, cauliflower encountered a more severe pest issue, with various pests such as aphids, cabbage loopers, and diamondback moths causing considerable damage. Despite hand-picking efforts, chemical insecticides, including pyrethroids and neem oil, were necessary to control these pests, alongside management strategies for diseases like downy mildew and black rot. Regular monitoring and cultural practices were crucial for mitigating these challenges and protecting overall crop health.

Harvesting

Harvesting of both crops took place between March 10 to March 24, 2022, with the timing influenced by variations in curd initiation and maturation among plants, likely due to differing biochar application rates. Only compact, mature curds were collected to ensure quality, as secondary shoots were anticipated to yield smaller curds following the harvest of the primary curd. However, increased disease severity and the approaching end of the growing season significantly hindered the development of these secondary curds. The harvesting process adhered to the guidelines established by Thompson and Kelly (1985), focusing on collecting compact curds before the flower buds opened to maximize yield and quality.

Methods of data collection

Data for this study were collected from three randomly selected plants per unit plot, ensuring that measurements accurately reflected the entire experimental area. Growth parameters were recorded at three key intervals: 15, 35, and 60 days after transplanting (DAT), while yield and other development parameters were assessed at harvest.

Plant height (cm)

Plant height was measured from the base to the tip of the main stem of three randomly selected plants per unit plot at 15, 35, and 60 DAT. The average heights were calculated to monitor growth over time.

Number of leaves per plant

The number of leaves on three randomly selected plants per unit plot was counted at 15, 35, and 60 DAT, and averages were calculated to track leaf development.

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 from three randomly selected plants at each growth stage, focusing on mature leaves.

Leaf breadth (cm)

Leaf breadth was measured at the broadest part of the leaf using a meter scale. Data were collected from three randomly selected plants at 15, 35, and 60 days after sowing (DAS), emphasizing mature leaves.

Stem diameter (cm)

At final harvest, stem diameter was measured at multiple points around the circumference to ensure accuracy, and an average diameter was recorded in centimeters (cm).

Primary curd weight (g)

The weight of the primary curd was recorded for each plant, excluding secondary marketable curds. The weight was noted in grams (g).

Curd dry weight (g)

The curds were harvested at maturity and a representative sample of each plot was taken. Samples were first chopped into small pieces and then oven-dried at 70 °C for 48 hours until a constant weight was achieved. The dry weight was recorded using a digital balance (± 0.01 g) and expressed in grams per curd. This measurement contributed to the assessment of curd quality.

Yield (kg)

Yield per plot was calculated by summing the fresh weight of all curds harvested from each plot, expressed in kilograms (kg). The fresh weight per plot was then converted to tons per hectare to determine the yield per hectare.

Statistical analysis

Data were analysed using R programming for both statistical computations and graphical representations. A two-way Analysis of Variance (ANOVA) was performed to evaluate the impact of two factors: crop type (cauliflower vs. broccoli) and biochar treatment (control and four application rates: 2, 4, 6, and 8 tons/ha) on individual growth and yield parameters. Tukey's Honestly Significant Difference (HSD) post-hoc test was applied to identify significant differences between treatment means. Interaction plots and bar plots were generated using R to visualize the relationships between crop types, biochar treatments and the measured parameters. Statistical significance was determined at the 5% level and all numerical data were presented as means \pm standard error of the mean (SEM).

Results

The analysis of variance (ANOVA) results for various growth and yield parameters of cauliflower and broccoli in response to biochar application at different stages of growth (15, 35, and 60 days after planting) reveal significant effects of crop type and biochar treatments, with some variations between the two crops.

Plant height

At 15 days after planting, crop type significantly influenced plant height ($F = 52.427$, $p < 0.001$), but biochar treatments and its interaction with crop type did not show significant effects, suggesting minimal influence of biochar at this early stage. By 35 days, both crop type ($F = 252.307$, $p < 0.001$) and biochar treatments ($F = 4.886$, $p = 0.007$) had a significant impact on plant height, although the interaction between crop type and biochar was not significant. By 60 days, crop type continued to have a significant effect ($F = 417.912$, $p < 0.001$), but the effects of biochar and the interaction term were no longer significant. This indicates that while biochar influenced growth at 35 days, its impact diminished by 60 days, with crop type remaining the primary determinant of plant height.

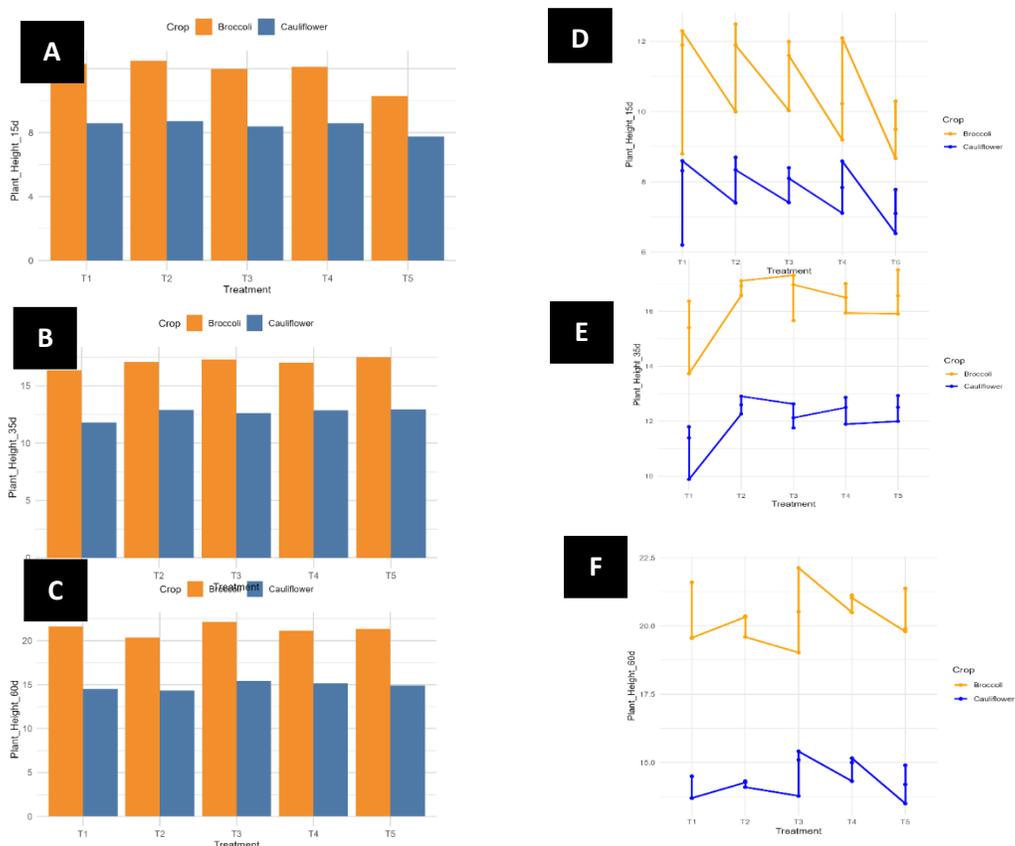


Fig. 1. Effect (A, B, C) and Interaction (D, E, F) of maize straw biochar doses on plant height at 15, 35 and 60 DAT. T₁ = Control, T₂ = 2 ton/ha, T₃ = 4 ton/ha, T₄ = 6 ton/ha, T₅ = 8 ton/ha. Data are the averages of three replicates \pm SEM (standard error mean).

Leaf number

Significant effects were observed for both crop type ($F=111.928$, $p < 0.001$) and biochar treatment ($F=4.372$, $p=0.011$) on leaf number at 15 days. Biochar application positively affected leaf development at this early stage, but the interaction between crop type and treatment was not significant. By 35 days, crop type remained highly significant ($F=187.577$, $p < 0.001$), but biochar's effect on leaf number was no longer significant ($F=2.144$, $p=0.113$). By 60 days, crop type continued to exert a significant influence ($F=94.131$, $p < 0.001$), while neither biochar treatments nor the interaction term showed significance, indicating that the effect of biochar on leaf number was temporary and did not persist.

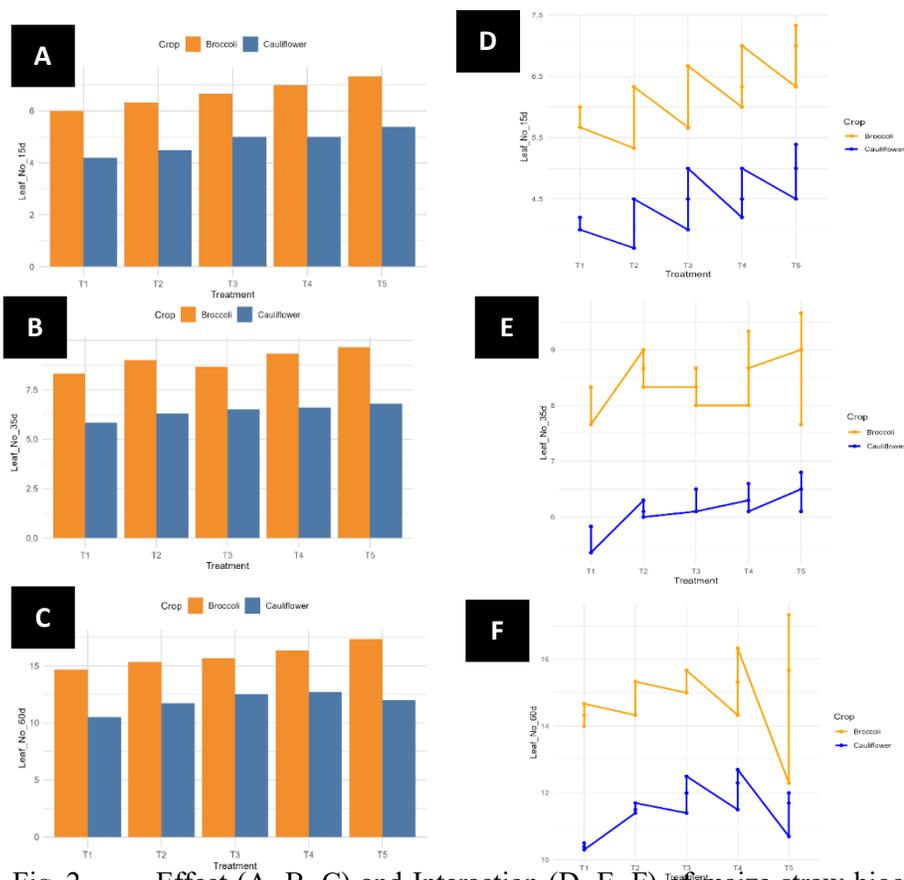


Fig. 2. Effect (A, B, C) and Interaction (D, E, F) of maize straw biochar doses on leaf number at 15, 35 and 60 DAT. T₁ = Control, T₂ = 2 ton/ha, T₃ = 4 ton/ha, T₄ = 6 ton/ha, T₅ = 8 ton/ha. Data are the averages of three replicates \pm SEM (standard error mean).

Leaf breadth

Both crop type and biochar treatments had significant effects on leaf breadth at 15 days (crop type: $F = 169.421$, $p < 0.001$; treatment: $F = 13.234$, $p < 0.001$), 35 days (crop type: $F = 441.800$, $p < 0.001$; treatment: $F = 9.847$, $p < 0.001$), and 60 days (crop type: $F = 842.551$, $p < 0.001$; treatment: $F = 20.027$, $p < 0.001$). However, the interaction between crop type and biochar treatments was not significant at any time point, suggesting a similar response to biochar across both crops.

Biochar enhanced leaf breadth at all stages, but crop type remained the dominant factor in determining leaf size.

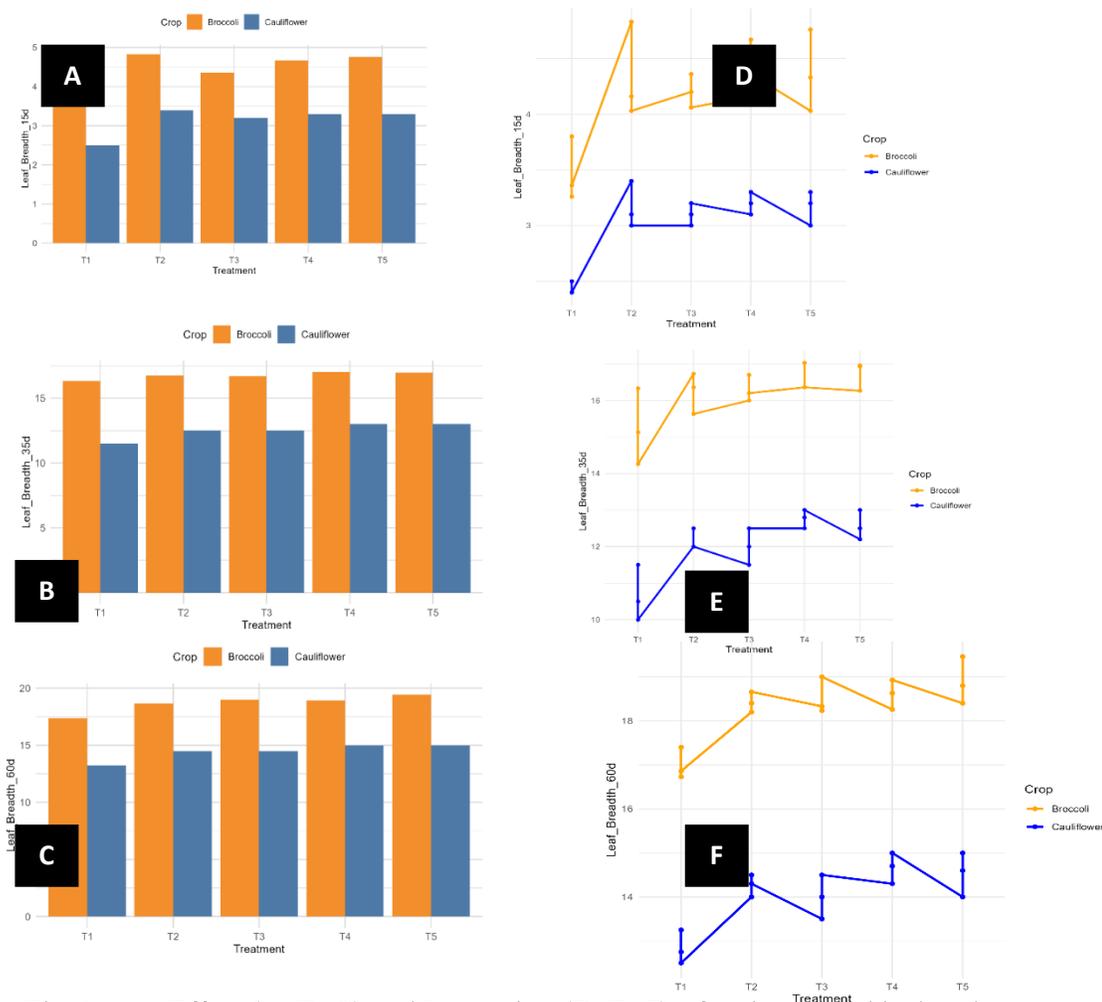


Fig. 3. Effect (A, B, C) and Interaction (D, E, F) of maize straw biochar doses on leaf breadth at 15, 35 and 60 DAT. T₁ = Control, T₂ = 2 ton/ha, T₃ = 4 ton/ha, T₄ = 6 ton/ha, T₅ = 8 ton/ha. Data are the averages of three replicates \pm SEM (standard error mean).

Leaf length

Similar to leaf breadth, both crop type and biochar treatment significantly influenced leaf length at 15 (crop type: $F=325.320$, $p < 0.001$; treatment: $F=13.428$, $p < 0.001$), 35 (crop type: $F= 662.938$, $p < 0.001$; treatment: $F = 13.165$, $p < 0.001$), and 60 days (crop type: $F=244.618$, $p < 0.001$; treatment: $F=3.387$, $p=0.029$). The interaction between crop and treatment was not significant at any stage, indicating consistent positive effects of biochar on leaf length across both crops. Crop type, however, remained the primary determinant of leaf length.

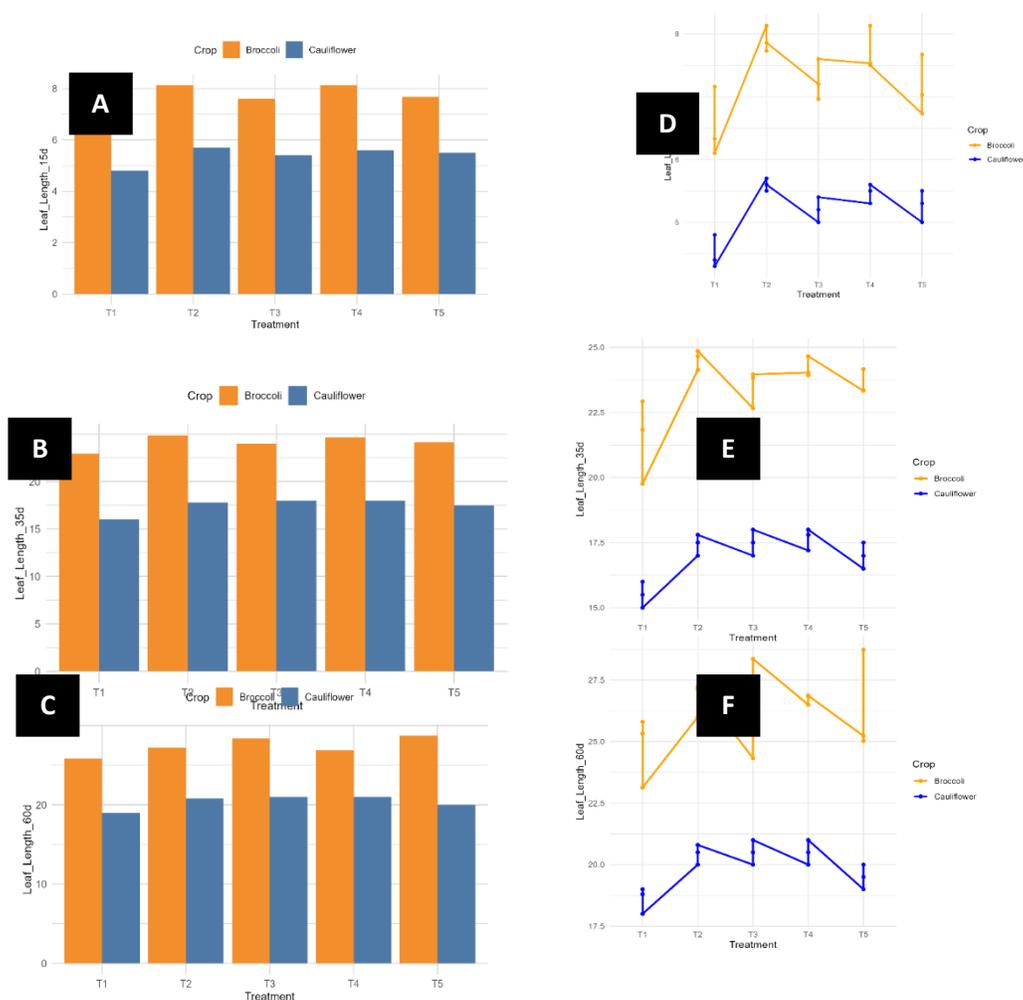


Fig. 4. Effect (A, B, C) and Interaction (D, E, F) of maize straw biochar doses on leaf length at 15, 35 and 60 DAT. T₁ = Control, T₂ = 2 ton/ha, T₃ = 4 ton/ha, T₄ = 6 ton/ha, T₅ = 8 ton/ha. Data are the averages of three replicates \pm SEM (standard error mean).

3.5 Primary curd weight:

The ANOVA for primary curd weight revealed significant effects of crop type ($F = 640.994$, $p < 2e-16$) and biochar treatments ($F = 89.993$, $p < 1.71e-12$), with an interaction effect between crop type and treatment ($F = 4.474$, $p = 0.00959$). Tukey's HSD test showed that biochar-treated plants had significantly higher curd weights compared to controls for both crops, with cauliflower showing a more pronounced increase in curd weight than broccoli. These results suggest that biochar significantly enhanced curd weight. The curd weight enhancement was greater for cauliflower than that for broccoli.

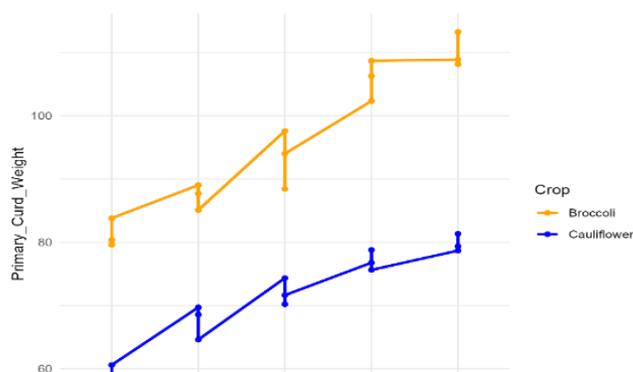


Fig. 5. Interaction on primary curd weight of maize straw biochar doses. T₁ = Control, T₂ = 2 ton/ha, T₃ = 4 ton/ha, T₄ = 6 ton/ha, T₅ = 8 ton/ha. Data are the averages of three replicates \pm SEM (standard error mean).

Curd's dry weight

Curd's dry weight was also significantly influenced by both crop type ($F = 464.04$, $p < 2.60e-15$) and biochar treatment ($F = 221.22$, $p < 3.00e-16$), with a significant interaction between crop type and treatment ($F = 43.37$, $p = 1.39e-09$).

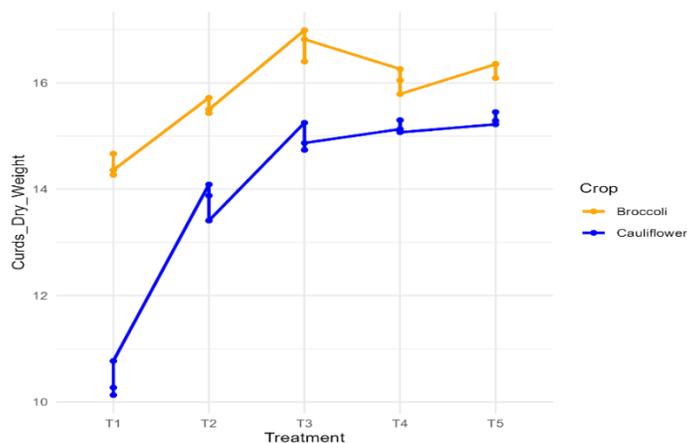


Fig. 6. Interaction on curd's dry weight due to maize straw biochar doses. T₁ = Control, T₂ = 2 ton/ha, T₃ = 4 ton/ha, T₄ = 6 ton/ha, T₅ = 8 ton/ha. Data are the averages of three replicates \pm SEM (standard error mean).

The Tukey HSD test revealed that biochar treatments led to higher curd dry weights compared to controls, especially at higher dosages. Biochar's effect on curd dry weight was more pronounced in cauliflower, indicating a dose-response relationship, with higher biochar doses yielding the greatest improvements in curd weight.

Stem diameter

Stem diameter was significantly influenced by both crop type ($F = 48.651$, $p = 9.05e-07$) and biochar treatment ($F = 29.442$, $p = 3.97e-08$), with a marginally significant interaction between crop and treatment ($F = 2.821$, $p = 0.0525$). While biochar treatment resulted in noticeable changes in stem thickness, the effect was not markedly different between cauliflower and broccoli, suggesting that biochar improved stem diameter irrespective of crop types.

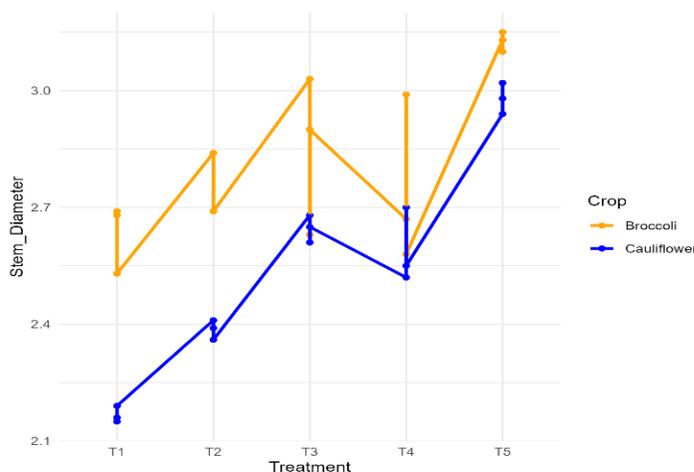


Fig. 7. Interaction on stem diameter due to maize straw biochar doses. T_1 = Control, T_2 = 2 ton/ha, T_3 = 4 ton/ha, T_4 = 6 ton/ha, T_5 = 8 ton/ha. Data are the averages of three replicates \pm SEM (standard error mean).

Yield

The yield was significantly influenced by crop type ($F = 311.225$, $p < 1.17e-13$) and biochar treatments ($F = 137.119$, $p < 3.09e-14$), with a significant interaction between crop and treatments ($F = 5.403$, $p = 0.00407$). Tukey's HSD test revealed significant yield improvements for both biochar-treated broccoli and cauliflower compared to their respective controls, but the effects varied between the two crops. These results suggest that while biochar generally improved yield, its impact was crop-dependent, with some treatments being more beneficial for one crop than the other.

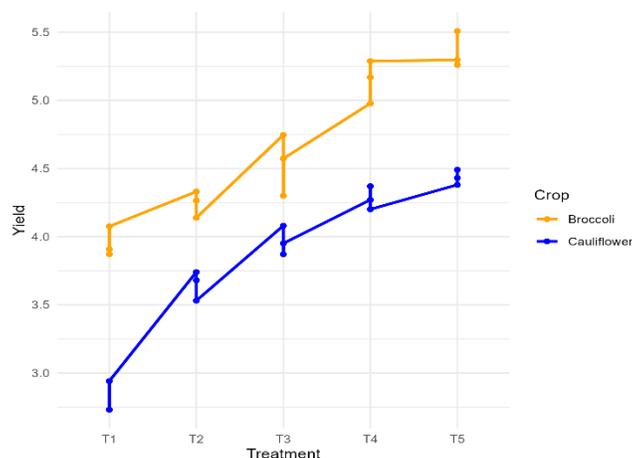


Fig. 8. Interaction on yield due to maize straw biochar doses. T₁ = Control, T₂ = 2 ton/ha, T₃ = 4 ton/ha, T₄ = 6 ton/ha, T₅ = 8 ton/ha. Data are the averages of three replicates \pm SEM (standard error mean).

The overall results show that both broccoli and cauliflower benefitted from biochar application in various growth parameters, with crop type being the dominant factor in most cases. Biochar had a temporary, early-stage effect on leaf number but enhanced leaf size (breadth and length) throughout the growing season for both crops. In terms of yield and curd weight, cauliflower exhibited the most significant response to biochar, particularly in primary curd weight and dry weight. However, both crops showed overall improvements in yield with biochar treatments, with some differences depending on the specific biochar dosage and crop. These findings suggest that biochar amendment might be an effective practice for enhancing late-season growth and yield of both the cruciferous vegetables in coastal Bangladesh, with cauliflower showing the greatest potential benefit.

Discussion

This study assessed the impact of biochar on the growth and yield of cauliflower and broccoli under coastal conditions in Bangladesh (Nayem et al., 2024). Results indicate that biochar positively influenced growth and yield, though the response varied with crop type and growth stage.

At early vegetative stages (15 days after transplanting), biochar had little effect on plant height but slightly increased leaf number, reflecting transient early-stage benefits reported in previous studies (Carter et al., 2013; Hamad et al., 2017). By later growth stages (35–60 days), biochar significantly improved leaf size (length and breadth) and curd development, with effects consistent across both crops, suggesting a uniform benefit on leaf expansion (Haque et al., 2019).

Yield parameters, including curd weight and dry weight, were significantly enhanced by biochar, particularly in cauliflower. Higher doses generally produced greater improvements, indicating a dose-response relationship, in line with previous findings (Manna et al., 2012; Losacco et al., 2022). Stem diameter also increased under biochar, although differences between crops were minimal, highlighting a structural benefit without crop-specific variation (Khadka, 2017).

Overall, these results demonstrate that biochar can enhance late-season growth and yield in coastal vegetables, especially cauliflower, supporting its use as a practical soil amendment in saline-prone areas. Variation in crop response underscores the need for tailored application rates to optimize benefits. Future research should refine dosage and application timing to maximize effectiveness under diverse coastal agroecosystems.

Conclusion

This study demonstrates the significant potential of biochar as an agricultural amendment for enhancing the late season growth and yield of cruciferous vegetables, particularly cauliflower and broccoli, in coastal Bangladesh. The results indicate that biochar positively impacted key growth parameters, including leaf size, curd weight, and yield, with cauliflower showing the most substantial response, especially in terms of primary curd weight and dry weight. While biochar's effects on early-stage growth were temporary, its benefits for later stages of development were evident, particularly in improving yield and curd quality. The variation in effect of biochar amendment between cauliflower and broccoli underscores the need for crop-specific application strategies. Future research should focus on optimizing biochar dosage considering cost benefit analysis and application timing to further refine its benefits for different crops and environmental conditions. Moreover, exploring the long-term effects of biochar on soil health and its interaction with other agricultural amendments will provide further insights into its role in sustainable agriculture.

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