

EFFECTS OF BIOCHAR AND FERTILIZER ON THE YIELD OF TOMATO AND SOIL FERTILITY

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Abstract

Biochar derived from different feedstocks may vary in quality and effectiveness. Therefore, evaluation of locally produced and industrial biochars with or without nitrogen fertilizer is essential to optimize tomato yield and soil fertility. A pot experiment was conducted to assess the effect of native local biochar and commercial industrial biochar, applied alone or in combination with recommended fertilizer dose (RFD) and urea nitrogen, on the growth, yield, and post-harvest soil properties of tomato (*Lycopersicon esculentum* L., BARI Hybrid Tomato-18). Eight treatments were arranged, including control, urea nitrogen alone, RFD with local biochar (30 t ha⁻¹), RFD with industrial biochar (30 t ha⁻¹), their 50:50 combination, and combinations with additional urea nitrogen. All biochar-amended treatments significantly improved plant growth, yield attributes, and soil fertility compared to the control. The combined application of 50% local biochar and 50% industrial biochar with RFD (T5) produced the tallest plants, highest number of clusters and fruits per plant, and maximum fruit weight per plant (2.67 kg). This treatment also enhanced fruit dimensions and improved soil properties, including available phosphorus and sulphur, soil pH, electrical conductivity, organic carbon, and organic matter. The highest total N was observed in T8 (RFD + urea + biochar) treated soil, which also showed the second-best overall performance. Industrial biochar-based treatments consistently outperformed native biochar alone, indicating the importance of biochar quality. Overall, integrating high-quality biochar with recommended fertilizers enhances tomato productivity and improves post-harvest soil fertility, supporting sustainable crop production.

Keywords: Local-biochar, Industrial biochar, Soil properties, Tomato, Urea

1. Introduction

World food security is under challenge to a great extent due to the effect of climate change, population growth, and resource-depleting practices on agriculture (IAASTD, 2008). Farmers use either organic manure or inorganic fertilizers for maintaining soil fertility (Craswell and Lefroy, 2001). However, the organic manure amendments are generally short-lived because of the rapid decomposition of soil organic matter under high

temperature and aeration. Therefore, organic amendments need to apply almost every year to sustain soil fertility and productivity. Use of more stable compounds such as biochar instead of the easily degradable organic manures could be an alternative for these respects. Moreover, biochar as stable forms enhance soil organic matter in the soil, mitigate climate change vulnerability by sequestering of carbon.

Biochar is a solid carbon-rich organic material generated by heating biomass at 300–600°C under condition of limited or no oxygen (Lehmann and Joseph 2009). It is attracting great interest for sustainable agriculture because of some innate benefits such as increasing C levels, improving soil quality characteristics, increasing water and nutrient retention capacity, improving nutrient-use efficiency (Ippolito *et al.*, 2012), and stimulating soil biological activity. Apart those positive effects, biochar have high cation exchange capacity and habitat for beneficial microorganisms, which can promote to release nutrients and thus uptake of nutrients by plants (Atkinson *et al.* 2010). The intensification of agricultural activities has accelerated degradation and loss of soil fertility, leading to increase production costs to maintain soil productivity. Therefore, strategies favoring preservation or increase of the soil organic matter content through biochar play a key role for maintaining crop productivity in agricultural systems in sustainable manner.

As an agricultural and densely populated country, Bangladesh produces a great amount of straw, vegetable waste, wood material, crop residues, manure, chicken litter, and sewage sludge. Currently the utilization rate of these properties is low and more than 50% are directly burned in the field, abandoned at the edge of the field, or combusted as cooking and heating fuel (Zeng *et al.*, 2007). All these are not only waste the resources but also cause serious local and regional environmental impact due to release of pollutants, including particular matter mostly dust and ash, unburnt hydrocarbon, nitrogen oxides and carbon monoxides. Biochar can be generated from a range of wood materials, crop residues (straw, rice husks, and nutshells), chicken litter, dairy manure and sewage sludge. These diverse source materials usually lead to great variability of physical, chemical, and biological properties of their biochar and consequently have varying influences on a soil's response to biochar incorporation (Lehman *et al.*, 2011). Pyrolysis condition mainly pyrolysis temperature, is another critical factor influencing biochar properties because during pyrolysis, biomass undergoes a variety of physical, chemical and molecular changes.

Tomato is an important, popular, and nutritious vegetable all over the world. Tomatoes are a rich source of many factors beneficial to health, such as vitamin C, vitamin E, and carotenoids (lycopene and b-carotene). In Bangladesh, the average yield of tomato is 7.42-ton ha⁻¹, which is very low compared to other tropical & sub-tropical countries (Anonymous 1989). This could be due to poor soil health where low in organic matter (<1%) present in soils of Bangladesh (Huq and Shoaib, 2013) that is alarming for sustainable agriculture production for long-term basis. On the contrary, farm available natural biomass resources *i.e.*, plant and crop residues,

industrial waste materials and by-products, organic manures are available in abundance. These natural resources should be utilized effectively and efficiently for the betterment of ecosystem functioning, and soil-crop improvement. Thus, the study aim was to test various combinations of biochars (either made from local resources or imported) and nitrogenous fertilizers to determine if biochar can reduce the required nitrogen application rate while maintaining or increasing yield. The main objective is to evaluate the effects of native and industrial biochar, alone and in combination with nitrogenous fertilizers, on soil fertility and the yield of tomato. The specific objectives of the study were to assess the effect of native and industrial biochar on soil fertility parameters, including soil organic matter, pH, and the total nitrogen (N), available phosphorus (P) and sulphur (S), and to evaluate the impact of biochar and nitrogenous fertilizers on the growth, development, and yield of tomato.

2. Materials and methods

2.1 Experimental site, soils for pot experimentation, treatments and design

The experiment was conducted in a net house of Sher-e-Bangla Agricultural University, Dhaka-1207 during the period from November 2019 to March 2020. Before preparing the pots, soil samples were collected from the field of Sher-e-Bangla Agricultural University at a depth of 0–15 cm on the basis of composite sampling method. The collected soil was air dried ground and passed through a 2-mm sieve and stored in a clean, dried plastic container for analysis.

There were twenty-four pots and each pot was 30 cm height and 15 cm width. The pots were cleaned thoroughly and filled with 8 kg air dried soil. The texture of the soil was clay loam (consisting of sand 30.85%, silt 39.4%, and clay 29.47%). The pots were prepared with as per treatment. Biochar was applied to the top 20 cm of the soil at 7 days before planting as per treatment. When the seedlings were 25 days old, uniform-sized tomato plants were transplanted at the rate of two seedlings per pot and finally healthy one seedling was kept and discarded other one. The pots were arranged in a completely randomized block design with eight treatments and three replications.

2.2 Availability of biochar, tomato variety and treatments

A locally-sourced (by burning of Mahogany wood) native biochar produced by “Akha” cookstove developed by the Christian Commission for Development in Bangladesh Biochar Initiative. This type of biochar is much cheaper than industrial biochar. A commercial industrial biochar was made of whole pyrolysis in pyrolysis oven. In Bangladesh, agricultural residues like rice husk, locally available wood are abundant, providing a readily available source for producing a low-cost, "native" biochar. Comparing this native biochar with a high-quality costly "industrial" biochar imported from outside of Bangladesh is critical to provide farmers with a practical, cost-effective solution. Seedlings of BARI hybrid tomato -18 were collected from Bangladesh Agricultural Research Institute (BARI), Gazipur.

There were eight treatments in the study viz., T_1 = Control, T_2 = Urea N (UN) @ 133 mg/8kg soil in each split, UN_{62} (Urea @ 218 kg ha⁻¹), T_3 = RFD + Native Biochar (NB) @ 30-ton ha⁻¹, NB_{30} , T_4 = RFD + Industrial Biochar (IB) @ 30-ton ha⁻¹, IB_{30} , T_5 = RFD + NB_{30} + IB_{30} , T_6 = RFD + UN + NB_{30} , T_7 = RFD + UN + IB_{30} and T_8 = RFD + UN + NB_{30} + IB_{30} . RFD means recommended fertilizer dose (kg ha⁻¹) of Urea (218), TSP (190), MoP (126), Zinc oxide (3.14), Gypsum (100) and Boric acid (8.82).

2.3 Intercultural Operation and crop harvesting

After transplanting of the seedlings, various intercultural operations such as weeding, earthing up, gap filling, irrigation and drainage, mulching, stacking and pruning, pest and disease control such as Rivcot and neem extract were performed for growth and development of the tomato plants. Tomato Fruits were harvested at five days interval during early ripe stage when they attained slightly red color. The maturity of the crop was determined on the basis of red coloring of fruits. Harvesting was started from 1st March, 2020 and completed by 20 March, 2020.

2.4 Data collection

The plant height was measured from plant of each unit pot from the ground level to the top of the sample through a cm scale. The days required for transplanting to initiation of flowering, fruiting and harvesting were recorded. The number of flowers per cluster and cluster per plant were counted from each unit pot and recorded. The number of fruits per cluster and fruits per plant were counted and recorded. The yield of tomato was measured as the whole fruit per pot harvested in different time intervals and was expressed in kilogram. The length and width of fruit was recorded with slide calipers from the neck of the bottom and one side to another side respectively from five selected marketable fruits and their average was taken and expressed in mm.

2.5 Post-harvest soil sampling

After harvesting of tomato, soil samples were collected from each. Soil samples of each pot was air-dried, crushed and passed through a two mm (10 meshes) sieve. The soil samples were kept in plastic container to determine the chemical properties of soil. Total nitrogen of the soil was determined by Micro kjeldahl method (Jackson, 1973) where soil was digesting by 30 % H_2O_2 , conc. H_2SO_4 and catalyst mixture (K_2SO_4 : $CuSO_4 \cdot 5H_2O$: Se powder in the ratio of 100:10:1). The digested nitrogen was estimated by distillation with 40% NaOH followed by titration of the distillate trapped in H_3BO_3 with 0.01N H_2SO_4 . The amount of N was calculated by using the formula:

$$\% N = (T - B) \times N \times 0.014 / W$$

where T = Sample titration (ml) value of standard H_2SO_4 ,

B= Blank titration (ml) value of standard H_2SO_4 ,

N= Strength of H_2SO_4 ,

W= Sample weight in gram.

Available Sulphur in soil was determined by extracting the soil samples with 0.15% CaCl_2 solution (Page *et al.*, 1982). The S content in the extract was determined turbidimetrically and the intensity of turbid was measured by spectrophotometer at 420 nm wave length. Available phosphorus was extracted from soil by shaking with 0.5 M NaHCO_3 solution of pH 8.5 (Olsen *et al.* 1954). The P in the extract was then determined by developing blue color using SnCl_2 reduction of phosphomolybdate complex. The absorbance of molybdophosphate blue color was measured at 660 nm wave length by spectrophotometer and available P was calculated with the help of standard P curve (Page *et al.* 1982). Organic carbon (%) of the soil was determined by Wallkley and Black's (1934) wet oxidation method. The underlying principle is to oxidize the organic carbon with an excess of 1 N $\text{K}_2\text{Cr}_2\text{O}_7$ in presence of conc. H_2SO_4 and to titrate the residual $\text{K}_2\text{Cr}_2\text{O}_7$ solution with 1 N FeSO_4 solution. The result was expressed in percentage (Jackson, 1973). Soil organic matter content was calculated by multiplying the percentage value of organic carbon with the Van Bemmelen factor, 1.724. The pH of the soil was determined with the help of a glass electrode pH meter using soil: water ratio being 1:2.5 (Jackson, 1973). Electrical conductivity was determined with the help of a conductivity meter following Jackson (1973).

2.6 Statistical analysis

Statistical package program 'Statistix 10' was used for analysis of the experimental data. The means of all the treatments were calculated and the analysis of variance for each of the characters under study was performed by F test. The difference among the treatment means was evaluated by Least Significant Difference (LSD) test (Gomez and Gomez, 1983) at 0.05% level of probability.

3. Results and Discussion

3.1. Effects of biochar on the growth parameters of tomato

The plant height varied significantly due to the application of different levels of different biochars (Table 1). The tallest plant (75.67 cm) was produced at T_5 treatment where maximum amount (50%) of Native (NB_{30}) and industrial biochar (IB_{30}) was used. The shortest plant (41.33 cm) was found in control treatment. The combination of industrial, native, with urea (T_8 treatment) also provided 2nd tallest plant. The number of flower cluster per plant (8.67), flowers per cluster (9.67), number of fruits per cluster (7), and fruits number per plant (37.33) were also highest at T_5 treatment and lowest at control. These factors represent that using of both type of biochar together provided maximum growth parameter. In addition, both biochar with nitrogenous fertilizer also increased growth parameters significantly (Table 1). Sarfraz *et al.*, (2017) reported that combined application of biochar and nitrogenous fertilizers can optimize plant growth i.e., plant height by enhancing nutrient availability. Such strategies can significantly improve soil health as well as improve crop quality and yield over time.

First flowering (25.00 DAT), first fruiting (35.00 DAT), and first harvesting (79.33 DAT) occurred in the T₅ treatment whereas, these parameters were observed later in the control where nothing was applied. These findings reflect that the application of biochar and/ or nitrogenous fertilizer accelerates the physiological function of plants and thus maximum number of clusters per plant (8.67), maximum number of flowers per cluster (9.67), maximum number of fruits per cluster (7.00), and maximum number of fruits per plant (37.33) were occurred at T₅ treatment (Table 1). Similar positive growth and agronomic parameters were observed on maize when biochar and nitrogen fertilizers were applied together (Sarfranz *et al.*, 2017). The number of clusters per flower, no. of cluster per plant, number of fruits per cluster, number fruits per plant and plant height at harvest were greater in T₄ treatment compare to T₃ treatment i.e., the treatment where industrialized biochar were applied provided higher agronomic parameters compare to the treatment where locally produced native biochar were applied (Table 1). Lei *et al.* (2024) reported that the type of biochar feedstock has played a significant role in the variation in outcomes, with biochar produced by wood and straw leading to the greatest enhancement in yield and quality of tomatoes compared to all other sources of biochar. In our present study, the similar impact might have occurred.

Table 1. Effects of biochar on the growth parameter of tomato

Treat-ments	No. of flowers/cl uster	No. of clusters /plant	No. of fruits/ cluster	No. of fruits/ plant	Days to 1 st flowering	Days to 1 st fruiting	Days to 1 st harvesting	Plant height at harvest (cm)
T ₁	2.67 f	2.67 f	3.00 e	9.33 e	37.7 a	46.3 a	94.3 a	41.3 e
T ₂	4.67 e	3.00 ef	3.67 e	14.0 d	34.0 b	44.0 b	90.0 b	45.0 e
T ₃	6.00 cd	4.00 e	4.67 d	20.0 c	31.0 c	40.0 c	86.7c	43.7 e
T ₄	6.33 cd	5.67 d	5.33 cd	23.0 c	28.0 d	39.7 c	83.3 d	54.0 d
T ₅	9.67 a	8.67 a	7.00 a	37.3 a	25.0 f	35.0 d	79.3 f	75.7 a
T ₆	5.67de	7.33 bc	5.66 bc	32.0 b	26.7 de	35.7 d	81.7de	63.0 c
T ₇	7.00 bc	7.00 c	7.33 ab	33.3 b	26.0 ef	35.7 d	82.0de	68.0 b
T ₈	8.00 b	8.33 ab	7.00 a	35.0ab	25.3 ef	35.7 d	80.0ef	71.0 b
LSD	1.178	1.238	0.776	3.59	1.5	1.2	2.3	4.2
(0.05) CV	10.76	12.12	8.31	8.03	2.84	1.7	1.57	4.19
(%)								

In a column values having similar letter are statistically identical and those having dissimilar letter differ significantly as per 0.05 level of probability.

3.2. Effect of biochar on the yield parameters of tomato

The maximum fruit weight per plant (2.66 kg), fruit diameter in length (55.33 mm), fruit diameter in width (38 mm), and the weight of each fruit (64 g) were found in the T₅ treatment and the T₈ treatment also provided the second highest amount of these parameters, indicating that the highest yield and best fruit quality could be obtained combined application of biochar and chemical fertilizers (Figure 1 & 2). Lei *et al.*, (2024) demonstrated the joint application of biochar and nitrogen showed the significant increase of tomato fruit yield and quality, as well as water-nitrogen productivity. In addition, it was observed that biochar application significantly increased tomato yield by 29.55% compared to control treatments without biochar (Lei *et al.*, 2024). An increment in tomato yield was observed with increasing rates of biochar application. Zhang *et al.* (2023) examined the impact of varying rates of biochar (0, 22.5, 67.5, and 112.5 t ha⁻¹) on tomato yield and observed that yield increased along with the rate of biochar application. Additionally, the higher application rates of biochar significantly improved the quality of tomato fruits (Abdelghany *et al.*, 2023). Nitrogen plays an crucial role in the growth of tomatoes as it is an essential element and necessary component for the plant. Frequent reports of improved plant yield following biochar application are attributed to enhanced soil nitrogen retention and utilization efficiency, which are a result of the additional nitrogen supply and the biochar's positive impact on the nitrogen cycle (Ding *et al.*, 2016). The addition of biochar with chemical fertilizer enhanced soil properties by increasing soil porosity and reducing bulk density, which facilitated better plant growth and higher yields (Abdelghany *et al.*, 2023).

The greater fruit wt. per plant, dry wt. per plant, raw fruit wt. fruit length, fruit diameter was recorded at T₅ treatment where industrialized biochar were applied compared to the treatment where locally produced native biochar were applied i.e., T₃ treatment (Figure 1&2). The different sources of biochar's have chief role on the productivity of crops. Lei *et al.* (2024) theorized that, biochar from different sources had different level of impact on crop yield for example sludge biochar, biochar from wood, straw, shell residues, and mixed materials all demonstrate a positive effect on tomato yield enhancement but different grade.

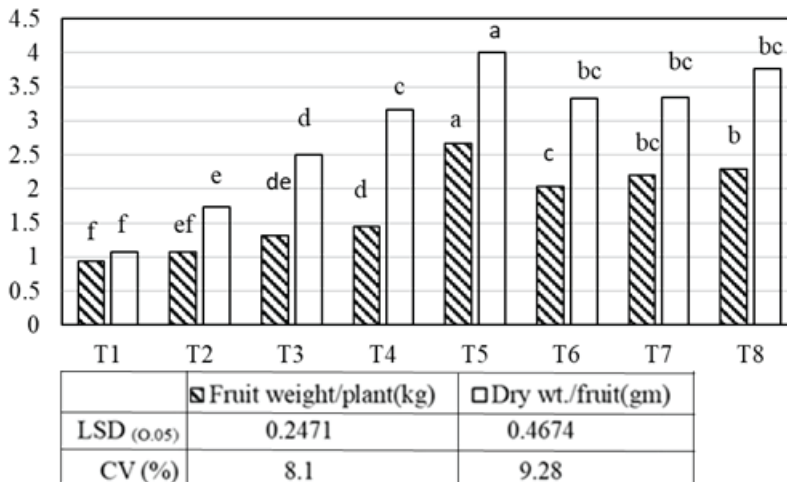


Fig. 1 Effect of biochar on yield parameter of tomato

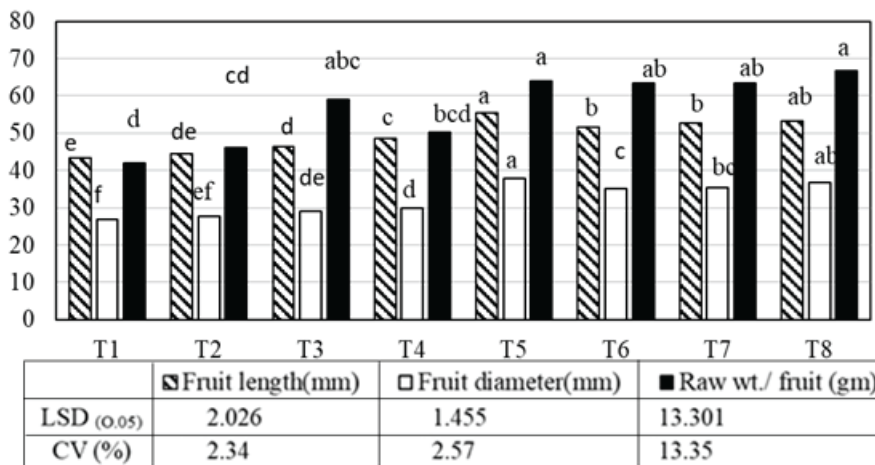


Fig. 2 Effects of biochar on the yield parameters of tomato

3.3. Effect of biochar on soil properties

The initial soil's pH was 5.6, S content was 16 ppm, P content was 13.7 ppm, electrical conductivity was 3 ds/m, N content was 0.06%, and it had a low level of organic carbon (0.4%) and soil organic matter (0.862%). Biochar application with or without nitrogenous fertilizer increased the fertility status of the post-harvest soil. The highest amounts of available S (26.067 ppm), P (26.667 ppm), organic carbon (0.753%), and organic matter (1.2987%) were

found in the T₅ treatment, where a 50% combination of 30-ton ha⁻¹ local biochar and 30-ton⁻¹ industrial biochar were used. The T₈ treatment, where RFD + UN44 + LB30 + IB30 (50:25:25 w/w) was used, provided the second highest amount of these soil chemical properties (Table 4). Earlier research has demonstrated that a higher biochar application rate improves organic matter, nitrogen, phosphorus, and other essential nutrients in the soil (Wang *et al.*, 2019), and subsequently increases plant yield and quality.

Table 4 Effect of biochar on soil chemical properties

Treatments	%N	P(ppm)	EC (ds/m)	pH	S (ppm)	%OM
T ₁	0.06 e	14.17 g	3.31 f	5.72 e	16.17 f	1.034 e
T ₂	0.073 d	17.00 f	3.99 ef	5.72 e	17.83 e	1.092 d
T ₃	0.083 cd	19.33 e	4.60 de	5.83 d	19.73 d	1.126 d
T ₄	0.093 c	22.67 d	5.33 d	5.89 cd	22.33 c	1.201 c
T ₅	0.116b	26.67 a	8.00 a	6.06 a	26.07 a	1.299 a
T ₆	0.12 ab	23.67cd	6.33 c	5.87cd	24.50 b	1.231 bc
T ₇	0.127 ab	24.67bc	6.90 bc	5.93bc	25.00 ab	1.259 ab
T ₈	0.130 a	26.00 ab	7.67 ab	6.00 ab	25.67ab	1.287 a
LSD (0.05)	0.0112	1.568	0.952	0.072	1.398	0.052
CV (%)	0.638	4.11	3.75	0.70	3.60	2.49

The total N content (0.13%) was highest in the T₈ treatment, where a biochar combination with urea was applied, and the total N increased in the post-harvest soil compare to other treatments and initial soil (Table 5). The high adsorption capacity of biochar may lead to the fixation of nutrients. Addition of nitrogen might have contributed the presence of N in T₈ treatment. Moreover, biochar application can increase the total nitrogen content in the soil. The available phosphorus (P) increased in the post-harvest soil compared to the initial soil (Table 4). The highest P and S was recorded in the T₅ treatment and the lowest was recorded in the control treatment (Figure 4). Biochar is considered a vital source of nutrients such phosphorus (P) and potassium (K) for plant growth. The application of biochar can significantly improve the content of available P and K in the soil.

Soil organic carbon, which is also known as organic matter, also increased in the post-harvest soil (Table 4). An application rate of biochar (20 t ha⁻¹) is a highly successful method to enhance the stability of soil organic carbon sequestration and boost a rice crop's output (Yang *et al.*, 2024). In our study, we applied 30 t ha⁻¹, and thus the soil organic carbon and organic matter increased compared to the control and initial soil (Table 4). The initial soil reports indicated the tested soil was acidic (pH was 5.6). After applying biochar, it was evident that the pH was higher in treatments T₅ and T₈, where biochar was applied in higher amounts compare to control. Similar findings also recorded in other studies because soil pH showed a

consistent increase with higher biochar application rates (Frimpong *et al.*, 2025). It was also evident that the pH level increased after applying biochar to acidic soil (Kannan *et al.*, 2021).

The soil fertility properties such as total N, available S, available P, soil organic carbon, soil organic matter, soil pH was higher in the treatment T₅ where industrialized biochar was applied compared to the treatment T₃ where locally produced native biochar was applied (Table 4). The physical structure and chemical composition of biochar determine the potential of biochar to affect soil ecosystems. Wood and straw biochar, with its porous nature and large surface area, can absorb various substances including minerals and organic compounds with diverse molecular dimensions and chemical properties. The biochar derived from wood and straw exhibited a comparatively elevated carbon-to nitrogen (C/N) ratio compared to other types (Mukome *et al.*, 2013). Additionally, wood biochar contained a significantly higher number of ferric ions than the other biochar (Mukome *et al.*, 2013). In addition to the biochar feedstock types, the pyrolysis temperature is another crucial determinant of biochar's physicochemical characteristics. The meta-analysis conducted reveals that biochar produced at pyrolysis temperatures between 401 and 500°C exhibits a more pronounced improvement in the quality than biochar produced at 400 °C (Lei *et al.*, 2024). The above findings confirmed that our finding is fully evident that the quality of locally produced biochar was lower grade than the industrialized produce biochar.

4. Conclusions

The study demonstrates that integrating biochar with chemical fertilizers significantly enhances tomato growth, yield, and post-harvest soil fertility. Industrially produced biochar consistently outperformed locally produced "Akha Chula" biochar, indicating that biochar quality and production temperature are critical determinants of agronomic performance and soil improvement. These findings highlight the importance of standardized biochar production and quality characterization to maximize its benefits under different agro-climatic conditions, which should be a priority in future research. For improved tomato yield and soil health, farmers are advised to apply high-quality industrial biochar in combination with the recommended fertilizer dose where available.

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Conflicts of Interest

The authors declare no conflicts of interest regarding publication of this paper.

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