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Effect of biochar on growth, yield attributes and yield of tomato

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Abstract
A field experiment was conducted at the Organic Research Farm, Karguan Ji, Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Bundelkhand University, Jhansi, U.P., during the *kharif* season of 2024. The results revealed that application of biochar significantly improved plant height, plant stem diameter, no. of leaves, days taken to first flowering, days taken to first fruiting, number of flower per cluster/plant, number of fruits per plant, fruit diameter, average fruit weight and yield at harvest stage of tomato were observed with application of MF + 10t/ha^{-1} SBB (T_5) over rest of treatments. Based on this experimentation, it is concluded that (T_5) in tomato should be applied for better nutrient and water management throughout the cropping season for obtaining higher yields and economic returns over rest of the treatments.

Keywords: Biochar, tomato, growth attributes, yield attributes

Introduction
The tomato, or *Lycopersicum esculentum* L. (2n=24), is a widely recognized fruit often treated as a vegetable in cooking. It is also known as "Poor Man's Orange". Native to the Andes Mountains in South America, it has become a crucial ingredient in many cuisines around the world. Tomato is rich in vitamins, minerals, sugars, dietary fibers, and antioxidants such as vitamin C (VC), phenols, and lycopene, which are helpful to human health. However, tomatoes are among the crops that require the most water. The total cultivated area of tomatoes is 5 million hectares. In India, the total area is 0.85 million hectares with a production of 16.34 million tonnes and 20.36 tonnes per hectare productivity. Its versatility and nutritional benefits have led to its extensive cultivation. In India, the tomato is a staple in various dishes, including curries, chutneys, salads, and soups, and is primarily grown in states like Karnataka, Andhra Pradesh, Maharashtra, and Uttar Pradesh.

Biochar enhances plant growth by optimizing soil chemical properties (nutrient retention and availability), improving physical characteristics (bulk density and water-holding capacity), and boosting biological properties, all of which are critical for increasing crop productivity (Glaser *et al.*, 2002; Lehmann and Rondon, 2006; Yamato *et al.*, 2006) [9, 23, 38]. Moreover, its strong resistance to microbial decomposition guarantees lasting benefits for soil fertility (Steiner *et al.*, 2007) [35].

Historically, the use of biochar in agriculture has proven effective in enhancing crop production, as evidenced by practices like slash-and-burn cultivation in Northeast India. Utilizing biochar not only fulfils multiple agricultural objectives but also protects biomass from oxidation, directly reducing CO_2 emissions. Biochar significantly improves crop yields, stimulates beneficial soil microbes (Warnock *et al.*, 2007) [37], and enhances soil water retention and physical properties (Kramer *et al.*, 2004; Liang *et al.*, 2010) [20, 25]. Additionally, it raises soil pH and increases the availability of key nutrients, particularly potassium, phosphorus, and zinc (Lehmann *et al.*, 2003) [24]. One such amendment, biochar, is a solid, carbon-rich material created from various organic materials through a process called pyrolysis, which involves heating in a limited oxygen environment (Laird *et al.*, 2009) [21]. Biochar is often referred to as an "anthropogenically produced black carbon (BC) material". As a result, biochar facilitates the transformation and turnover of essential nutritional elements (Pietikainen *et al.*, 2000) [30]. Biochar contributes to the expansion of beneficial microbial populations, such as rhizobacteria and fungi (Graber *et al.*, 2010) [10], and helps neutralize phytotoxic molecules (Wardle *et al.*, 1998) [36]. Its effects on soil biomass composition often lead to improved plant fitness and productivity. This has been observed in several crops, including wheat, maize, cucumber, beans, tomatoes, strawberries, and sweet peppers (Graber *et al.*, 2010; Harel *et al.*, 2012; Cornelissen *et al.*, 2013; Jaiswal *et al.*, 2014, 2015; De Tender *et al.*, 2016) [10, 13, 3, 15, 16, 4]. However, there have been instances where biochar showed no effects or even negative effects on plant growth (Jeffery *et al.*, 2011; Kammann *et al.*, 2015; Haider *et al.*, 2016; Shackley *et al.*, 2016) [17, 19, 11, 32]. This variability in the agronomic value of biochar primarily stems from factors such as the type of starting biomass used, the conditions during pyrolysis (including temperature and duration of heat exposure), as well as climatic and soil chemistry conditions (Elad *et al.*, 2011; Juriga and Simansky, 2018) [6, 18]. According to Hannachi *et al.* (2023) [12], applying biochar at 4.8 tons per hectare improved vegetative growth traits, the number of flowers, and fruit diameter. However, it did not alleviate the yield decrease or lower sodium ion content in fruits under salinity stress (Hazman *et al.*, 2022) [14].

Materials and Methods

A pot experiment was conducted during the *kharif* season of 2024-2025. Organic Research Farm, Kargua ji, Department of Soil Science, Institute of Agricultural Sciences, Bundelkhand University, Jhansi, U.P., situated at Bundelkhand region of Uttar Pradesh at 25°31'07.1" N latitude and longitude of 78°33'47.4 E with 284 meters above mean sea level (MSL). According to NARP, Bundelkhand falls in Agro-climatic Zone VI (Bundelkhand Zone of UP). The soils of the district are characterized by their varying depth, topographic situations, and colors. The two main soil groups are red and black, generating four soil series locally known as rakar, parwa, kabar, and mar. The soil texture varies from rocky, gravelly, sandy, and sandy loam to clay loam. It has a gentle to steep (0.5 to 10%) slope with low to medium organic carbon content and very low to high water holding capacity. Jhansi situated in the tropical and subtropical climatic tract of India. The average annual rainfall is 884.6 mm, with 90-95 percent of that rainfall occurring during the southwest monsoon, which commences in June and reaches a peak in August and ends in October.

There are two main soil groups and four soil series present in Bundelkhand, which is a mixture of black or heavy soil (Mar), clay loam (Kabar), sandy or red soil (Rakar), and sandy loam or yellow soil (Parwa) that are mostly deficient in organic matter, nitrogen, phosphorus, and sulfur apart from this there is presence of underground rocks. The soil of the experimental pot was red loam in texture with a slight gentle slope.

The treatments were T_0: NF (No Fertilizer), T_1: MF (Mineral Fertilizer/RDF), T_2: ½ MF+15 t/ha^{-1} PB (Parthenium Biochar), T_3: MF+10 t/ha^{-1} PB, T_4: ½ MF+15 t/ha^{-1} SBB (Sugarcane Bagasse Biochar), T_5: MF+10 t/ha^{-1} SBB. Different observations of the plant were taken during the Crop period. The height of plants was measured from ground level to the extreme growing tip using a meter scale. Observations were recorded at three stages: 30, 60, and 90 DAT, The number of leaves was counted of each plant at three stages: 30, 60, and 90 DAT, The number of branches was counted of each plant at three stages: 30, 60, and 90 DAT, The average fruit diameter of randomly chosen healthy fruit was measured by a calliper meter after each harvest, average fruit weight, no. of fruits per plant, days taken to first flowering, days taken to first fruiting, no. of flowers per cluster, The diameter of the plant stem is measured by a Vernier calliper at three stages: 30, 60, and 90 DAT and fruit yield per plant.

Statistical analysis

The experimental data recorded for growth, yield, and other characters were subjected to statistical analysis by the "Analysis of Variance" technique suggested by (Fisher, 1936) [8]. The appropriate standard error for each of the factors was worked out. The significance of differences among treatment effects was tested by "F" test. Critical difference (CD) was worked out, wherever the difference was found significant at 5.0 or 1.0 percent level of significance.

Results and Discussion

Plant height at 30, 60 and 90 days after transplanting is clearly evident that, the maximum (59.25 cm) plant height at 30 days after transplanting was recorded in treatment T_5 MF + 10T/ha^{-1} SBB, followed by 59.00 cm in T_2 $^1/_2$ MF + 15T/ha^{-1} PB and 58.00 cm in T_1 MF (250 kg/ha^{-1} N:120 kg/ha^{-1}P:120 kg/ha^{-1})/RDF. In contrast, the minimum (38.50 cm) was recorded under the treatment control (T_0). Similarly, the maximum (77.00 cm) plant height at 60 days after transplanting was recorded in T_5 MF + 10T/ha^{-1} SBB, which was statistically at par with T_3 (76.25 cm) in MF + 10T/ha^{-1} PB and T_1 (76.25 cm) in MF (250 kg/ha^{-1} N:120 kg/ha^{-1}P:120 kg/ha^{-1})/RDF, while the minimum (61.50 cm) was recorded under control (T_0). Also the maximum (106.75 cm) plant height at 90 days after transplanting was recorded in T_5 MF + 10T/ha^{-1} SBB, which was statistically at par with T_3 (106.50 cm) in MF + 10T/ha^{-1} PB and T_1 (106 cm) in MF (250 kg/ha^{-1} N:120 kg/ha^{-1}P:120 kg/ha^{-1})/RDF, while the minimum (92 cm) was recorded under control (T_0). The findings obtained from the current study conform to the existing literature. In the present study, the maximum plant height was observed in T5 which gets its support from the study of Cong *et al.* (2023) [2], who reported that one-time application of biochar significantly increased maize plant height. This increase in height is credited to the enhanced nutrient availability provided by the biochar amendments. In this study, the maximum mean plant height was observed to be higher in the capsicum grown in treatment T5. The addition of biochar to soil improved soil quality and nutrient retention, resulting in increased plant growth (Bonanomi *et al.*, 2017) [1].

The data regarding the effect of biochar on number of leaf days after transplanting is presented in Table 1, it is evident from the data it is clearly evident that, the maximum (27.25) number of leaf at 30 days after transplanting was recorded in treatment T_5 MF + 10T/ha^{-1} SBB, followed by T_3 (27.00) T_3 MF + 10T/ha^{-1} PB, while the minimum (22.00) was recorded under control (T_0). Similarly, T_5 MF + 10T/ha^{-1} SBB had the highest number of leaf (55.25) at 60 days after transplanting, which was statistically comparable to T_3 (54.25) in MF + 10T/ha^{-1} PB, while T_0 had the lowest number of leaves (45.25). Also the maximum (85.75) plant height at 90 days after transplanting was recorded in T_5 MF + 10T/ha^{-1} SBB, which was statistically at par with T_3 (85.50) in MF + 10T/ha^{-1} PB and T_1 (85.25) in MF (250 kg/ha^{-1} N:120 kg/ha^{-1}P:120 kg/ha^{-1})/RDF, while the minimum (73) was recorded under control (T_0). Biochar application also increases chlorophyll content in leaves, facilitating the synthesis of various enzymes and supporting electron transport in photosynthetic carbon assimilation. Consequently, this enhances the photosynthetic functions in the leaves (Mollinedo *et al.*, 2016; Egamberdieva *et al.*, 2019) [28, 5].

The data regarding the effect biochar application on days taken to first flowering the after transplanting is presented in Table 1. The minimum (27.49) days taken to first flowering was observed in treatment T_5 MF + 10T/ha^{-1} SBB, which were found to be superior over other treatment, followed by (30.14) in Treatment T_4 $^1/_2$ MF + 15T/ha^{-1} SBB, whereas the maximum (30.64) days taken to first flowering was observed in T0 (Control). The physiological processes of plants were altered by drought stress, and biochar supports physiological activity, which leads to plant flowering, improved plant development, and an influence on the number of days until first flowering (Mannan *et al.*, 2020) [27].

The data related to days taken to first fruiting are presented in Table 1, which clearly shows that there were significant differences in days taken to first fruiting among different treatments. The maximum (34.19) days take to first fruiting was recorded in T0 (Control), in T_3 (33.85) MF + 10T/ha^{-1} PB, and (33.51) in T_2 $^1/_2$ MF + 15T/ha^{-1} PB. However, the treatment recorded T_5 MF + 10T/ha^{-1} SBB the minimum (32.18) days taken to first fruiting. Biochar amendments significantly increased the number of flowers and fruits progressively at all growth rates at 12WAT. Thus, increasing the yield of tomato production. This is in line with earlier study that biochar application enhanced crop yield, especially maize and tomato, Faloye *et al.* (2020) [7] and Ronga *et al.* (2020) [31].

Table 1: Effect of biochar on plant height, no. of leaves at 30, 60 and 90 DAT, days taken to first flowering and fruiting of tomato (*Solanum lycopersicum* L.)

Treatments	Plant height (cm)			No. of leaves (days)			Days taken to first flowering	Days taken to first fruiting
	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT		
T_0	38.50	61.50	92.00	22.00	45.25	73.00	30.64	34.19
T_1	58.00	76.25	106.00	26.50	53.00	85.25	28.38	33.04
T_2	59.00	75.00	104.25	26.00	52.75	83.50	29.34	33.51
T_3	58.75	76.75	106.50	27.00	54.25	85.50	29.47	33.85
T_4	56.50	75.00	104.25	26.00	52.75	83.50	30.14	33.05
T_5	59.25	77.00	106.75	27.25	55.25	85.75	27.49	32.18
S.Em (±)	4.11	2.65	5.41	2.70	3.45	4.14	0.34	0.26
CD at 1%	1.01	0.65	1.33	0.66	0.85	1.02	1.14	0.86

The data related to the number of flowers per cluster/plant at 30 and 60 DAT as affected by time of application and different concentrations of biochar on carbon pools is presented in table 2. The mean data for the number of flowers per cluster/plant at 30 DAT was recorded as maximum (16.22) under T_5 MF + 10T/ha^{-1} SBB, while the minimum (8.45) was observed under T_0 Control. Also, the maximum (38.74) number of flowers per cluster/plant at 60 DAT after transplanting was recorded in T_5 MF + 10T/ha^{-1} SBB, while the minimum (28.19) was recorded under control (T_0). Biochar amendments significantly increased the number of flowers and fruits progressively at all growth rates at 12WAT. Thus, increasing the yield of tomato production. This is in line with earlier study that biochar application enhanced crop yield, especially maize and tomato, Faloye *et al.* (2020) [7] and Ronga *et al.* (2020) [31].

The data pertaining to the number of branches per plant is presented in Table 2. After observing the data very carefully it was revealed that, the maximum (25.75) number of branches per plant was recorded in T_5 MF + 10T/ha^{-1} SBB, which was found to be significant superior over other treatment followed by (24.50) in T_3 MF + 10T/ha^{-1} PB, 24.00 in T_1 MF (250 kg/ha^{-1} N:120 kg/ha^{-1}P:120 kg/ha^{-1})/RDF, (23.25) T_2 $^1/_2$ MF + 15T/ha^{-1} PB and T_4 $^1/_2$ MF + 15T/ha^{-1} SBB, in while the treatment T0 (Control) recorded the minimum (19.50) number of secondary branches per plant. Similar findings were reported by Shukla *et al.* (2018) [34], who experimented to assess the effect of vermicompost and biochar on the growth and yield of wheat.

The data presented in the Table 2 revealed that, the maximum (23.50mm) Stem diameter was recorded in T_5 MF + 10T/ha^{-1} SBB, which was statistically at par with T_4 (23.25mm) in $^1/_2$ MF + 15T/ha^{-1} SBB, T_3 (22.75mm) in MF + 10T/ha^{-1} PB, T_2 (22.25) $^1/_2$ MF + 15T/ha^{-1} PB and T_1 (22.00) MF (250 kg/ha^{-1} N:120 kg/ha^{-1}P:120 kg/ha^{-1})/RDF which was found significant over rest of the treatment. However, the minimum (19.00mm) Stem diameter was recorded in T_0 (Control). She *et al.* (2018) [33] observed that Biochar application at B1, B2 and B3 revealed a significant increase in tomato height and stem girth across the weeks after transplanting compared to the control. There were also significant differences in the leaf area and number of fruits at different biochar application rates compared to the control. This is congruent with previous studies on tomato, where biochar amendment was reported to reduce transient sodium ions by adsorption and release mineral nutrients such as potassium, calcium, and magnesium into the soil solution, which in turn have the potential to ameliorate salt stress and enhance tomato production.

Table 2: Effect of biochar on number of flowers per cluster/plant at 60 and 90 DAT, number of branches per plant, and stem diameter of tomato (*Solanum lycopersicum* L.)

Treatments	Number of flowers per cluster per plant		Number of branches per plant	Stem diameter (mm)
	30 DAT	60 DAT		
T_0	8.45	28.19	19.50	19.00
T_1	13.74	32.67	24.00	22.00
T_2	10.09	32.63	23.25	22.25
T_3	10.76	35.41	24.50	22.75
T_4	10.88	35.73	23.25	23.25
T_5	16.22	38.74	25.75	23.50
S.Em (±)	0.261	0.29	0.90	0.52
CD at 1%	0.863	0.97	3.66	2.10

The data number of fruit per plant presented in the Table 3 revealed that, the maximum (42.75) number of fruit per plant was recorded in T_5 MF + 10T/ha^{-1} SBB, which was statistically at par with T_3 (41.25) in MF + 10T/ha^{-1} PB and T_1 (40.50) in MF (250 kg/ha^{-1} N:120 kg/ha^{-1}P:120 kg/ha^{-1})/RDF, which was found significant over rest of the treatment. However, the minimum (26.50) number of fruit per plant was recorded in T_0 (Control). Plant development, nitrogen uptake, auxin and gibberellic acid concentrations, and yield characteristics, such as fruit weight and number of fruits per plant, are all significantly impacted by biochar (Langeroodi *et al.*, 2019) [22].

The data pertaining to the average fruit weight is presented in Table 3. After observing the data very carefully it was revealed that, the maximum (78.81g) average fruit weight was recorded in T_5 MF + 10T/ha^{-1} SBB, which was found to be significant superior over other treatment followed by 77.90 g in T_3 MF + 10T/ha^{-1} PB, 76.86 g in T_1 MF (250 kg/ha^{-1} N:120 kg/ha^{-1}P:120 kg/ha^{-1})/RDF, 76.63 g in T_4 $^1/_2$ MF + 15T/ha^{-1} SBB and 76.34g in T_2 $^1/_2$ MF + 15T/ha^{-1} PB while the treatment T_0 Control recorded the minimum (61.88 g) average fruit weight. The enhanced bio-stimulant effects from biochar and RDF (NPK) influenced these hormonal balances, leading to changes in fruit weight. Biochar is an efficient soil amendment that enhances soil properties and sustains long-term soil productivity and yield (Naeem *et al.*, 2017) [29]. This is in congruence with the previous study by Ronga *et al.* (2020) [31], who recorded higher mean values for fruit weight of tomatoes after biochar application (82.67 g) compared to the control (65.33 g).

The data presented in the Table 4 revealed that the maximum (5.81 cm) fruit diameter was recorded in T_5 MF + 10T/ha^{-1} SBB, which was statistically at par with T_3 (5.78 cm) in MF + 10T/ha^{-1} PB, which was found significant over rest of the treatment. However, the minimum (5.10 cm) fruit diameter was recorded in T_0 Control. The study on cucumber fruit size and shape variations by Liu *et al.* (2020) [26] highlighted the role of endogenous hormones in fruit development. The enhanced bio-stimulant effects from biochar and RDF (NPK) influenced these hormonal balances, leading to changes in fruit length.

It is evident from the data presented in Table 4 that the fruit yield per plant was significantly influenced by different treatments. The maximum (9.95 kg) fruit yield per plant of tomato was recorded in T_5 MF + 10T/ha^{-1} SBB, followed by 8.60 kg in T_4 $^1/_2$ MF + 15T/ha^{-1} SBB and 8.34 kg in T_2 $^1/_2$ MF + 15T/ha^{-1} PB. However, the minimum (4.41 kg) tomato fruit yield per plant was recorded in T0 (Control). The increased number of fruits per plant and higher fruit yield per plant ultimately culminated in the highest yield. The results conform with the study of Kebede (2023) also reported an increase in the capsicum yield with biochar application. The addition of biochar to the soil increased its water-holding capacity and permeability, both of which increase yield (Langeroodi *et al.*, 2019) [22].

Table 3: Effect of biochar on number of fruit per plant, average fruit weight, fruit diameter (cm), and fruit yield per plant of tomato (*Solanum lycopersicum* L.).

Treatment	Number of fruit per plant	Average fruit weight (g)	Fruit diameter (cm)	Fruit yield per plant (kg)
T_0	26.50	61.88	5.10	4.41
T_1	40.50	76.86	5.62	7.39
T_2	39.00	76.34	5.28	8.34
T_3	41.25	77.90	5.78	7.53
T_4	39.00	76.63	5.59	8.60
T_5	42.75	78.81	5.81	9.85
S.Em (±)	0.86	0.85	0.36	0.19
CD at 1%	3.51	2.60	0.09	0.79

Conclusion

On the basis of this experimentation, it is concluded that MF + 10T/ha^{-1} SBB (T_5) in tomato should be applied for better nutrient and water management throughout the cropping season for obtaining higher yields and economic returns over rest of the treatments.

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