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Influence of Biochar on Growth, Yield and Quality of Broccoli

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Abstract: *Broccoli is one of the most important, nutrient-rich vegetables among cole crops which belong to the family Brassicaceae. It is known to be a healthy and delectable vegetable which is rich in many nutrients. Biochar is considered as a potential substitute for soil organic matter (SOM). Biochar addition to low organic carbon soils can act as a feasible solution to keep soil biologically active for the cycling of different nutrients. The application of biochar could improve soil fertility, increase crop yield, enhance plant growth and microbialabundance, and immobilize different contaminants in the soil. Due to thelarge surface area of biochar, which generally depends upon the types of feedstock and pyrolysis conditions, it helps to reduce the leaching of fertilizers from the soil and supplies additional nutrientsto growing crops. In view of the above importance all possible issues related to biochar application should beconsidered. Previous literature review shows that applying biochar to the broccoli plant improved only the leaf area and root length with significant changes. The highest yield per plot (4.49 kg), bud weight (499.37g), bud diameter (16.55 cm), and yield per hectare (14.98 t ha^{-1}) of broccoli was found to be significant in biochar treated plot (T_2: PSB 100 L/ha + Biochar 30 t ha^{-1}). Considering classification of the flowering heads by categories, M (manure pellet) + EB (enriched-biochar amended soil and organic fertilizer) + AND (manure pellet and enriched-biochar amended soil treated with organic fertilization) treatments showed a higher number of first category flowering heads with regard to other treatments. Therefore, the use of biochar is an effective approach for potential nutrient reservoir for plants and a good amendment to improve soil properties.*

Keywords: Biochar, soil organic matter, feedstock, depletion of nutrients adsorption, flowering heads, and potential nutrient reservoir

I. INTRODUCTION

Broccoli is one of the most important, nutrient-rich vegetables among cole crops which belong to the family Brassicaceae. Broccoli has a reputation as a supplementary vegetable in salads and in supper food. It is known to be a healthy and delectable vegetable which is rich in many nutrients. Broccoli is rich in vitamins, minerals, fibers and antioxidants that support many dimensions of human health (Tarafder *et al*., 2023). It is characterized by a low Glycemic Index (GI=10) for diabetics (Nagraj *et al*., 2020). The rest was produced by USA, Mexico, Spain, Italy, Turkey, Bangladesh, Poland and France (FAOSTAT, 2020). Farmers in Bangladesh are very much interested to produce broccoli for its high value. The Excessive use of chemical fertilizers to meet the crop demand has badly affected the soil health and productivity and is also adding high economic load but at present condition it is not possible to completely eliminate the use of chemical fertilizers. On the other hand, reliance on organic fertilizers and biofertilizer's alone is also not feasible because they are comparatively low in nutrient amount and can better serve as a supplement rather than substitute (Chojnacka *et al*, 2020). Biochar (BC) is a carbon-rich material produced from the pyrolysis of biomass. The pyrolysis temperature and the composition of feedstock material significantly influence the properties of biochar (Tomczyk *et al.*, 2020). Biochar (BC) is a carbon-rich material produced from the pyrolysis of biomass. The pyrolysis temperature and the composition of feedstock material significantly influence the properties of biochar (Tomczyk *et al.*, 2020). Therefore, the application of biochar to soils offers a considerable "climate-smart" opportunity to improve soil fertility and the resilience of smallholder farming systems in the tropics, and increase food security (Schmidt *et al*., 2021). Wang *et al.* (2019) reported improved plant height, root and shoot dry weights, and root/shoot ratio in apple seedlings in response to different BC doses. Moreover, BC application to sandy soil improved the growth, dry matter, and pod yield of green pea (*Pisum sativum* L.) under low water availability (Youssef *et al*., 2018). In a field study, 2,544-2,625 kg/ha of BC-based fertilizer improved fertilizer efficiency and provided economic benefits in eggplant production relative to traditional fertilization practices (Zhang *et al*., 2022). Montoya *et al*. (2022) reported that enriched-biochar application increases broccoli nutritional and phytochemical content without detrimental effect on yield. In field experiments, BC-based fertilizer amendments increased eggplant yield and quality, including vitamin C and soluble sugar contents (Zhang *et al*., 2022). Since the nutritional requirement of vegetable crops are different from cereal crops, it would be interesting to monitor the effect of biochar application on the vegetable crops both in the presence and absence of inorganic fertilizers.

II. MATERIALS AND METHODS

This paper is utterly a review paper so all of the information has been collected from the secondary sources. During preparation of this paper, I went through various comprehensive studies of relevant books, journals, proceedings, reports, publications etc. Different published reports of different journals mainly supported in providing data for this paper. Findings related to my topic have been reviewed with the help of the library facilities of Sher-e-Bangla Agricultural University (SAU). Information has also collected from Department of Agroforestry and Environmental Science, SAU. I have also searched related internet web sites to collect information. After accumulating all the available information, I myself compiled and prepared this paper.

III. RESULTS AND DISCUSSION

3.1. Biochar

Biochar is a dark-black-colored, partially combusted (pyrolyzed), and recalcitrant compound which helps to enrich the nutrient balance and carbon stock in the soil (Figure 4). It is a porous carbonaceous sorbent generally produced from materials of biological origin (crops residues) which is formed after specific thermochemical conversions (pyrolysis) under limited oxygen supply conditions. Most frequently, biochar is a product of plant and agricultural residues derived biomass carrying oxygen-containing functional and aromatic groups. It has physicochemical properties which allow it to be used for a long time, safely accumulate carbon in the environment, and improve soil health (Jatav *et al*., 2021).

3.2. The role of biochar in organic waste composting and soil improvement

Large amounts of organic wastes, which pose a severe threat to the environment, can be thermally pyrolyzed to produce biochar. Biochar has many potential uses owing to its unique physicochemical properties and attracts increasing attentions. Therefore, the agronomic functions of biochar used as compost additives and soil amendments. As a soil amendment, biochar shows a good performance in improving soil properties and plant growth, alleviating drought and salinity up taken from soils to plants.

3.3. Applications of biochar and their effect on soil properties

Depending on the quantity of biochar added to soil significant improvements in plant productivity have been achieved (Rajput *et al.* 2020) As yet there is limited critical analysis of possible agricultural impacts of biochar application in temperate regions, nor on the likelihood of utilizing such soils as long-term sites for carbon. On the other hand, soil application of biochar can, permanently appropriate C in the soil and reduce net emissions of carbon dioxide gas improve crop productivity through enhanced physio-chemical and biological properties, nutrient release pattern, reduce denitrification and soil pollutants (Horák *et al.,* 2021). Thus, biochar can potentially provide two simultaneous economic benefits. One, it may improve the agronomic and environmental sustainability of biomass production systems. Two, it may improve the economic sustainability of bioenergy enterprises by offsetting feedstock purchases with revenue from biochar sales (Wang *et al*., 2020). Its benefits on crop production, environment, and soil will be a moot point if it is not reproducible and consistent. Biochar and its beneficial properties are presented in Table 1 and 2.

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3.3.1 Physical properties

Table 1. Biochar and its beneficial component in the environment

Properties	**Effect of biochar application on various factors**
Soil fertility	Biochar can improve soil fertility, stimulating plant growth, which then consumes more CO_2 in a positive feedback effect.
Reduced fertilizer inputs	Biochar can reduce the need for chemical fertilizers, resulting in reduced emissions of greenhouse gases from fertilizer manufacture.
Reduced N_2O and CH_4 emissions	Biochar can reduce emissions of nitrous oxide (N_2O) and methane (CH_4), two potent greenhouse gases from agricultural soils.
Enhanced soil microbial life	Biochar can increase soil microbial life, resulting in more carbon storage in soil.
Reduced emissions	Converting agricultural and forestry
from feed stocks	waste into biochar can avoid CO_2 and CH_4 emissions otherwise generated by the natural decomposition or burning of the waste.
Energy generation	The heat energy and also the bio oils and synthesis gases generated during biochar production can be used to displace carbon positive energy from fossil fuels.

(**Source**: Oni *et al*., 2019)

3.3.2 Chemical properties

Table 2. Various physio biochemical properties of biochar

Parameter	**Value**	
	Minimum	**Maximum**
pH	4.5	12.9
Electrical conductivity (mS cm^{-1})	20	10,260
Cation exchange capacity (cmolþ kg^{-1})	3.8	272
Surface area (m^2 g^{-1})	0.1	410
Bulk density (g cm^{-3})	0.05	0.7
Volatile matter (%)	0.6	85.7
N (g kg^{-1})	0.1	6.4
K (g kg^{-1})	0.3	74.0
P (g kg^{-1})	0.005	59
Ca (g kg^{-1})	0.04	92
Mg (g kg^{-1})	0.009	37
Carbon (%)	17.7	92.7
Hydrogen (%)	0.05	5.30
Oxygen (%)	0.01	39.2
H/C	<0.01	1.14
O/C	0.02	1.11

(**Source:** Tomczyk *et al*., 2020)

3.4. Advantages and limitations of different applications of biochar

The eco-friendly, inexpensive and ease of preparation from various biomass using thermochemical techniques for addressing vast environmental applications makes biochar an intensive area of interest among researchers. The carbon-rich biochar produced using high pyrolysis temperature has more removal efficiency of organic pollutants due to its enriched properties such as porosity, surface area, pH, less dissolved carbon content and hydrophobic nature. Similarly, the biochar produced using lower temperature possess oxygen-containing functional groups, high dissolved organic carbon and less porous so these types of biochar are more suitable for removing inorganic pollutants. Biochar can also be used for other applications such as catalysts, wastewater treatment, composting, energy storage, carbon sequestration and soil amendment (Yaashikaaa *et al*., 2020).

Table 3. Advantages and limitations of different applications of biochar

Applications	**Aim**	**Advantages**	**Limitations**
Catalyst	Act as supporting materials for direct catalysis	Low cost, more functional groups, large surface area	Efficiency may be less
Energy storage	Utilizing as electrode materials	Low cost, highly porous, large surface area	Performance is low
Soil amendment	Enhancing soil fertility and quality and carbon sequestration	Low cost, minimize emission of greenhouse gases, helps to retain nutrients and water, controls nutrient loss	Contamination of heavy metals and poly aromatic hydrocarbons may persist
Adsorbents	Removal of organic and inorganic pollutants in soil and aqueous system	Low cost and more oxygen groups present in biochar enhances adsorption of pollutants	Removal efficiency of pollutants is undetermined and heavy metals retains in soil
Composting	Improving structure of microbial population and carbon mineralization	Porous, reducing emission of greenhouse gases, large surface area and retains nutrients	There may be chance of heavy metals and other contaminants invading into soil

(**Source:** Yaashikaaa *et al*., 2020).

3.5. Impact of biochar on horticultural crops

Table 4. Effect of biochar on horticulture crops

Name	**Functions**
Broccoli (*Brassica oleracea* var.)	Improved chlorophyll contents, amylase activity, total soluble sugars, decreased Na+ uptake, MDA, and improved plant growth and biomass, enhanced chlorophyll content, decreased MDA, H_2O_2, sucrose and proline content, enhanced leaf nutrient elements, decreased Na and Cl content in plant.
Tomato (*Solanum lycopersicum*)	Improved chlorophyll contents, improved yield and fruit, quality, decreased uptake of heavy metals in both plant parts and fruits
Lettuce (*Lactuca sativa* L.)	Restored antioxidant activity and flavonoids, increased total phenols, phenolic acids and anthocyanins

(**Source:** Zulfiqar *et al*., 2022).

3.5. Impact of biochar on growth, yield and quality of broccoli

3.5.1 Growth parameters

Mean square values and probabilities of growth and yield traits of broccoli are given in Table 4. In the case of charcoal, the treatment that received 7.5% produced a plant with a maximum leaf area (482.83 cm^2) that was at par with treatment that received 5%. The minimum leaf area (396.01 cm^2) was produced in the plant receiving 2.5%. Root length significantly (<0.05) differed with various levels of charcoal. An increasing level of charcoal increased root length in broccoli with the longest root length (28.19 cm) at 7.5% that was at par with 5% and the shortest route length (20.77 cm) at control.

Table 5. Effect of different levels of charcoal (biochar) on no. of leaves, leaf area, root length, head diameter, head weight and above-ground biomass of broccoli at Lamjung, Nepal during the winter season of 2019–2020.

Charcoal levels (%/soil weight)	**No. of leaves**	**Leaf area (cm^2)**	**Root length, (cm)**	**Aboveground biomass (g)**
C_1 (0 g charcoal pot^{-1})	12	412.93 b	20.77 c	483.19
C_2 (125 g charcoal pot^{-1})	12	396.01 b	22.55 bc	433.51
C_3 (250 g charcoal pot^{-1})	12	435.22 ab	26.42 ab	488.89
C_4 (375 g charcoal pot^{-1})	12	482.83 a	28.19 a	519.87
Mean	12	431.75	24.48	481.36
SEM	0.28	20.3	1.38	31.9
F test	NS	*	**	NS
LSD $_{(0.05)}$	0.804	57.774	3.950	90.616

NS – not significant, * – significant at 0.05 level of probability, ** – significant at 0.01 level of probability, SEM – standard error of mean, LSD – least significant difference. Means followed by the same letters in the same column are not significantly different at the 0.05 level of probability. C_1: 0 % by soil weight = 0 g charcoal pot^{-1}, C_2: 2.5 % by soil weight = 125 g charcoal pot^{-1}, C_3: 5 % by soil weight = 250 g charcoal pot^{-1} and C4: 7.5 % by soil weight = 375 g charcoal pot^{-1}.

(**Source**: Bhattarai *et al*., 2022)

3.5.2. Yield parameters

The highest yield per plot of broccoli was in treatment T_2 (PSB 100L/ha + Biochar 30t/ha) (4.49 kg) treatment. The highest bud weight (499.37g), maximum bud diameter (16.55 cm), and maximum yield per hectare (14.98 t ha^{-1}) was also found in T_2 (PSB 100 L/ha + Biochar 30 t ha^{-1}) treatment followed by T_9 (PSB 150 L/ha + Biochar 30 t ha^{-1}and T8 PSB 100L/ha + Biochar 20 t ha^{-1}) treatment. Similarly, Lee *et al.*, (2022) reported that photosynthetic bacteria can increase the yield and quality of vegetables, may be due to photosynthetic bacteria metabolites rich in nutrients, rich in various vitamins. Trupiano *et al.,* (2017) also had a similar report that biochar helped in the conditioning of the soil, increase in biomass, bettering the growth.

Table 6. Influence of photosynthetic bacteria and biochar on yield parameters of broccoli

Treatment symbol	**Treatment combination**	**Head yield per plot (kg)**	**Head weight (g)**	**Head diameter (cm)**	**Head yield (t ha^{-1})**
T_0	Control	1.76	195.74	12.82	5.87
T_1	PSB 50L + Biochar 20t	2.12	235.71	12.95	7.07
T_2	PSB 100L/ha + Biochar 30t/ha	4.49	499.37	16.55	14.98
T_3	PSB 150L/ha + Biochar 50t/ha	3.09	343.63	16.01	10.30
T_4	PSB 50L/ha + Biochar 30t/ha	2.97	299.65	15.80	9.90
T_5	PSB 100L/ha + Biochar 50t/ha	2.81	293.18	15.40	9.39
T_6	PSB 150L/ha + Biochar 20t/ha	2.69	330.07	15.20	8.98
T_7	PSB 50L/ha +Biochar 50t/ha	2.63	313.18	14.96	8.79
T_8	PSB 100L/ha + Biochar 20t/ha	3.22	358.03	16.09	10.73
T_9	PSB 150L/ha + Biochar 30t/ha	4.22	468.82	16.13	14.06
F-test		S	S	S	S
S. Ed (±)		0.09	9.75	0.18	0.29
C.D at 5%		0.18	20.48	0.38	0.61

(**Source:** Jamir *et al*., 2020)

3.5.3. Flowering head categories classification

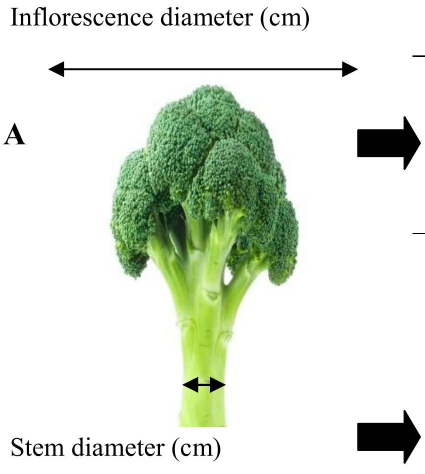
Considering classification of the flowering heads by categories (Table 1), EB (enriched-biochar amended soil and organic fertilizer) + AND (manure pellet and enriched-biochar amended soil treated with organic fertilization) and M (manure pellet) + EB + AND treatments showed a higher number of first category flowering heads with regard to CF (control plants with no organic amendment and conventional inorganic fertilization) and M + CF, while these last treatments presented a higher number of second category flowering heads with regard to the two first treatments. Only significant differences were found between M + CF and M + EB + AND treatments in the fourth category flowering heads, the number being higher in the last one. Finally, EB +AND and M + EB + AND treatments resulted in a lower amount of industry category flowering heads in comparison to CF and M + CF. Regarding the percentage of flowering heads or stalks that were refused due to their no-commercial characteristics (hollow stem, too small size, etc.), CF and M + CF showed a percentage of 30%, following by M + EB + AND treatment, where 22% of the flowering heads where discarded, and EB+AND treatment with 18% of refused flowering heads.

Table 7. Flowering head categories classification of broccoli

Treatment	First	Second	Fourth	Industry/local market
CF	66.40 ± 2.51b	10.29 ± 1.59a	18.96 ± 3.0ab	7.39 ± 1.37a
M + CF	64.81 ± 6.54b	12.21 ± 2.96a	15.88 ± 3.53b	7.11 ± 2.37a
EB+AND	71.92 ± 2.87a	6.64 ± 0.85b	16.62 ± 2.81ab	3.70 ± 0.51b
M + EB + AND	74.45 ± 6.43a	5.23 ± 0.30b	20.74 ± 5.42a	3.70 ± 0.1b
LSD $_{(0.05)}$	2.55	2.00	4.50	1.20
Level of significant	*	*	*	*

CF, control plants with no organic amendment and conventional inorganic fertilization; M + CF, manure pellet amended soil and conventional fertil- ization; EB+AND, enriched-biochar amended soil and organic fertilizer AND; M + EB + AND, manure pellet and enriched-biochar amended soil treated with organic fertilization AND. Numbers show average value per treatment in the eight randomized subplots (n = 8) ± standard deviation. One-way analysis of variance (ANOVA) following by multiple-range Tukey's test was used to separate means. Different letters indicate statistically significant differences ($P < 0.05$).

(**Source**: Montoya *et al*., 2022)



Inflorescence diameter (cm)	
CF	13.82 ± 0.20 a
M + CF	13.424 ± 0.24 b
EB+AND	13.324 ± 0.23 b
M + EB + AND	13.312 ± 0.16 b
Stem diameter (cm)	
CF	4.04 ± 0.20 a
M + CF	3.80 ± 0.77 a
	3.96 ± 0.79 a
EB+AND	
M + EB + AND	3.77 ± 0.85 a

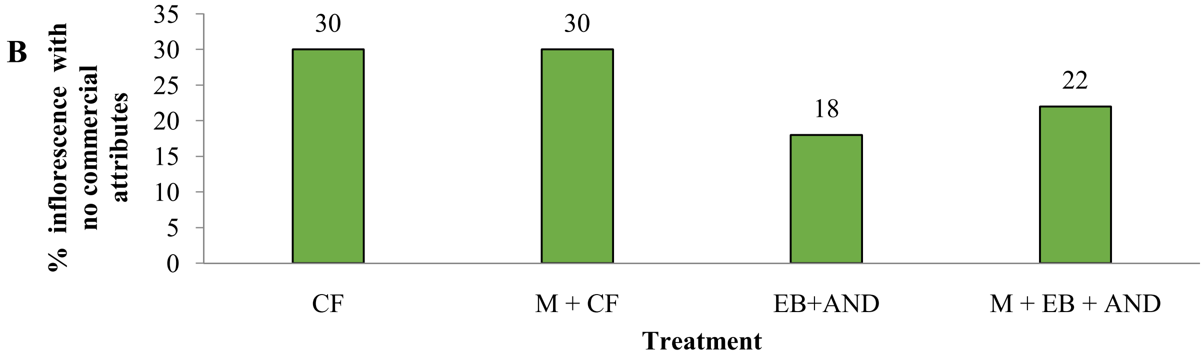


Figure 1. Percentage of flowering heads refused due to no-commercial characteristics (A). External diameter and inner diameter of the harvested flowering heads at a fixed commercial length of 200 mm (B). CF, control plants with no organic amendment and conventional inorganic fertilization; M + CF, manure pellet amended soil and conventional fertilization; EB+AND, enriched-biochar amended soil and organic fertilizer AND; M + EB + AND: manure pellet and enriched-biochar amended soil treated with organic fertilization AND. Numbers show average value per treatment (n = 20) ± standard devi- ation. Different letters indicate statistically significant differences ($P < 0.05$).

(**Source**: Montoya *et al*., 2022)

3.5.4. Quality

3.5.4.1. Broccoli head nutrient content

Nitrogen content of the broccoli heads was highest in heads harvested from plots amended with CWCR and CF with 4.38% and 4.37% N respectively. Phosphorus content was higher in broccoli heads that were obtained from CF treated plots, while K content was higher in broccoli heads that were obtained from CC treated plot. Calcium and Mg content results were inconsistent as broccoli heads harvested from control plots had generally higher Ca and Mg contents compared to the amendments. Sulphur is an important constituent of chlorophyll molecule, broccoli heads harvested from plots amended with CWCR and CF had higher S content of 1.16% and 1.08%, respectively. Broccoli head S content results are consistent with broccoli head N content results as heads produced from plots amended with CWCR and CF were also high in N content relative to those produced from other plots. Concentration of the following micro nutrients: iron, manganese, boron and zinc are very critical to evaluate in crops, as human deficiencies may cause anaemia, osteoporosis, arthritis and eczema; respectively. Concentration of Fe, Mn, B and Zn were all higher in broccoli heads harvested from plots amended with CF while CB treated plots resulted in second best in Fe content whereas CWCR plot was second best in Zn.

Table 8. Broccoli head nutrient content from plots amended with organic and inorganic soil amendments, and from the control

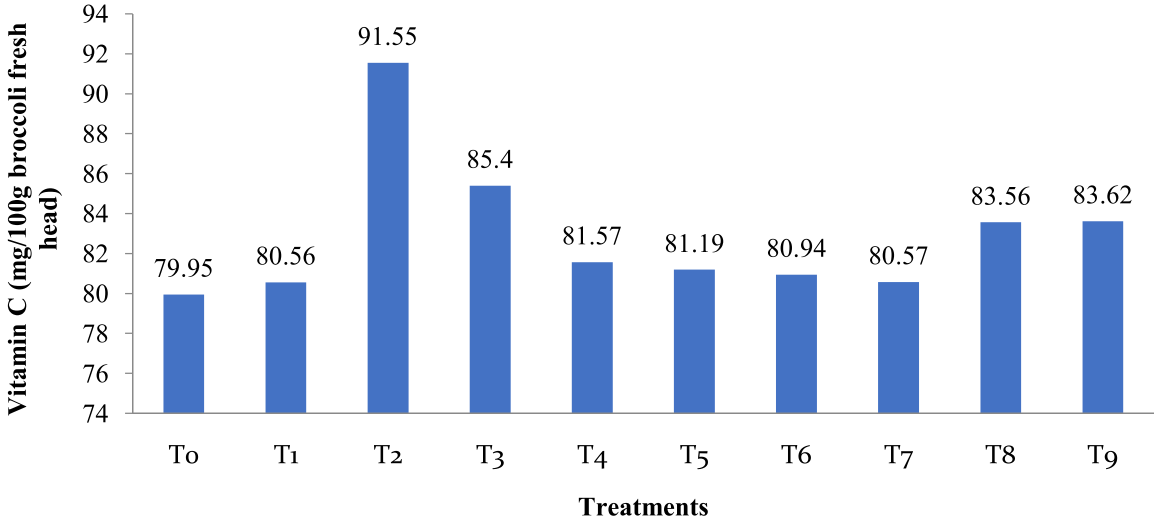
Treatment	**Broccoli heads mineral content**											
	N	**P**	**K**	**Ca**	**Mg**	**S**	**Na**	**Fe**	**Cu**	**Zn**	**Mn**	**B**
	(%)						(mg/kg)					
Control	3.68	0.50	2.75	1.32	0.26	0.94	429.67	112.69	5.39	37.81	11.20	49.04
Commercial compost (CC)	3.93	0.49	2.87	0.95	0.24	1.01	477.67	111.79	4.62	38.13	9.16	51.43
Commercial fertilizer (CF)	4.37	0.59	2.78	0.90	0.24	1.08	485.33	201.71	4.41	43.67	13.45	60.67
Composted biochar (CB)	3.93	0.57	2.73	1.06	0.25	1.06	484.00	142.97	5.69	42.65	9.75	50.60
Composted	3.88	0.54	2.64	0.84	0.23	1.04	426.67	82.31	6.39	41.42	10.48	52.36

waste (CW)												
Composted waste (Commercial Rate) (CWCR)	4.38	0.58	2.83	0.87	0.29	1.16	513.33	142.07	4.62	43.47	3.68	53.56

(**Source:** Gobozi, 2018)

3.5.4.2. Vitamin c content

The result of the data showed that the treatment T_2 (PSB 100L/ha + Biochar 30t/ha) observed maximum vitamin 'C' mg/100g (91.55mg) followed by T3 (PSB 150L/ha + Biochar 50t/ha) whereas minimum findings were associated with T_0 Control as presented in figure 2.



Here, T_0 Control, T_1 (PSB 50L/ha + Biochar 20t/ha), T_2 (PSB 100L/ha + Biochar 30t/ha), T_3 (PSB 150L/ha + Biochar 50t/ha), T_4 (PSB 50L/ha + Biochar 30t/ha), T_5 (PSB100L/ha + Biochar 50t/ha), T_6 (PSB 150L/ha + Biochar 20t/ha), T_7 (PSB 50L/ha +Biochar 50t/ha), T8 (PSB 100L/ha +Biochar 20t/ha), T9 (PSB 150L/ha+ Biochar 30t/ha).

Figure 2. Influence of photosynthetic bacteria and biochar on Vitamin c content of broccoli

(**Source:** Jamir *et al*., 2020)

IV. CONCLUSION

Farmers in Bangladesh are very much interested to produce broccoli for its high value however excessive use of chemical fertilizers to meet the crop demand has badly affected the soil health and productivity. Soil amendments to improve soil water and nutrient holding capacity have become an important tool to enhance soil properties. Biochar is being suggested as a soil amendment for improving the quality of the agricultural soils. Biochar application has great impacts on soil physical, chemical, and biological properties, plant growth, and crop yield. It directly affects soil bulk density, pH, water holding capacity, and nutrients contents. Due to the vast differences in biochar, its application methods and rates, the responses of soils and plants to biochar application vary dramatically among different experimental studies. Previous literature review shows that applying biochar to the broccoli plant improved only the leaf area and root length with significant changes. The highest yield per plot (4.49 kg), bud weight (499.37g), bud diameter (16.55 cm), and yield per hectare (14.98 t ha^{-1}) of broccoli was found to significant in biochar treated plot (T_2: PSB 100 L/ha + Biochar 30 t ha^{-1}). Considering classification of the flowering heads by categories, M (manure pellet) + EB (enriched-biochar amended soil and organic fertilizer) + AND (manure pellet and enriched-biochar amended soil treated with organic fertilization) treatments showed a higher number of first category flowering heads with regard to other treatments. Therefore, the use of biochar is an effective approach for long-term improvement of soil fertility and crop productivity.

V. RECOMMENDATION

Biochar, an environmentally friendly soil amendment, is produced using several thermochemical processes. To accomplish this, the following actions may be considered for the development of different doses of biochar application in vegetable crops:

Long-term field studies are needed rather than pot or column studies to understand the impact of biochar in soil.

The feedstock selection and application rate should be studied in relation to availability of nutrients.

Methods to increase the N content of biochar should be considered, for example by adjusting the pyrolytic conditions, because N is reduced by increasing the pyrolysis temperature.

The availability of P as a result of different pyrolytic temperatures needs to be studied.

Studies are needed to understand the interaction of biochar and microbes and how they affect nutrient transformation in different vegetable crops.

Innovative treatment methods could be explored for fabricating modified/engineered biochar with improved physicochemical properties, which could be used to ameliorate adverse effects of temperature rise, drought, flood, and salinization on the soil–plant systems. Realtime applicability of modified biochar’s should also be analyzed keeping in mind the cost of fabrication and their life cycle assess.

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