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A Comparative Study on Hydrothermal Liquefied Biochar as Biofertilizer for Increased Plant Yield

M. Subathra[1], R. Devika[1]

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ABSTRACT

Background: The agriculture sector is moving towards ecofriendly fertilizers to promote quality food products and to reduce the pollution caused on the environment by chemical fertilizer producing industries such as air pollution by releasing toxic gas and water pollution by discharging the untreated water from the chemical fertilizer industry. Though chemical fertilizer yield high productivity in short time, they reduces the soil fertility gradually, reduces the quality of the agricultural products and also implies toxic effects toward the human population. To rule out the above mentioned disadvantages and to maintain the sustainable environment, current study aims in utilizing the biochar as biofertilizer to replace the existing chemical fertilizer.

Methods: In this present study the biochar obtained as the byproduct of Hydrothermal liquefaction process from various wastes like groundnut shell, sewage waste, citrus fruit peel, food waste and rice husk were mixed in equal ratio and used as a biofertilizer on three different plants (Tomato, Chilly and Lady's finger) in the field environment. Since the biochar is rich in carbon and holds a good amount of moisture content, this acted as a promising alternate to the existing chemical fertilizer.

Result: The yield % of all the plants treated with biochar were recorded and found to be 84%, 30% and 93% for tomato, chilly and lady's finger, respectively during the period of the study. Whereas the yield % of the plants treated with chemical fertilizer were 81%, 23% and 84% for Tomato, Chilly and Lady's finger respectively. Existing commercial biofertilizer gave a mild rise in efficiency when compared with biochar. So a future plan is proposed to treat the biochar with the agro based fertilizer industry effluent to adsorb the nutrients present in it, there by the efficiency of biochar can compete well with the existing biofertilizer.

Key words: Biochar, Chilly, Hydrothermal liquefaction process, Lady's finger, Tomato.

INTRODUCTION

Biofertilizer plays a major role in current agricultural practices because of toxic effects produced by the chemical fertilizer over the soil, promoting soil degradation and the plant yield. The chemical fertilizer normally increases the yield at initial application and later it produces toxic effect towards the soil fertility and reduces the yield as the year passes. In order to overcome this issue, old way of eco-friendly agricultural practices are coming back in to this current ages in order to prevent the soil fertility. In olden days cow dung played a major role as a fertilizer, but due to lesser cow dung availability in modern days, different methods for producing biofertilizers are emerging in present technology. The usage of biofertilizer also decrease the erosion of fertile soil, protect the soil from the environmental problem created in the aquatic ecosystem like algal bloom due to erosion of high nutrients from the agricultural land during heavy rainfall (Sunardi *et al.,* 2022). Biofertilizer has a major importance in plant yield, preventing the fertility of the soil and enrichment of the soil nutritive value as year progress. A review on efficiency of the biofertilizers in improving the fruit productivity and novel tool for agriculture which was illustrated by Mosa *et al.* (2014) and Boraste *et al.* (2009). Hazarika and Ansari, (2007) demonstrated the effect of biofertilizer on fruit yield and reported that, about 20%-25% yield increased when compared to the chemical fertilizers. Irin and Biswas (2023) improved the crop efficiency by incorporating green manure that slowly releases the nutrients into the soil which last long. On holding many advantage on biofertilizer, this also face the constrain created by environmental factors which pulls down its survival in the soil as mentioned by Ganesh *et al.* (2023). This can be over ruined by incorporating appropriate substance to the biofertilizer.

The word "reuse" plays a major role in producing biofertilizer from waste. One such waste management method is Hydrothermal liquefaction process, which is currently used by majority of the researchers in managing

[1]Department of Biotechnology, Aarupadai Veedu Institute of Technology, Vinayaka Mission's Research Foundation (Deemed to be University), Paiyanoor-603 104, Tamil Nadu, India.

Corresponding Author: M. Subathra, Department of Biotechnology, Aarupadai Veedu Institute of Technology, Vinayaka Mission's Research Foundation (Deemed to be University), Paiyanoor-603 104, Tamil Nadu, India. Email: subu110494@gmail.com

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the wet waste efficiently and producing value added products that are considered as non-renewable source such as bio oil that can be blended along with commercial fossil fuels to pull down the cost of the existing petrol and diesel. One of the byproduct of hydrothermal liquefaction process is biochar that again enters the environment as waste without any utilization. Such biochar obtained as byproduct from hydrothermal liquefaction process is rich in carbon (C), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), aluminium (Al) and iron (Fe) which are essential for plant and growth in terms of water retention, aerobic respiration, capturing sunlight energy, helps in metabolism, chlorophyll synthesis, activate tolerance and abiotic stress gene, improves defense response, activate enzyme involved in ATP production and helps in seed production (Ammal *et al.,* 2020). Best route of producing the biochar is hydrothermal carbonization on comparing with other existing thermal treatments in terms of cost, temperature and pressure. The high temperature also reduces the nutrient content of biochar which may pull down its application as biofertilizer (Arun *et al.,* 2020). The biochar produced out of hydrothermal liquefaction process are more advantageous in terms of water holding capacity for long period of time, reduced water evaporation from the field, supply nutrients, reduced pest activity on the plant and reduced disease caused by the organism present on the soil, *etc* (Bakhat *et al.,* 2021). To commercialize and replace the existing chemical and commercial biofertilizer by biochar, few significant nutrients has to be supplied or a mixture of commercial biofertilizer and biochar can be used on the agricultural field (Oladele *et al.,* 2019) or pulverized manure to improve the yield (Mohan and Jayan, 2024) or engineered biochar (Akhil *et al.,* 2021) or combination of conventional biofertilizer with nanofertilizer (Tamilarasan and Raja, 2024) earthworm proliferated farm waste as manure (Cerci *et al.,* 2020) can be used to enhance the yield and the usage of biochar pulls down the soil pollution and frame way towards the sustainable agricultural goal (Danapriatna *et al.,* 2023). Charcoal based biofertilizer has increased the yield of chickpea as reported by Sharma and Nagpal, (2021). Such biochar hold 99% of efficiency to degrade naturally thereby promoting sustainable environment (Gopinath *et al.,* 2020). Therefore the present study aimed to determine the efficiency of the biochar on the agricultural field against the chemical fertilizer usage with three different plant such as tomato, chilly and lady's finger.

MATERIALS AND METHODS

Soil collection and sample collection

The soil for field test was collected from the location near Aarupadai Veedu Institute of Technology, Paiyanoor, Chennai. The entire study was carried out between 2020 to 2023. The nature of the soil was loamy - a mixture of sand, clay and red soil. Loamy soil promotes the growth by allowing the roots to spread easy due to the granulated nature. This soil also holds the water content better than the usual red soil.

Sample for hydrothermal liquefaction process was collected from the nearby areas. The first biomass- sewage water was collected from the sewage treatment plant of Aarupadai Veedu Institute of Technology, Paiyanoor, Chennai and stored it overnight without disturbance. The solid substances present in the collected water gets settled down due to gravitational force which was separated from the top liquid phase and taken further for hydrothermal liquefaction process. Second biomass- citrus fruit peel waste was collected from the canteen of Aarupadai Veedu Institute of Technology, Paiyanoor, Chennai. The collected peel was segregated and three peel were separated namely lemon, orange and sweet lime. All the peels were grinded and mixed in 1:1:1 ratio and made ready to undergo hydrothermal liquefaction process. Third biomass was food waste collected from Aarupadai Veedu Institute of Technology mess hall and directly used for thermal liquefaction process. The fourth biomass was groundnut shell collected after domestic usage and grounded into coarse powder before entering thermal treatment. Fifth biomass was rice husk collected from Padalam rice mill from Chengalpattu district. The collected husk underwent thermal processing. Last biomass was mixture of all six biomass mixed in equal ratio (1:1:1:1:1) and exposed to liquefaction process.

Biomass and soil characterization

The collected biomass underwent biochemical analysis to determine the parameters that plays a vital role in determining the yield of bio oil and biochar from hydrothermal liquefaction process. The parameters analyzed include total solid%, cellulose%, volatile solid%, nitrogen%, phosphorous%, potassium%, moisture content and pH. The amount of cellulose, volatile solids and pH plays a major role in thermal liquefaction process determining the yield from the process.

The soil collected for field test underwent biochemical method to identify the presence of organic matter, carbon, nitrogen, potassium, phosphorous, carbon:nitrogen ratio and pH. These parameters determine the plant growth partially and act as a control in determining the plant growth yield by chemical fertilizer, commercial biofertilizer and biochar.

Biochar from hydrothermal liquefaction process

The hydrothermal liquefaction process was carried out for sewage sludge, citrus fruit peel, food waste, groundnut shell, rice husk and mixed biomass by the thermal autoclave reactor of capacity 5 l, with the operating temperature of 350°C with a heating rate of 10°C/min. The optimization of reactor was carried out with different temperature ranging from 200°C, 220°C, 240°C, 260°C, 280°C and 300°C, different concentration of 20 g/l, 40 g/l, 60 g/l, 80 g/l and 100 g/l, different time 30 min, 60 min and 90 min. The optimum parameter was found to be 260°C

temperature, 20 g/l concentration and 60min reaction time. The hydrothermal liquefaction process produces 3 different products- Bio oil, biochar and liquid phase. The bio oil produced can be blended with the fossil fuel and used for transportation purpose. In this study the biochar produced was used as a fertilizer to substitute the usage of the existing fertilizer in the market. All the biochar from different thermal liquefaction process was mixed in equal ratio and taken further for field test.

Biochar characterization

The biochar from the thermal liquefaction process was characterized by Field Emission Scanning Electron Microscopy (FESEM) with energy dispersive spectroscopy (EDS) analysis to determine the concentration of various parameters present along with the structural representation. FESEM was used to obtain the structural information at the nuclear envelope of the molecule. Here electron beam was focused towards the sample in which the atoms on the surface of the material get excited and produce signal that contain the composition and surface structural topographical information with the minimum resolution of 1 nm. Secondary electron imaging emits the electrons that are very close to the surface of the materials that gives exact surface information which can be imaged. EDS determines the parameters present in the biochar and quantify the same.

Germination test

Biochar (20 g) was taken and added with 20 ml of distilled water and mixed well. The above mixture was kept undisturbed for 20 min. The seeds were washed well and shade dried. The seeds were sowed on the biochar and monitored until the seeds started to germinate. Only distilled water measuring 5 ml was added every day to the fertilizer to maintain the moisture content of the biochar. The entire process was carried out in dark and the test was carried to prove whether the biochar had the ability to germinate the seeds by supplying the nutrients needed for its growth without the use of soil. Only lady's finger was used since the germination time for this is very less on comparing with other two seeds (chilly and tomato).

Field test

Black plant bags were purchased with dimension of 45 cm height, 30 cm width and 30 cm diameter. 36 bags were filled with 30 kg of loamy soil each. 3 bags were grouped and splitted as 4 groups for each palnt. First group served as control, second group served as chemical fertilizer, third group served as commercial biofertilizer and last group as biochar. 10 g of fertilizer and char was mixed alon with the soil in each bag except control and set ready for field test. Seeds of tomato, lady's finger and chilly plants were purchased and soaked in water for 8 hours. After 8 hours seeds were sown in the bags by splitting it into 4 sets. One set of seeds were sown in the soil (control), next set of seeds was sown in the soil with chemical fertilizer. The third set of seeds was with commercial biofertilizer and final set with biochar respectively for all three types of plants. Each set contains three plants. The efficiency of the biochar was found by comparing the growth of plant under various parameters such as plant height, breadth of the leaves, weight of the fruit/vegetable produced. Ist flowering day, total number of fruits/vegetable produced under regular basis and monthly intervals among the various sets.

RESULTS AND DISCUSSION

Biomass and soil characterization

The biomass was characterized that revealed the presence of parameters mentioned in the Table 1. Among all the biomass collected, citrus fruit peel holds the highest cellulose content that played a major role in conversion of biomass into bio oil and biochar. The other parameters like nitrogen, phosphorous, potassium, total solids and volatile solids impacts on biochar and its efficiency towards plant growth. The yield of biochar from the biomass by hydrothermal liquefaction process is influenced by the presence of cellulose, hemicellulose, lignin and carbon content (Zheng *et al.,* 2015). The lignocellulosic substances present in the biomass and carbon content present in the biomass determines the yield percentage of bio oil and biochar produced from hydrothermal liquefaction process (Anastasakis and Ross, 2015).

Table 1: Biomass characterization.

Parameter	Sewage sludge	Citrus fruit peel	Food waste	Groundnut shell	Rice husk	Mixed biomass
Lignocellulose	-	57.4%	-	47.3%	48.6%	23%
Carbon	37%	-	54.59%	-	-	42%
Total solids	69%	8%	46%	72%	87.3%	71%
Volatile solids	68%	79%	16.9%	65%	71%	60%
pH	6.8	3.9	6.5	7	7	7.2
Nitrogen	3.5%	11.2%	4.8%	3.4%	1.5%	7.4%
Phosphorous	2.4%	14%	0.04%	0.01%	0.3%	3.35%
Potasium	0.0.7%	0.24%	0.15%	0.62%	0.71%	0.35%
Moisture	92%	78%	74%	6.2%	8.4%	84%

The soil source used for the field trails was loamy soil which was analyzed to know about the nutritive nature and the results were illustrated in Table 2. The pH of the soil in region was found to be around 7.5 which were mild alkaline. Based on the rainfall in the area, the acidity of the soil varied. During high rainfall the soil appeared acidic and during less rainfall, the soil recorded alkaline nature. Other parameters like carbon, phosphorus, potassium, electrical conductivity and nitrogen varied from one place to another (Nisha *et al.,* 2017).

Comparitive study of physico chemical parameters of Chemical fertilizer, commercial biofertilizer and biochar

Various physico chemical parameters were analyzed such as colour, odour, ash, fat, porosity, moisture content, bulk density, water holding capacity, pH, electrical conductivity, total solid, volatile solid, carbon, C:N ratio, nitrogen, phosphorous and potassium were analyzed during the period of investigation for Chemical fertilizer, biochar and commercial biofertilizer as per standard protocol and readings were registered in Table 3. The colour of the three samples were dark brown and pH registered were 8, 5.6 and 5.5, for chemical fertilizer, biochar and commercial biofertilizer respectively and C:N ratio was 4:1 for biochar and 1:93 for commercial biofertilizer during the period of study. The water holding capacity was found to be maximum in biochar 280 ml/kg and 260ml/kg for commercial biofertilizer and the porosity recorded during the period of the study were 88.88%, 85.71% and 31.9% for biochar, commercial fertilizer and chemical fertilizer respectively which has correlated with the degree of water holding capacity. Oladipupo and Ayorinde (2015) analyzed biofertilizer on various parameters like pH, N, P, K concentration, *etc* to obtain the nutritive value of the produced biofertilizer. Katre (2012) converted the vegetable waste to biofertilizer. The carbon, nitrogen, pH and moisture content were determined for the produced biofertilizer. Igbokwe *et al.* (2015) manufactured biofertilizer from saw dust with organic waste - urine, sewage sludge, cow dung. On measuring the nutritive value, the saw dust with sewage sludge possessed more nutritive value and suitable for the plant growth.

Table 2: Soil characterization.

Parameters	Results
pH	5.3
Electrical conductivity (EC)	0.003
Organic matter (OM)	0.10%
Carbon (C)	0.05%
C:N ratio	1:808
Nitrogen (N)	40.4 kg/acre
Potassium (K)	52.41 kg/acre
Phosphorous (P)	1.15 kg/acre

Biochar characterization

The FESEM imaging of biochar gave non uniform pore size with non-uniform structural morphology. According to the study carried out by earlier researchers, crystalinity of the elements present in biochar, the structure, pore distribution of biochar and structure of aromatic substances present in biochar were dependent highly on the reaction temperature of the thermal process (Kim *et al.,* 2012; Kloss *et al.,* 2012). The elemental composition of the obtained biochar was listed below in Table 4. All the elements present in the biochar holds advantage and improves the plant growth in one or the other way thereby proving the efficiency of the biochar towards better plant growth and could act as a good competitor for the existing chemical and biofertilizer

Table 3: Properties of fertilizer.

Parameters	Chemical fertilizer	Commercial biofertilizer	Biochar
Colour	Dark brown	Dark brown	Dark brown/Black
Odour	Acidic with pungent	Odour free	Odour free
Ash	Trace amount	Trace amount	Trace amount
Fat	Nil	Nil	Nil
Porosity	31.9%	85.71%	88.88%
Moisture content	11%	9%	9%
Bulk density	6.03	0.38	0.37
Water holding capacity	Nil	260 ml/kg	280 ml/kg
pH	8	5.5	5.6
Electrical conductivity (EC)	1.36	0.31	0.49
Total solid	89%	91%	91%
Volatile solid	69.07%	5.33%	5.33%
Organic matter (OM)	Nil	0.77%	0.86%
Carbon (C)	Nil	0.427%	57.477%
C:N ratio	-	1:93	3:1
Nitrogen (N) kg/acre	17	40.04	22.92
Potassium (K) kg/acre	17	255	9.15
Phosphorous (P) kg/acre	17	19.65	Nil

Table 4: EDS composition of biochar and its uses towards plant growth.

Element name	Weight % Biochar before treatment	Element use on plant growth
Carbon	57.44	Water retention and respiration
Nitrogen	0.26	Helps in capturing sunlight energy
Oxygen	36.51	Helps in aerobic respiration and promote growth by food molecule breakdown
Sodium	0.12	Aids in metabolism and synthesis chlorophyll (micronutrient)
Magnesium	0.11	Contribute central core of chlorophyll
Aluminium	0.10	Activate tolerance and abiotic stress gene
Silicon	3.59	Improves plant defence response
Chlorine	0.32	Regulates osmotic and stomatal regulation
Potassium	0.66	Helps in movement of water, nutrients, CHO, activates enzyme and produce ATP
Calcium	0.60	Structural role in cell wall, cell messenger
Iron	0.10	Maintain chlorophyll structure and function
Copper	0.17	-

in the agricultural market. The carbon, silicate, oxygen present in the biochar contributes towards soil amendment which plays an important role. Other nutrients present such as sodium, calcium, potassium are present in the biochar that improves the soil quality and increase the plant growth (Suarez-Hernandez and Barrera-Zapata, 2017; Qian *et al.,* 2013; Fidel *et al.,* 2017).

Germination test

The germination test proved that the biochar possess the ability to supply the nutrients needed for the seeds to germinate without the help of soil. Fig 1 gives the proof. Jiang *et al.* (2015) carried out germination assay that recorded similar results.

Field test

The field trials were carried out with three different seeds - tomato, lady's finger and chilly. At regular intervals the chemical fertilizer, biochar and commercial biofertilizers were applied on the field. 1st week plant growth was captured in Fig 2 and 15 days growth was captured in the Fig 3 for tomato, lady's finger and chilly. Various parameters like height of the plant, length of the leaves, breadth of the leaves, 1st flowering day, total number of flowers, total number of fruits and weight of the fruit were monitored to check the efficiency of biochar over the chemical fertilizers



Fig 1: Germination test for Biochar.



Fig 2: First week growth of 3 plants.



Fig 3: 15 days growth of 3 plants.

as described in Table 5, 6 and 7. Young *et al*. (2004) carried out field trails for water celery. Height and weight of the plant was measured to find the efficiency of the organic biofertilizer and biochar.

Comparative study of yield efficiency

From the above field test results the biochar and commercial biofertilizer had higher yield when considering all the parameters. The individual % of efficiency of all the

Table 5: Field test result for tomato plant.

Parameters for 4 month time period	Control (only Soil)			Chemical fertilizer			Biochar			Commercial Biofertilizer		
	1	2	3	1	2	3	1	2	3	1	2	3
Height of 1st	12	18	10	20	22	12	18	23	21	25	18	22
plant (cm) 2nd	30	36	32	43	36	32	38	42	42	45	35	40
3rd	72	68	62	95	80	77	84	82	94	102	98	95
4th	106	92	88	121	116	108	115	114	127	128	119	120
	7	6.8	7.5	8	9	8.6	10.5	11	11	12.5	13	12
Length of the leaves (cm)	5	5	5	6.5	6.7	6	8.5	8.2	8.5	10.5	10	10
Breadth of the leaves (cm)	47	48	45	46	46	45	45	46	43	42	41	44
1st flowering day	12	8	9	24	16	21	18	22	21	21	18	32
Total no. of flowers												
Total no. of fruits	-	1	2	7	4	5	8	5	7	10	14	12
Weight of the fruit (g)	15	18	24	34	56	39	71	56	68	82	75	69

Table 6: Field test result for lady's finger plant.

Parameters for 4 month time period	Control (only soil)			Chemical fertilizer			Biochar			Commercial biofertilizer		
	1	2	3	1	2	3	1	2	3	1	2	3
Height of plant 1st	22	23	18	32	28	25	35	31	28	36	32	2
(cm) 2nd	43	37	28	47	39	32	46	42	38	48	44	38
3rd	48	52	40	52	48	44	53	51	47	57	55	52
Length of the leaves (cm)	12	12	11.5	14.5	13	14	15	15.2	14.5	15.5	16	16
Breadth of the leaves (cm)	9.5	9	8	11	9.8	12	12	12	11	12	11.7	12.3
1st flowering day	33	33	33	28	30	30	27	27	28	27	27	27
Total no. of flowers	6	6	5	8	7	7	8	9	7	10	10	9
Total no. of vegetables	6	6	5	8	7	7	8	9	7	10	10	9
Weight of the vegetable (g)	18	15	16	20	22	16	26	20	18	28	32	28

Table 7: Field test result for chilly plant.

Parameters for 4 month time period	Control (only Soil)			Chemical fertilizer			Biochar			Commercial biofertilizer		
	1	2	3	1	2	3	1	2	3	1	2	3
Height of plant 1st	10	9	9	16	12	11	15	13	16	17	15	17
(cm) 2nd	17	13	12	22	27	33	32	28	35	38	45	45
3rd	32	38	46	51	47	47	64	59	68	79	73	81
4th	57	78	81	79	66	88	92	85	97	105	95	112
Length of the leaves (cm)	6	5.3	6.2	7	8	7.8	9	8.5	8.5	11	9.6	10.5
Breadth of the leaves (cm)	4	4	4	5.7	5.5	5.5	7	7	7.4	8.5	7	7.2
1st flowering day	-	-	48	48	47	47	45	46	44	42	43	42
Total no. of flowers	8	6	10	15	13	13	21	19	22	25	23	23
Total no. of spices	-	1	1	3	5	5	10	12	10	12	13	10
Weight of the spices (g)	6	8	7	7	9	9	10	8	11	12	10	8

Table 8: Percentage of yield in tomato, chilly and lady's finger plant.

Parameters	Chemical fertilizer yield %			Biochar yield %			Commercial biofertilizer yield %		
	T	L	C	T	L	C	T	L	C
Height	17.13	2.79	7.28	19.64	7.23	21.13	22.07	14.5	30.76
Leaf length	16.47	14.46	23.28	34.25	20.60	32.55	43.2	25.26	44.01
Leaf breadth	21.87	19.21	28.05	40.47	24.27	43.89	50.49	26.41	47.08
1st flowering	2.14	11.12	1.39	4.29	17.27	6.25	9.22	18.18	11.81
No. of flowers	52.48	23.28	41.43	52.48	30	61.27	59.17	41.66	66.18
No. of fruits/veg/Spice	81.13	23.28	84.75	84.84	30	93.80	91.66	41.66	94.33
Weight of fruit/veg/spice	55.8	15.51	15.66	70.76	23.44	27.08	74.76	44.32	30

T- Tomato plant; L- Lady's finger plant; C- Chilly plant.

three fertilizers - chemical, Biochar and commercial biofertilizer were illustrated in Table 8. for all the three plants (tomato, lady's finger and chilly). Among the three plants, tomato plant gave maximum yield with commercial biofertilizer followed by Biochar when compared with other two plants (chilly and lady's finger).

CONCLUSION

The Biochar used as biofertlizer had significant effect on the tomato, chilly and lady's finger plant. But this treatment is not as significant as the commercially available biofertilizer but still could give better results than the chemical fertilizer. Among the three different plant, tomato gave the best result with best yield percentage on 7 different categories such as height of the plant, leaf lengyj, breadth of the leaf, 1st flowering day, total number of flower, fruits/vegetables/spice and weight of harvested fruits/ vegetable/spices. The yield % on total number of flowers produced by tomato plant using chemical fertilizer and biochar was 52.48%, using biochar was 59.17%. Yield % of tomato plant interms of total number of fruits/ vegetables/spices produced by using chemical fertilizer was 81.13%, 84.84% for biochar and 91.66% for commercial biofertilizer during the period of study. In terms of weight yield % for tomato plant was recorded as 55.8% using chemical fertilizer, 70.79% using biochar and 74.76% using commercial fertilizer. Further to increase the efficiency of the plant yield, the biochar can be treated with agro biofertilizer effluent where all the nutrients in the effluent will be adsorbed by the biochar and expected to give a better result than the existing commercial biofertilizer.

Conflict of interest

All authors declare that they have no conflicts of interest.

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