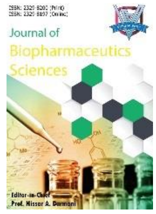
Journal of Biopharmaceutics Sciences (JBS)

DOI: http://doi.org/10.26480/jbs.01.2022.06.10

ISSN: 2329-8200 (Print)
ISSN: 2329-8197 (Online)
CODEN: JBSOC4



RESEARCH ARTICLE

ROLE OF BIOCHAR AND BIOFERTILIZER TO ENHANCE GROUNDNUT PRODUCTION APPROACHING SUSTAINABLE AGRICULTURE

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ARTICLE DETAILS

Article History:

Received 20 May 2022
Accepted 27 June 2022
Available online 30 June 2022

ABSTRACT

A field trial was conducted at Regional Agricultural Research Station (RARS), Jamalpur, Bangladesh during 2016-2018 with the objectives to increase the groundnut yield productivity and carbon accumulation in soil considering sustainable agriculture using biochar and biofertilizer (*Rhizobium*). The crop variety was BARI Chinabadam-8 and Bradyrhizobium strain was BARI RAh-892. There were seven treatments comprising T_1: Control, T_2: Soil test based (STB) dose following FRG-2012, T_3 : (T_2 - N) + biofertilizer, T_4 : (T_3 + biochar), T_5 : (STB +Biochar), T_6 : only biofertilizer, and T_7: only biochar, which was replicated in three times. The highest number of the nodule (78.17 plant^{-1}) was obtained from T_4 treatment. The lowest number of the nodule (43.83 plant^{-1}) was obviously recorded from the control (T_1) treatment. The highest weight of nodule (122.97 mg plant^{-1}) was obtained from T_4 treatment which was statistically identical with the T_3 treatment (115.33 mg plant^{-1}). The lowest weight of nodule (53.67 mg plant^{-1}) was recorded from the control (T_1) treatment. The highest root weight (1.47 g plant^{-1}) was obtained from T_4 treatment and the highest shoot weight (35.47 g plant^{-1}) was recorded from T_3 treatment**.** The lowest root weight (0.65g plant^{-1}) and lowest shoot weight (16.50 g plant^{-1}) were recorded from the control (T_1) treatment. The highest nut yield (2.30 t ha^{-1}) was obtained from T_4 treatment and the lowest nut yield (0.79 t ha^{-1}) was recorded from the control (T_1) treatment. It was seen from the results that the highest nut yield performed by T_4 treatment might be due to the combining effect of biochar and biofertilizer**.** Rhizobium could be inoculated in biochar amended soil to improve nodulation and growth parameters of groundnut plants. On the other hand, the highest soil organic carbon (SOC) was recorded in soil amended biochar and biofertilizer, about 26 % more than the control. The highest total SOC was obtained where biochar and biofertilizer were applied, leading to increased soil carbon accumulation in aspects of sustainable agriculture.

KEYWORDS

Biochar, Biofertilizer, Groundnut, Sustainable Agriculture.

1. INTRODUCTION

The term "sustainable agriculture" is defined as the integration of biological, chemical, physical, cological, economic and social sciences in a comprehensive way to develop new farming practices that are safe and do not degrade our environment (Lichtfouse et al., 2009). The most promising options include humic and fulvic acids, organo-mineral fertilizers, and biochar which can efficiently improve soil fertility, stimulate plant growth, and promote plant tolerance to adverse conditions acids (Barakat et al., 2015; Muscolo et al., 2013; Nardi and Pizzeghello, 2002; Abd El-Mageed and Semida, 2015; Deeks et al., 2013; Rady et al., 2016; Akhtar et al., 2015; Beesley et al., 2011). In addition, these practices also increase agronomic productivity and support a range of ecosystem services.

Biomass or wood has a carbon content of about 50%, whereas biochar has about 70–80%, which can be permanently sequestered in soil (Qambrani et al., 2017; Winsley, 2007). Rhizosphere bacteria and fungi may also promote plant growth directly (Compant et al., 2010). Changes in microbial community composition or activity induced by biochar may affect nutrient cycles, plant growth, and soil organic matter cycling (Kuzyakov et al., 2009; Liang et al., 2010) . Biochar addition may affect the soil biological community composition as demonstrated for the biochar rich Terra preta soils in the Amazon (Grossman et al., 2010), and has been shown to increase soil microbial biomass (Jin, 2010; Liang et al., 2010). Whether the abundance of microorganisms increases or not, as discussed for mycorrhizal fungi, is likely connected to the intrinsic properties of both biochar and the soil (Warnock et al., 2010). Biochar properties vary widely and profoundly in their nutrient contents and pH and their organo-chemical and physical properties (Johannes Lehmann, 2007; Lehmann, 2007a). Therefore, the role of biochar in soil biological processes represents a frontier in soil science research, with many unexplained phenomena awaiting exploration. Recent advances in our understanding of biochar warrant an evaluation of the relationship between its properties and its impact on the soil biota. Influence of bacterial adhesion to biochar on microbial abundance Bacteria may sorb to biochar surfaces, rendering them less susceptible to leaching in soil (Pietikäinen et al., 2000). Therefore, it is likely that biochars' ability to retain bacteria will vary greatly depending on the biochar properties, including the ash content, pore size, and Functional ecology of microorganisms with biochar.

Biochar as inoculant carrier Soil additives and inoculant carriers have been used, for example, Azotobacter, Bacillus, Clostridium, Frankia, Pseudomonas, or Rhizobium, but little is understood in terms of their mode of action, even as far as the relatively well-studied rhizobia are concerned (Deaker et al., 2004; Van Beek et al., 2019). Some properties of biochars offer advantages over using the very effective peat to improve inoculant survival under some conditions.

Groundnut (Arachis hypogaea L.) is one of the world's most popular crops cultivated throughout the tropical and subtropical areas. Groundnut or peanut is the sixth important oilseed crop globally and is the second important oilseed producing crop in Bangladesh. Groundnut has played a pivotal role in meeting the growing oil requirements and ensuring nutritional security to a population of over 1.6 million in our country. Though nutritionally, groundnut is an energy-rich crop, it is grown mainly on energy-starved conditions of poor fertility soils. Under rain-fed conditions, it is generally grown and utilized for extracting cooking oil and confectionary in Bangladesh. Groundnut seeds contain about 48%- 50% edible oil, 22-29 % protein, and 20% carbohydrate, with an average yield that ranges between 2.30 – 3.00 tha^{-1}. Groundnut is cultivated about 32000 ha of land in Bangladesh (Azad et al., 2019). The total production of groundnut is about 47000 Mt in Bangladesh (Azad et al., 2019). Being a legume, groundnut improves soil by fixing nitrogen biologically without consuming non-renewable energies and without disturbing agro-ecological balance. The economically vital part of the groundnut plant is the pod which encloses the seeds. Groundnut is an unpredictable crop due to the development of pods underground (Zaman et al., 2011).

The size of the seed and the number of seeds per pod are essential criteria that determine the market value of groundnut in general. Inoculation of legumes with rhizobium increased the nodule and nitrogen-fixing activity of the crop. When inoculated with the proper strain of bacteria, legumes can supply up to 90% of their nitrogen. Similarly, (Sajid et al., 2010) reported that inoculation with rhizobium brings about significant increases in all the growth and yield parameters than when not inoculated; biochar addition to soil increases soil nutrient concentrations and microbial activity leading to the development of plant growth (Ishii et al., 1994). Biochar-based rhizobial inoculants can significantly improve the symbiotic performance of legumes with rhizobia, reducing N fertilizer demand and thus promoting the sustainability of crop production in any agroecosystems (Egamberdieva et al., 2018). Legumes have symbiotic relationships with rhizobia and are known as the most efficient system for biological nitrogen fixation (Reckling et al., 2016). A study evaluated biochar produced from rice straw as a carrier material for rhizobia and found evidence for improved colonization and survival of bacterial inoculants (Ghazi, 2017). The biochar-based inocula increased root and

shoot biomass, nodulation and nutrient uptake of a kidney bean. Biochar-based inoculants promoted plant growth and nutrient uptake (Egamberdieva et al., 2017c; Tripti et al., 2017). So this study aims to increase the groundnut yield productivity concerning how biochar amendment influences rhizobium nodulation and growth performance of groundnut plants.

The following specific objectives were stated

i. To recognize the role of biochar as carrier of rhizobia and soil amendment.
ii. To increase the groundnut yield improving soil health considering sustainable agriculture.

2. Materials and Methods

2.1 Experimental Site

The experiment was started in the 2016-17 period at the Regional Agricultural Research Station (RARS) field under Jamalpur district in Bangladesh. Before initiation of the experiment, the soil samples were collected from a depth of 0-15 cm for each replication and analyzed following standard methods (***Table 1***). The chemical properties of soils in the experimental site were silt clay loam in texture belonging to Sonalata series under Agro-Ecological Zone-9 (AEZ-9), 24°56′11′′N latitude and 89°55′54′′E longitude and an altitude of 16.46m.

3. Soil Organic Carbon

Composite soil samples were collected from soil surface at depth of 0-15 cm. Soil parameters were determined for bulk density using the core sampling method (Rahman et al., 2021) and soil organic carbon (SOC) before the experiment and at the end of the two-year cropping.

About 58% of the mass of organic matter exists as carbon. We can estimate the percentage of SOM from the SOC% using the conversion factor 1.72 (derived from 100/58).

Organic matter (%) = total organic carbon (%) x 1.72.

The nutrient status of the initial soil prior to fertilization is presented in Table 1.

Table 1: Initial Soil Chemical Properties of The Experimental Soils

Location	pH	OM (%)	BD (%)	Ca	Mg	K	Total N (%)	P	S	B	Cu	Fe	Mn	Zn
				meq $100g^{-1}$				µg g^{-1}						
RARS, Jamalpur	6.0	0.83	1.46	5.2	1.8	0.12	0.04	15.6	10	0.3	1.5	28	2.2	1.42
Critical level	-	-		2.0	0.5	0.12	-	10	10	0.2	0.2	4	1	0.6

4. Biochar Production

The biochar was produced using rice husk that was locally collected. The rice husk was loaded in the iron drum covered with a metal sheet along with a chimney at the top which was placed into an earthen kiln (developed by Soil Science Division, RARS, Jamalpur, BARI) and biochar was produced using pyrolysis method with oxygen-limited condition. The rice husk was burnt in the presence of partial oxygen condition. The pyrolysis temperature was recorded at 30-minute intervals by a digital temperature recorder by placing the sensor into the kiln through an aeration hole. The burnt husks were then ground and allowed to cool to room temperature. The product was used as biochar. The chemical compositions (such as organic carbon, N, P, K, S, B, Cu, Fe, Mn, Zn, Mg, Ca and pH) of biochar were determined (Table 2)

Table 2: The Chemical Composition of Biochar Used for The Experiment From The Rice Husk

pH	OC (%)	Ca	Mg	K	Total N (%)	P	S	B	Cu	Fe	Mn	Zn
		meq $100g^{-1}$				µg g^{-1}						
8.7	39.2	1.81	0.92	0.92	2.10	0.73	0.27	0.011	0.0012	0.12	0.03	0.016

5. Chemical Analysis of Biochar

Chemical analysis was done in Soil Science Division, Bangladesh Agricultural Research Institute, Gazipur, following the standard methods.

6. Experimental Design and Layout

The experiment was laid out in randomized complete block (RCB) design with seven treatments replicated thrice. There were seven treatments viz. T_1=Control , T_2 = Soil test based (STB) following fertilizer recommendation guide (FRG)-2012 (Fertilizer Recommendation Guide, 2012), T_3 = (T_2–N) + Biofertilizer , T_4 = T_3 + Biochar ,T_5 = STB + Biochar ,T_6 = only biofertilizer, T_7 = only biochar

7. Biochar Incorporation and Rhizobium Inoculation

Biochar was used in the furrow at the rate of 10 tha^{-1}. The tested crop was groundnut (cv. BARI Chinabadam-8). Peat-based rhizobial inoculum (*Bradyrhizobium* strain BARI RAh-892) was used containing 10^8 cells g^{-1} inoculum was used at the rate of 1.5 kg ha^{-1}. Groundnut seeds were mixed throughly with the inoculum before sowing. The unit plots measured 10 m × 8 m. Seeds were used at the rate of 75 $kgha^{-1}$. Both the rhizobium inoculants and the groundnut variety were sourced from Bangladesh Agricultural Research Institute, Joydebpur, Gazipur.

8. Sowing, Fertilization and Weeding Practices

The seeds were planted by dibbling method on 22 November 2017. Note that the uninoculated seeds were sown first to avoid contamination. Nitrogen, phosphorus, potassium, sulfur, zinc and boron were used in the form of urea, TSP, MoP, gypsum, zinc sulphate, and boric acid, respectively. All P, K, S, Zn, B and one-third of urea-N were applied at the time of final land preparation, and the remaining urea-N was applied in two equal installments at 30 and 50 days of sowing. All the intercultural operations (such as irrigation, weeding, insect control etc.) were done as and when necessary.

9. Data Collection and Statistical Analysis

Data were collected on the following parameters; plant height(cm) using meter rule, number of nut plant^{-1}, 100-nut weight (g), kernel weight of 100-nut (g), 100 kernel weight (g), nut yield (t ha^{-1}), Shelling (%), stover yield (t ha^{-1}), nodule number plant^{-1}, nodule weight (mg) plant^{-1}), root weight (g plant^{-1}), and shoot weight (g plant^{-1}). Nodules were collected by carefully uprooting five sample plants selected randomly from each unit plot at the 50 percent flowering stage. Nodules were separated from the roots, counted and then oven-dried and weighed. Data on yield and yield components were recorded at maturity. The crop was harvested on 27 May 2018. Data on yield and yield contributing characters were recorded and analyzed statistically using statistical software STAR which was developed by IRRI. The analyzed data were compared with the least significant (LSD) test at a 5% level.

10. Results and Discussion

10.1 Effect of Biochar, Rhizobium and Chemical Fertilizers on Nodulation, Dry Matter Production, and Plant Height of Groundnut Cultivation

The effect of biochar and biofertilizer on the growth and yield of groundnut was significantly compared with the control treatment (Table 3). The highest number of nodule (73.67 plant^{-1}, 2016-17 and 82.67 plant^{-1}, 2017-18) was obtained from T_4 (T_3 + biochar) treatment which was followed by T_3 treatment (62.51 plant^{-1}, 2016-17 and 73.53 plant^{-1}, 2017-18). The lowest number of the nodule (43.83 plant^{-1}) was recorded from the control (T_1) treatment. The highest weight of nodule (122.97 mg plant^{-1}) was obtained from T_4 (T_3 + biochar) treatment which was statistically identical with T_3 treatment (115.33 mg plant^{-1}). The lowest weight of nodule (53.67 mg plant^{-1}) was recorded from control (T_1) treatment. The highest root weight (1.47 g plant^{-1}) was obtained from T_4 (T_3 + biochar) treatment, and the highest shoot weight (35.47 g plant^{-1}) was recorded from T_3: (T_2 –N) + Biofertilizer treatment. The lowest root weight (0.65g plant^{-1}) and lowest shoot weight (16.50 g plant^{-1}) were recorded from the control (T_1) treatment. The highest plant height (50.53cm) was obtained from T_5 (STB + Biochar) (Table 3), and the lowest plant height (19.15 cm) was recorded from the control (T_1) treatment. Studies reported that the biochar-based inoculants increased root and shoot biomass, nodulation and nutrient uptake of plants like groundnut in pot and field experiments (Egamberdieva et al., 2018). Moreover, applying biochar and rhizobium inoculation on groundnut plants increased the number of effective nodules, shoot, and roots dry weights (Yusif et al., 2016). So the highest nodule number performed by T_4 treatment might be due to the effect of biochar and biofertilizer. In addition, biochar-based microbes promoted plant growth and nutrient uptake (Tripti et al., 2017).

11. Effect of Biochar, Rhizobium and Chemical Fertilizers on Plant Characters, Yield and Yield Contributing Characters of Groundnut

Nut plant^{-1}, stover yield (t/ ha.) and shelling (%) was found non-significant (Table 4). The highest 100 nut weight (96.33 g) was obtained from T_4 (T_3 + biochar) treatment which was statistically identical with T_3 (T_2 –N) + Biofertilizer and T_5 (STB + biochar) treatment which had (86.33 g) and (84.00 g) respectively. The lowest 100 nut weight (66.67 g) was obviously recorded from the control (T_1) treatment. The highest 100 kernel weight (50.92 g) was obtained from T_4 (T_3 + biochar), which was followed by T_5 treatment which had (45.52 g). The lowest 100 kernel weight (30.07 g) was recorded from the control (T_1) treatment. The highest nut yield (2.30 t ha^{-1}) was obtained fromT_4 (T_3 + biochar) treatment and The lowest nut yield (0.79 t ha^{-1}) was recorded from the control (T_1) treatment. The highest nut yield performed by T_4 treatment might be due to the effect of biochar and biofertilizer. Furthermore, Biochar-based inoculants also enhanced plant growth and grain yield in pot and field experiments (Egamberdieva et al., 2018). It was reported that inoculation with rhizobium brings about significant increases in all the growth and yield parameters than when not inoculated; Biochar addition to soil increases soil nutrient concentrations and microbial activity, leading to plant growth (Yusif et al., 2016). Influence of bacterial adhesion to biochar on microbial abundance Bacteria may sorb to biochar surfaces, rendering them less susceptible to leaching in soil (Pietikäinen et al., 2000).

Table 3: Effect of Biochar, *Rhizobium* and Chemical Fertilizers on Nodulation, Dry Matter Production and Plant Height of Groundnut During 2017 – 2018

Treatments	Nodule Number Plant^{-1}			Nodule Weight	Root Weight	Shoot Weight	Plant Height
	2016-17	2017-18	Average	(mg plant^{-1})	(g plant^{-1})		(cm)
T1: Control	46.00d	41.67d	43.83	53.67e	0.65e	16.50e	19.15f
T2: Soil Test Based (STB)	55.84cd	60.00c	57.92	75.55d	0.98bc	28.18bc	32.78cd
T3: (T2 – N) + Biofertilizer	62.57bc	73.53b	68.01	115.33a	1.10b	35.47a	36.90c
T4: T3 + Biochar	73.67a	82.67a	78.17	122.97a	1.47a	30.44b	43.97b
T5: STB + Biochar	62.51 bc	72.00b	67.28	106.09b	0.97bcd	25.71c	50.53a
T6: Only Biofertilizer	61.17bc	62.33c	61.75	103.25bc	0.80cde	21.44d	27.12de
T7: Only Biochar	59.67bc	55.67c	57.67	96.46c	0.74de	18.37de	22.34ef
CV (%)	11.61	9.63	-	2.91	8.63	4.38	6.39

Values in a column having the same letter(s) do not differ significantly at 5% level by LSD.

Table 4: Effect of Biochar, *Rhizobium* and Chemical Fertilizers on Plant Characters, Yield and Yield Contributing Characters of Groundnut during 2017- 2018

Treatments	Nut Plant^{-1}	100-Nut Weight	100- Kernel Weight	Stover Yield (t ha^{-1})	Nut Yield (t ha^{-1})			Shelling (%)
		(g)			2016-17	2017-18	Average	
T_1: Control	15.93	66.67c	30.07f	13.07	0.81d	0.77d	0.79	62.07
T_2: Soil Test Based (STB)	20.13	78.67bc	35.92d	13.37	1.73b	1.75b	1.74	73.76
T_3: (T_2 – N) + Biofertilizer	23.87	86.33ab	40.07c	13.80	1.83b	1.86b	1.85	65.68
T_4: T_3 + Biochar	25.07	96.33a	50.92a	13.30	2.38a	2.23a	2.30	72.50
T_5: STB + Biochar	22.33	84.00ab	45.52b	12.97	1.96b	1.90b	1.93	73.36
T_6:Only Biofertilizer	23.33	72.33bc	30.67f	12.57	0.95d	0.91cd	0.93	70.57
T_7: Only Biochar	22.20	73.06bc	33.96e	12.63	1.24c	1.08c	1.16	72.40
CV (%)	13.55	7.34	9.03	8.03	6.26	11.2	-	8.75

Values in a column having the same letter(s) do not differ significantly at the 5% level by LSD.

12. Nutrient Status of Post-Harvest Soil

After completion of the experiment effect of biochar and biofertilizer was presented (Table 5) which indicates that the application of biochar and biofertilizer produced significant variations in the chemical properties of the soil. The highest pH value was observed in the trial treated with biochar-biofertilizer combined application, while the lowest values were recorded in the control trial. Increased soil pH as a result of biochar application has been extensively investigated in agricultural soils and the combined application of biochar with rate of (20tha^{-1}) and mulch (37 t ha^{-1}) increased soil pH from 5.7 to 6.4 in forest soil (Rhoades et al. 2017; Ding et al., 2016). The total N ranged from 0.041 to 0.067 %. Application of sole biochar and sole biofertilizer also increased the available N over control. Under T_4 (biochar- biofertilizer combined) treatment, about 63 % increases were observed in the soil's available N content compared to control. The P and exchangeable K ranged from 10.55 to 16.3 meq 100 g^{-1} and 0.14 to 0.18 meq 100g^{-1} respectively, which increases of about 54.5 % and 28.57 % were recorded for P and K respectively in the T_4 in comparison to the control. Biochar addition can induce changes in nutrient availability and may provide additional N and P (Prendergast-Miller et al., 2011) or bioavailable C sources for microbial proliferation in the rhizosphere depending on the type of biochar (Ding et al., 2016; Zimmerman, 2011). For example, observed an increase in P uptake and plant growth by applying biochar produced from willow woodchips compared to the non-amended soil (Shen et al., 2016). Soil amendment with pine-based biochar did not show any stimulatory effect on plant growth.The highest total SOC was obtained where biochar and biofertilizer were applied, leading to increased soil carbon accumulation.

The mechanisms directly involved are the large surface area, highly porous structure, and strong ion exchange capacity of biochars, which contribute to improving the physical and chemical properties of soil and which impact soil biological activities (Anderson et al., 2014; Lentz et al., 2014; Glaser et al., 2002).

Table 5: Nutrient Status of Post-Harvest Soil Under Groundnut Plant

Treatments	pH	Total N (%)	K	P	S	B	Zn	SOC
			meq 100g^{-1}	μg g^{-1}				
T_1: Control	6.53	0.041	0.14	10.55	13.62	0.25	1.12	0.46
T_2: Soil test based (STB)	6.60	0.048	0.16	13.82	16.25	0.39	1.73	0.45
T_3: (T_2 – N) + Biofertilizer	6.73	0.064	0.18	13.60	18.48	0.45	2.11	0.52
T_4: T_3 + Biochar	6.98	0.067	0.18	16.3	21.61	0.56	2.43	0.58
T_5: STB + Biochar	6.91	0.057	0.17	15.6	20.17	0.44	2.00	0.54
T_6: Only Biofertilizer	6.62	0.053	0.14	12.2	15.2	0.37	1.65	0.50
T_7: Only Biochar	6.85	0.049	0.15	11.6	16.3	0.42	1.71	0.57
Initial soil	6.50	0.044	0.12	9.6	12.6	0.30	1.42	0.48

13. Conclusion

The application of biochar and biofertilizer inoculation was eco-friendly, relatively inexpensive, non toxic that possesses the significant potential in ensuring sustainable agriculture by increasing plant growth, production and soil biota; in some cases increasing soil microbial composition . The interaction between biochar and rhizobium inoculation in all the growth performances and nodulation was mutually positive . From the trial, it can be concluded that combined use of biochar and biofertilizer is the best for successful management of the rhizosphere in sustainable agriculture aspects.

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