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Research Article

Biochar and Compost as Management Tools against *Rhizoctonia solani* in Potato under Field Conditions

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ABSTRACT

The development of alternative strategies for plant disease management is important to reduce dependence on synthetic agrochemicals. Thus, the growing interest about eco-friendly products is extremely necessary to reuse agro-industrial residues accessible to secure global health through an integrative agriculture. The biochar and compost could be used for the management of *R. solani*. A field experiment was conducted to evaluate the effectiveness of these amendments in reducing stem canker severity and improving potato plant development. The treatments were: control; C= compost; B= biochar; NPK= NPK; CB= Compost+ biochar; CNPK= compost+ NPK; BNPK= biochar + NPK; CBNPK= compost+ biochar + NPK. CBNPK gave maximum severity reduction of *R. solani* disease. Plants treated with CBNPK and CB decrease 88% and 58% the potato stem canker severity, respectively. The principal component analysis showed biochar and compost influencing the potato plant development, and revealed significantly different groups among control, compost and NPK. In general, CBNPK correlated with plant development parameters, mainly in size and weight of tubers and number of leaves. These findings improve our understanding of the use of biochar and compost as potential amendments for the management of stem canker (*R. solani*) in potato.

Keywords: Biocarbon; disease control; soil amendments; suppressiveness

INTRODUCTION

Rhizoctonia solani is recognized as a critical soil-dwelling Basidiomycete that inflicts substantial harm on agricultural crops across the globe (Hejazi *et al.*, 2022). Within the *Solanaceae* family, specifically in potatoes, this pathogen triggers stem canker and black scurf, resulting in worldwide yield declines estimated between 30% and 40% (Bains *et al.*, 2002; Burgos *et al.*, 2020).

R. solani is a necrotrophic fungus that infects seedlings, stems, tubers, and roots of potato. As the disease progresses, stem girdling occurs, which disrupts water and carbohydrate transport within the plant (Forghani *et al.*, 2021). However, management of *R. solani* is challenging due to its high aggressiveness, wide host range, and saprophytic survival in diverse geographic regions (Soheili-Moghaddam *et al.*, 2022). To reduce the occurrence and intensity of disease caused by *Rhizoctonia solani*, several strategies are commonly employed, including cultural techniques, rotational cropping, the use of resistant varieties, and comprehensive integrated pest management frameworks (Rahman *et al.*, 2020; Hejazi *et al.*, 2022). In addition, use of some practices not only improve soil biological, chemical, and physical attributes but also can manage plant diseases caused by soil borne pathogens by indirect mechanisms of pathogen suppression (Jaiswal *et al.*, 2019). The use of compost which is prepared from the decomposition of organic material such as greenhouse waste, animal manure, bark solids and vegetable wastes is effective against *Rhizoctonia* spp., *Pythium* spp., *Fusarium* spp., *Phytophthora* spp. and *Scelrotium* spp. (Hoitink *et al.*, 1997; Noble & Coventry, 2005; Carter *et al.*, 2004). The compost increases soil fertility by enhancing the nutrients and beneficial microorganisms, therefore plant-growth but it is environmentally friendly (Lima *et al.*, 2021). Following this, biochar is a solid sponge like particle rich in carbon produced from the pyrolysis of various organic matter (Kavitha *et al.*, 2018). Biochar increases soil quality, adjusts soil acidity, retains

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water, sequesters carbon, and promotes plant growth and can be used as management tool to manage the diseases using different strategies (Medeiros *et al.*, 2021; Jaiswal *et al.*, 2019). While some investigations have suggested that biochar improves the biological, chemical and physico-chemical properties of the soil (Silva *et al.*, 2021a; Silva *et al.*, 2021b), it has also been indicated as a way to reduce plant diseases caused by several pathogens like *R. solani* (Jaiswal *et al.*, 2014) using different methods (Debode *et al.*, 2020). Further research is needed to determine how soil-applied biochar and compost can contribute to the management of stem canker in potato. In the current study, it was postulated that biochar and compost may serve for *R. solani* control. To address this hypothesis, a field experiment was conducted to evaluate the efficiency of these amendments in reducing stem canker severity and improving potato plant development.

MATERIALS AND METHODS

Inoculum Production

Rhizoctonia solani isolate (CCRM Rs78) was acquired from the Tissue Culture Lab of College of Agriculture, University of Sargodha, Sargodha, Pakistan. Experimental potato seed was procured from Potato Research Institute Sahiwal, Pakistan. In laboratory conditions, *R. solani* was grown on wheat grains and used as soil inoculum applied to soil (colonized wheat grains) at planting. Flasks were packed with 100g of distilled washed, air-dried wheat. Subsequently, wheat-containing flasks were autoclaved at 121°C for 20 min. After 4-5 days of incubation when *R. solani* plugs were removed from the edge of one-week incubated culture for further transfers to flasks primer with wheat grains. Culture: Flasks were retained throughout at room temperature for the growth of fungus not exceeding a period of two weeks (Balali *et al.*, 1995).

Biochar and Compost Production and Attributes

The organic wastes were pyrolyzed (charred) for 10-12 h in the absence of oxygen, by mean of homemade metallic kiln (Lima *et al.*, 2021). Thermocouple was used to monitor the kiln temperature (500-530°C). Biochar and compost were also subjected to chemical analysis as well as the digestion techniques (Table 1).

Table 1. Physicochemical characteristics of compost derived from poultry manure and biochar produced from sugar industry waste.

Features	Unit	Compost	Biochar
pH	-	8.2	5.5
Carbon (C)	%	25	39
Nitrogen (N)	%	1.15	0.90
C/N	%	19	30
Phosphorus, P_2O_5	%	0.21	2.50
Potassium, K_2O	%	0.10	0.39
Silicon (Si)	%	0.001	0.5
Color	-	Gray	Black
Commercial name	-	Suraj	Kissan

Experiment Set-up

Soil was defined according to the Food and Agriculture Organization (FAO) classification system and Soil characteristics were ascertained and land of 2.5 Marla was tilled with power tiller for attaining proper tilth and weeds removal. Then ridges were prepared with spade (width= 60 cm and height=30 cm) and two feet space was maintained between two consecutive ridges (Shakur *et al.*, 2007). Randomized complete block design (RCBD) and the number of replicates was three. The applied treatments were: control= negative control (soil without amendments); C= compost applied at 10% (w/w); B= biochar applied at 5% (w/w); NPK= recommended NPK fertilizer; CB= compost (10% w/w) + biochar (5% w/w); CNPK= compost (10% w/w) + NPK; BNPK= biochar (5% w/w) + NPK; and CBNPK= compost (10% w/w) + biochar (5% w/w) + NPK. Land was divided in to five microplots and each plot consisted of 1/2 Marla. Three lines of sterilized potato tubers, 10 plants line 1 were sown for each microplot. Biochar, compost and NPK amendments were mixed well with the top 15 cm of soil prior to planting as per respective treatments. The trial was established in a Green-house environment and replicated three times to ensure statistical reliability.

Disease Severity

Symptom-based severity scoring for stem canker and black scurf was performed at 90 DAS following the 0-3 scale proposed by Abera *et al.* (2016), with evaluations timed to coincide with unambiguous symptom development (Table 2) (Naz *et al.*, 2008).

Table 2. Disease severity rating scale for stem canker and black scurf caused by *Rhizoctonia solani* in potato, adapted from Abera *et al.* (2016).

0	No disease	No canker and no sclerotia on tuber	No symptoms on tubers
1	Slightly diseased	Superficial canker	1-20% tuber area infected
2	Moderately diseased	Deep canker	20-50% tuber area infected
3	Severely diseased	Root girdled	More than 50% infected

Isolation and Identification of Pathogen

For the confirmation of pathogen, diseased plants showing stem canker symptoms were pulled out of the soil with tubers. Potato tubers exhibiting black scurf symptoms were rinsed under running tap water to eliminate soil particles, followed by surface disinfection using 2% sodium hypochlorite (NaOCl) for 2-3 minutes. Small tissue sections from symptomatic areas were aseptically excised with a sterile scalpel, transferred onto moistened blotter paper in sterile Petri dishes, and incubated at 22°C for 7 days to promote fungal colonization. Then pathogen was transferred into PDA amended petri plates for culture purification (Islam *et al.*, 2013). The pathogen was identified based on morphological characteristics under a compound microscope following the identification keys of Barnett and Hunter (1986). Molecular identification of the anastomosis group was not performed in this study.

Plant Variables

Following the experimental period, key morphological and yield-related traits of potato plants were measured, including plant height (cm), root length (cm), root and shoot fresh weights, number of tubers per plant, average tuber weight, tuber size classification, and total leaf count (Jaiswal *et al.*, 2014).

Statistical Analysis

All multivariate statistical analyses were conducted in R version 4.1.1 (R Core Team, 2021) via the RStudio integrated development environment (version 2021.09.0, Build 351; RStudio Team, 2021). Treatment differences were assessed using analysis of variance (ANOVA), with post-hoc mean separations performed via Tukey's honest significant difference test at α= 0.05, utilizing the agricolae package (v. 1.3.5). Visualizations, including bar charts, were created using the ggplot2 package (v. 3.3.5). Multivariate techniques-including redundancy analysis (RDA) ordination, Venn diagram construction, multivariate analysis of variance (MANOVA), and permutational multivariate analysis of variance (PERMANOVA) were executed using functions from the vegan package (v. 2.5.7).

RESULTS

Biochar and Compost Reduce Stem Canker Severity in Potato

Biochar, compost and NPK decrease the severity of stem canker and black scurf caused by *R. solani* on potato under field conditions (Figure 1). CBNPK was found most effective by decreasing the severity of *R. solani*. Plants treated with CBNPK and CB decrease 88% and 58% the disease severity respectively, as compared to the control.

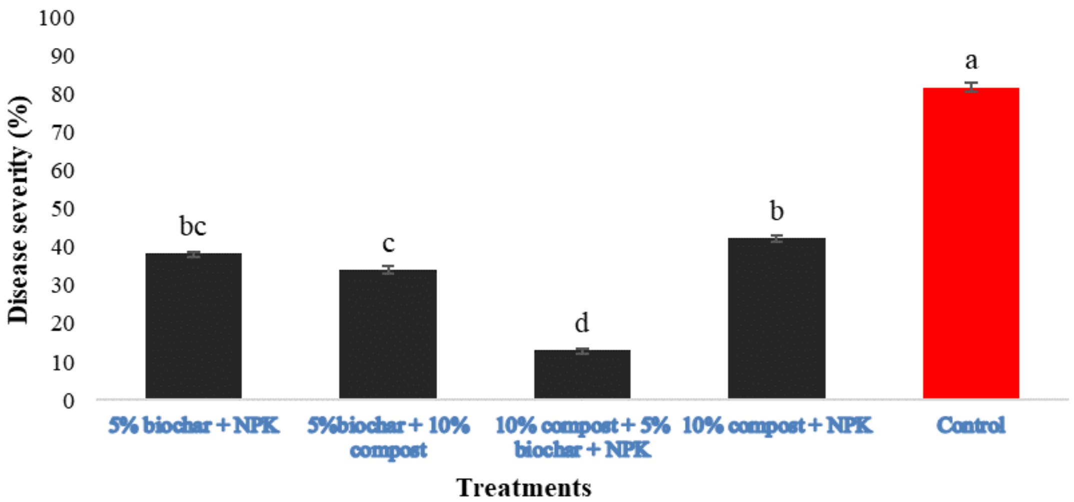

Figure 1. Influence of organic and mineral amendments on *Rhizoctonia solani* severity in field-grown potato. Treatments sharing a letter are not significantly different (ANOVA + Tukey's HSD, α = 0.05). Key: Control = unamended soil; C= 10% compost; B= 5% biochar; NPK= standard NPK fertilizer; CB= compost + biochar; CNPK= compost + NPK; BNPK= biochar + NPK; CBNPK= compost + biochar + NPK.

Biochar and Compost Improve the Potato Plant Development

Biochar and compost application of soil along with *R. solani* inoculum allowed a better development of potato plants (Figure 2). Compared to the control (without biochar or compost), the CBNPK treatment significantly increased all plant variables as number of leaves, plant height, Root length, Root weight, Shoot weight. In order to assess the efficiency of biochar and compost on potato tubers development, the different combination of compost and biochar with NPK were compared. The results show that the most efficient treatment was CBNPK that used all amendments together with increases weight, and size of potato tubers, respectively. Most plant growth parameters were higher in treatments receiving biochar and compost compared to the control, evidencing that CBNPK was the most efficient treatment by increasing number of leaves up to 96, plant height 58 cm, shoot weight 6.8 g, root weight 1.1 g, root length 5.6 cm, number of tubers 5.8, tuber weight 80 g and tuber size 57 mm.

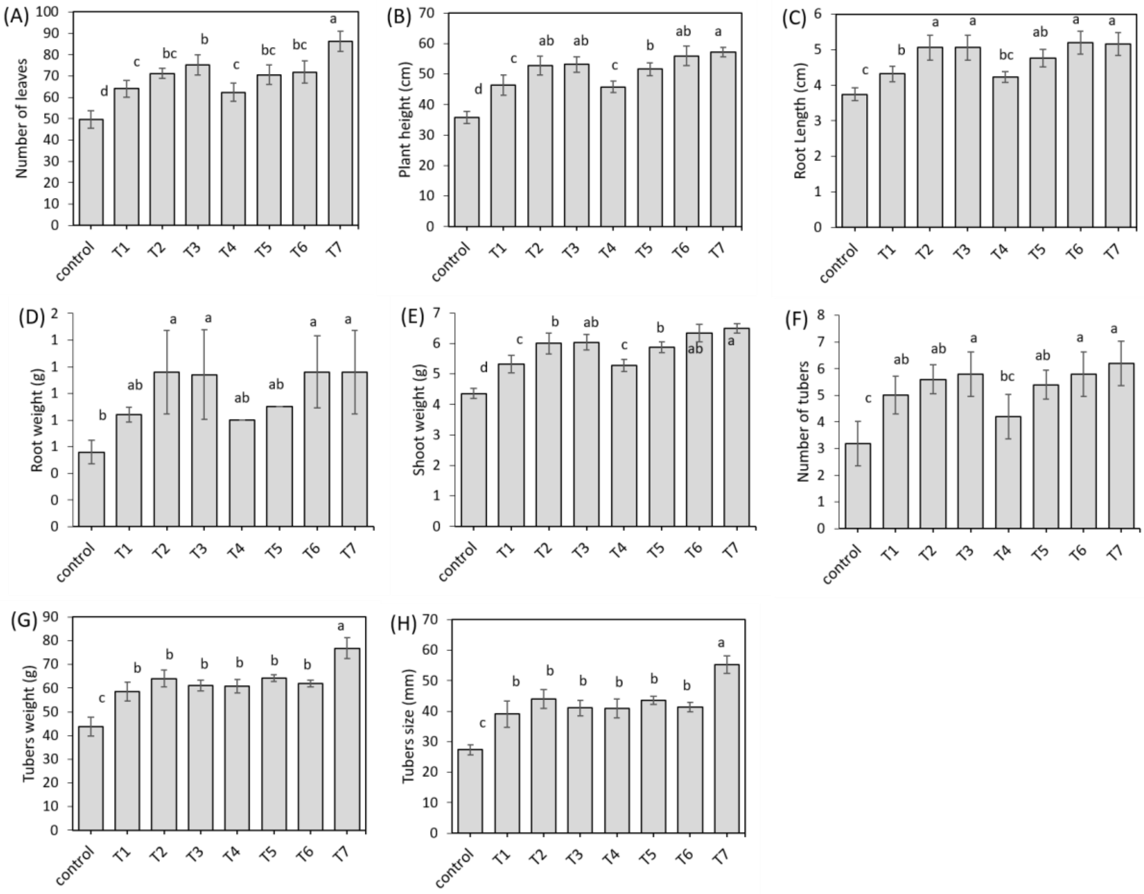

Figure 2. depicts the influence of various soil amendment strategies on the growth performance of potato plants inoculated with *Rhizoctonia solani*.

Evaluated parameters include (a) total leaf count, (b) above-ground plant height, and (c) primary root length. Treatments marked with the same lowercase letter are not statistically distinct, based on one-way ANOVA followed by Tukey's post-hoc test (significance threshold: $p < 0.05$).

Treatment designations are defined as follows:

Control: unamended soil (negative control)

C: 10% (w/w) compost amendment

B: 5% (w/w) biochar amendment

NPK: standard recommended NPK fertilizer application

CB: combined 10% compost + 5% biochar

CNPK: 10% compost supplemented with NPK fertilizer

BNPK: 5% biochar supplemented with NPK fertilizer

CBNPK: integrated application of 10% compost, 5% biochar, and NPK fertilizer

Multivariate Analysis

The principal component analysis (PCA) showed biochar and compost influencing the potato plant development (Figure 3). The PCA explained 89% of the total variation, with the first principal component accounting for 80% and the second component accounting for 9% of the total variation. The analysis revealed significantly different groups among control, compost and NPK. In general, CBNPK correlated with plant development parameters, mainly in size and weight of tubers and number of leaves.

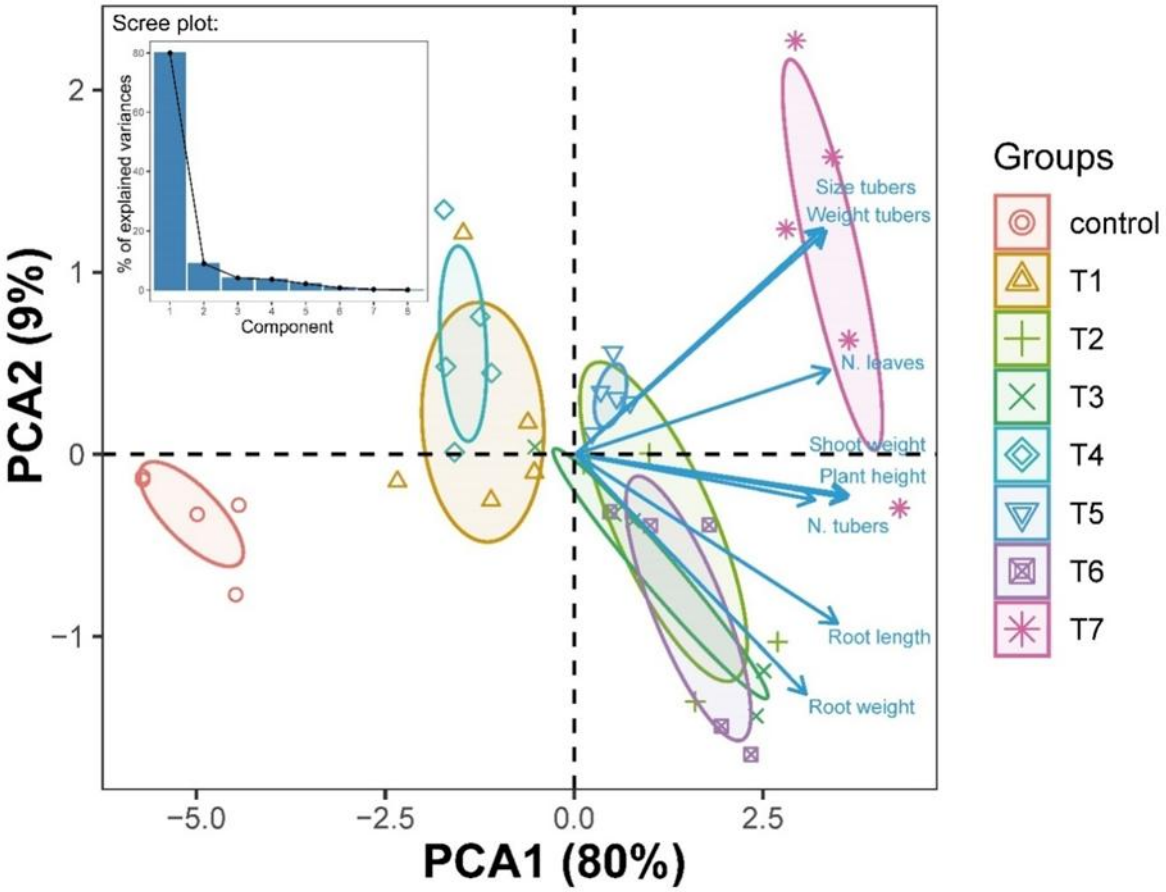

Figure 3. A principal component analysis (PCA) ordination examining how potato vegetative performance and susceptibility to *Rhizoctonia solani* induced stem canker co-vary across experimental soil amendments containing compost, biochar, or their combination with mineral fertilizer. Statistically distinct treatment groupings identified via PERMANOVA ($p < 0.05$) are highlighted by dashed boundary lines. Within the biplot, treatments annotated with identical lowercase letters do not exhibit significant differences, as determined by Tukey's post-hoc pairwise comparisons ($p \leq 0.05$).
Soil management regimes are abbreviated as follows:
Control: non-amended soil (baseline negative control)
C: 10% (w/w) compost incorporation
B: 5% (w/w) biochar incorporation
NPK: application of agronomically recommended NPK fertilizer rates
CB: dual amendment of 10% compost + 5% biochar
CNPK: 10% compost combined with standard NPK fertilization
BNPK: 5% biochar combined with standard NPK fertilization
CBNPK: triple amendment integrating 10% compost, 5% biochar, and NPK fertilizer

DISCUSSION

This study assessed the efficiency of biochar and compost against stem canker and black scurf caused by *R. solani* and confirmed the hypothesis that these two amendments applied to the soil improve the soil quality and potato plant development. In a general prospect, the results declared CBNPK as the most efficient treatment to act directly against *R. solani* on potato, and indirectly by increase plant growth and development. These results endorsed with earlier studies that used compost (Ebrahimi *et al.*, 2016; Debode *et al.*, 2020) and biochar against different plant diseases (Wang *et al.*, 2015; Silva *et al.*, 2021a). Many studies have shown that the biochar application can improve the soil quality by improving the soil pH, soil cation exchange capacity, carbon contents of organic, total N, and extractable nutrients, water content of soils, and reduced the content of Al^{3+} (Chen *et al.,* 2021). The biochar suppressiveness capacity is closely related to soil physicochemical and biological attributes, such as the improvement of soil microbial diversity that increase microorganisms with competitive capacity for nutrients or that produce compounds which kill the pathogen (Graber *et al.* 2014; Silva *et al.,* 2021a). Debode *et al.,* (2020) showed the complex interaction of host plant, soil attributes, pathogen, and microbiome rhizosphere that difficult the establishment the principal mechanism of biochar in the suppression plant disease capacity. A number of mechanisms to explain the use of biochar against plant disease were suggested including sorption of phytotoxic and allelopathic compounds toxic to plants, direct fungi-toxic effect of biochar; the ability of biochar in inducing resistance in plants; increasing in beneficial microorganism activities with biochar application as well as changing soil properties nutrient uptake and abiotic condition due to application of these materials (Bonanomi *et al.*, 2015; Medeiros *et al.,* 2021) that causes direct and indirect effect against plant diseases (Jaiswal *et al.,* 2019; Medeiros *et al.,* 2021). As hypothesized, the PCA showed a clear view of the treatments that received biochar and compost compared to control. Interestingly, CBNPK displayed a clear separation in relation to the other treatments and clustered with all variables of potato plant growth, such as size and weight of tubers and number of leaves. These results suggest that the combined amendment treatment was associated with improved plant growth parameters (pyrolyzed plant residues, compost, fertilizer) that is related in the literature as alternative management tool against *R. solani* and other soil-borne pathogens (Jaiswal *et al.,* 2014). Debode, (2020) used biochar blended in compost against *R. solani* in lettuce plants and observed that the suppressiveness was attributed to fungal biomass and the absorbance of suppressive compounds by high surface area of biochar. Compost and biochar amendments can be used against plant diseases but the suppressive capacity changes by source of residues used to production, the chemical composition and concentrations used (Jaiswal *et al.,* 2014; Medeiros *et al.,* 2021). Our results indicate that together, biochar and compost impact on soil attributes and plant resistance to stem canker in potato, caused by *R. solani.* However, our results explained the fact that important changes on soil quality and plant development against *R. solani* were obtained with the use of biochar and compost with NPK due the several benefits of each amendment that are complementary when used together. Therefore, the increased concern on eco-friendly products is highly important to recycle readily available agro-industrial residues for an integrative agriculture within a global health security and reduce the dependence of chemical inputs traditionally used for plant protection and soil nutrition throughout centuries. Our results broaden the understanding of biochar and compost use as a perspective to produce alternative, more effective products that may be used as stem canker (*R. solani*) management tool in potato crop.

CONCLUSION

In recent study, we evaluated the effectiveness of biochar and compost against stem canker in potato in field conditions. To address this hypothesis, we used biochar and compost applied together in soil cultivated with potato cultivar, inoculated with *Rhizoctonia solani*. Our analysis revealed that biochar and compost together was the most efficient to decrease the potato stem canker severity and the development of potato plant. Overall, the findings suggest that the combined use of biochar and compost may provide a promising approach for reducing stem canker severity and improving potato plant growth under field conditions and to develop strategies that mitigate this problem.

Author Contribution

Iram Bilqees: Data curation, investigation, methodology, writing- review & editing. Muhammad Usman Ghazanfar: Conceptualization, supervision, writing- review & editing. Muhammad Asif Shabbir: Validation, formal analysis and writing original manuscript. Muhammad Shah Jahan: Software, visualization, writing– review & editing.

Conflict of Interest

The authors of the manuscript have no financial or non-financial conflict of interest in the subject matter or materials discussed in this manuscript.

Data Availability Statement

Data supporting the findings of this study will be made available by the corresponding author upon request.

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Generative AI Disclosure Statement

The authors did not used any type of generative artificial intelligence software for this research.

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