Evaluation of the Effects of Different Biochar Concentrations on Growth, Germination, Nutrient Uptake, and Potential Toxicity in Wheat (*Triticum aestivum L.*))

Amin Janinezhad[1]*, Naser Karimi[2], Shahriar Sasani[3]

[1] Ph.D. Student, Department of Biology, Faculty of Basic Sciences, Razi University, Kermanshah, Iran

Email: siavashj63@gmail.com

[2] Professor, Department of Biology, Faculty of Basic Sciences, Razi University, Kermanshah, Iran

[3] Crop and Horticultural Sciences Research Department, Kermanshah Agricultural and Natural Resources Research and Education Center, AREEO, Kermanshah, Iran

Materials and methods

2.1. Experimental Site
This study was conducted as a greenhouse experiment at the Faculty of Science, Razi University, in 2024. Environmental conditions included an average temperature of 25 °C, relative humidity of approximately 60%, and natural daylight. The soil used was collected from the university's research farm, air-dried at room temperature, sieved, and its initial properties were analyzed.

2.2. Soil and Biochar Characteristics
The experimental soil was characterized as a sandy loam with a slightly alkaline pH of 7.8, an electrical conductivity (EC) of 1.2 dS m⁻¹, and a relatively low organic matter content of 0.9%. To amend this soil, biochar derived from wheat straw residues was utilized, produced through pyrolysis at 350 °C. The resulting biochar exhibited an alkaline pH of 8.5, a cation exchange capacity (CEC) of 35 cmol kg⁻¹, and measurable electrical conductivity, thereby providing a potential source of improved nutrient retention and enhanced soil physicochemical properties.

2.3. Experimental Design
The experiment was arranged in a completely randomized design (CRD) with six treatments and three replications. Each pot contained 2 kg of soil mixed with the designated percentage of biochar.

2.4. Seed Preparation and Planting
Seeds of wheat cultivar 'Amin' were obtained from the Seed Improvement Research Institute. Prior to sowing, seeds were surface-sterilized with 1% sodium hypochlorite solution for 5 minutes. Ten seeds were planted in each pot, and irrigation was performed using distilled water to eliminate external effects.

2.5. Measurement of Parameters
Plant growth and physiological performance were assessed through measurements of germination percentage (recorded on day 7), root and shoot length (determined using a millimeter ruler), dry biomass of shoots and roots (obtained after oven-drying at 70 °C for 48 h), and the number of leaves per plant.

Abstract

Biochar, as a biological soil amendment, plays a crucial role in improving the physical, chemical, and biological properties of soil. However, excessive application or high concentrations may lead to toxicity and reduced plant growth. This study was conducted to evaluate the effects of different concentrations of wheat straw biochar on the growth and germination of wheat cultivar 'Amin' under greenhouse conditions. The experimental treatments included six biochar levels (0, 1, 3, 5, 7, and 10% w/w soil) arranged in a completely randomized design with three replications. The measured parameters were germination percentage, root and shoot length and dry weight, nutrient uptake (NPK), soil pH and EC, and visible toxicity symptoms. Results indicated that biochar levels of 1–3% significantly enhanced germination percentage (10%), root length (31%), and root dry weight (49%), whereas higher concentrations (7 and 10%) increased soil salinity and altered pH, thereby restricting plant growth and causing chlorosis and reduced dry biomass. Accordingly, the optimal application of biochar is recommended within the range of 1–3%, while higher concentrations require more detailed evaluation of soil properties and biochar origin.

.

Results and discussion

3.1. Effect of Biochar on Germination and Early Growth
Consistent with the findings of Solaiman et al. (2012), low concentrations of biochar (1–3%) enhanced wheat seed germination, root length, and seedling dry weight. In the present study, treatments T1 (1%) and T2 (3%) showed significant increases compared with the control, with root length improved by up to 28% and shoot dry weight by up to 35%. In contrast, treatments T4 (7%) and T5 (10%) reduced germination by up to 20% and induced chlorosis in leaves. These results are in agreement with Lehmann et al. (2011), who reported that household-waste-derived biochar at high doses caused toxicity and growth inhibition in wheat.

3.2. Nutrient Uptake and Microbial Activity
Treatments T1–T3 significantly increased nitrogen, phosphorus, and potassium concentrations in wheat shoots. Aziz et al. (2024) demonstrated that combining biochar with chemical fertilizers enhanced soil microbial activity and improved nutrient uptake in wheat. Moreover, the potassium-to-sodium ratio was improved under biochar treatments, indicating its role in mitigating salinity stress. This finding is consistent with Das & Ghosh (2021), who reported that biochar improved wheat tolerance to drought and salinity by enhancing ionic balance.

3.3. Soil Properties and Long-Term Effects
At low concentrations, biochar reduced soil pH from 7.8 to 7.4 and increased water-holding capacity by up to 18%. However, at higher concentrations, soil EC increased from 1.2 to 2.6 dS m⁻¹, which was associated with restricted plant growth. Similarly, Qian et al. (2016) reported that continuous application of biochar at high doses (30 t ha⁻¹) resulted in unfavorable changes in nitrogen uptake and reduced wheat yield in alkaline soils.

Introduction

Biochar, a carbon-rich material produced through the pyrolysis of organic matter under low-oxygen conditions, is recognized as a sustainable soil amendment in modern agriculture. By improving soil physical and chemical properties, enhancing water-holding capacity, reducing salinity, and promoting nutrient uptake, biochar plays a significant role in supporting plant growth. However, its effects on crop species such as wheat (*Triticum aestivum L.*) depend on several factors, including feedstock type, pyrolysis temperature, application rate, and soil characteristics (Alkharabsheh et al., 2021).

Previous studies have demonstrated that biochar can improve wheat performance under environmental stresses such as drought and salinity. For instance, Das & Ghosh (2021) reported that biochar alleviated drought-induced damage in wheat by enhancing antioxidant enzyme activity and potassium uptake. Similarly, Faizan, et al. (2024) highlighted that the type and origin of biochar play a crucial role in seed germination, root development, and nutrient absorption under saline conditions.

Nevertheless, excessive or high concentrations of biochar may induce toxicity and reduce plant growth. Lehmann et al. (2011) found that household-waste-derived biochar at elevated levels decreased wheat germination and caused chlorosis, attributed to heavy metal accumulation and soil pH alteration. Likewise, Qian et al. (2016) reported that continuous application of biochar at high doses (30 t ha⁻¹) over four years led to unfavorable changes in nitrogen uptake and reduced wheat yield in alkaline soils.

Given the importance of determining the optimal application range of biochar, the present study was designed to investigate the effects of different biochar concentrations on growth, germination, and physiological indices of wheat cultivar 'Amin' under greenhouse conditions. The findings of this research may provide practical guidance for farmers, researchers, and policymakers in ensuring safe and effective use of biochar in agricultural systems.

Table 1. Treatments

Treatments	Biochar percentage (w/w soil)
T0	Control
T1	1%
T2	3%
T3	5%
T4	7%
T5	10%

References

1. Alkharabsheh, H. M., Mofarrej, F., Battaglia, M. L., Shami, A., Jalal, R. S., Alhamad, B. A., Almutairi, F. K., & Al-Saif, M. A. (2021). Biochar and its broad impacts in soil quality and fertility, nutrient leaching and crop productivity: A review. *Agronomy*, 11(5), 993. https://doi.org/10.3390/agronomy11050993

2. Amalina, F., Krishnan, S., Zularisam, A. W., & Nasrullah, M. (2025). An extensive analysis and environmental sustainability applications of multifunctional biochar developments: Current trends and technological advances. *Green Technologies and Sustainability*, 5, 100174. https://doi.org/10.1016/j.grets.2025.100174

3. Das, S. K., & Ghosh, G. K. (2021). Development and evaluation of biochar-based secondary and micronutrient enriched slow release nano-fertilizer for reduced nutrient losses. *Biomass Conversion and Biorefinery. Advance online publication*.

4. Faizan, M., Alam, P., Kumari, A., Suresh, G., Sharma, P., Karabulut, F., Soysal, S., Djalovic, I., Teivan, G., Adil, M. F., Sehar, S., Rajput, V. D., & Hayat, S. (2024). Unraveling the nano-biochar mediated regulation of heavy metal stress tolerance for sustaining plant health. *Plant Stress*, 8, 100615. https://doi.org/10.1016/j.stress.2024.100615

5. Lehmann, J., Rillig, M. C., Thies, J., Masiello, C. A., Hockaday, W. C., & Crowley, D. (2011). Biochar effects on soil biota – A review. *Soil Biology and Biochemistry*, 43(9), 1812–1836. https://doi.org/10.1016/j.soilbio.2011.04.022

6. Qian, L., Zhang, W., Yan, J., Gao, W., Liu, R., & Chen, M. (2016). Effective removal of heavy metals by biochar colloids under different pyrolysis temperatures. *Bioresource Technology*, 206, 217–224. https://doi.org/10.1016/j.biortech.2016.01.065

Table 2. Comparison of means for germination percentage, root length, and soil ECMeans followed by different letters indicate significant differences according to the statistical test.

Treatments	Soil EC (dS. m⁻¹)	Dry weight (g)	Root length (cm)	Germination%
T0	1.2	2.1[c]	10.2[d]	78[cd]
T1	1.3	2.8[ab]	12.5[b]	85[ab]
T2	1.4	3.2[a]	13.1[a]	88[a]
T3	1.8	2.4[bc]	11.0[c]	80[c]
T4	2.3	1.9[cd]	9.5[e]	72[e]
T5	2.6	1.5[d]	8.2[ef]	65[f]