Scientia Review, Vol. 02(02), February 2026, pp. 35-38 ISSN: 3107-7919

Scientia Review

Website: www.scientiafoundation.in

POPULAR SCIENCE ARTICLE

Turning Carbon into Control: Biochar-Driven Resistance to Soil-Borne Plant Diseases

Amit Kumar[1*], Rabindra Kumar[2] and Utkarsh Chaturvedi[2]
[1]Department of Plant Pathology, Bihar Agricultural University, Sabour - 813210, Bhagalpur, Bihar.
[2]Department of Plant Pathology, Bihar Agricultural University, Sabour - 813210, Bhagalpur, Bihar.
*Email: roya28641@gmail.com

Received: 17 February 2026
Revised: 18 February 2026
Accepted: 19 February 2026
Published online: 19 February 2026

Article ID: SR01084

Citation: Kumar, A., Kumar, R & Chaturvedi, U. (2026). Turning Carbon into Control: Biochar-Driven Resistance to Soil-Borne Plant Diseases. *Scientia Review*, 2(2), 35-38

Abstract

Soil-borne plant diseases pose a persistent and complex challenge to global agriculture, largely due to the long-term survival of pathogens in soil and their limited responsiveness to conventional chemical control measures. Pathogens such as *Fusarium* spp. and *Phytophthora* spp. are particularly destructive, causing severe root, collar, and vascular diseases across a wide range of crops. In recent years, biochar a carbon-rich material produced through biomass pyrolysis has gained attention as a soil amendment capable of transforming disease-conducive soils into suppressive systems. Rather than acting as a direct antimicrobial agent, biochar mediates disease resistance by modifying soil physicochemical properties, restructuring microbial communities, regulating rhizosphere chemistry, and priming plant defense responses.

Keywords: Biochar, Soil-borne diseases, Soil health, Induced resistance

Introduction

Soil-borne plant diseases remain one of the most difficult problems in crop production because they develop below ground, escape early detection, and persist for long periods in soil. Unlike foliar pathogens, soil-borne pathogens directly attack roots and vascular tissues, disrupting water and nutrient transport and ultimately reducing plant growth, yield, and survival. Among these pathogens, *Fusarium* spp. (true fungi) and *Phytophthora* spp. (oomycetes) are globally important due to their wide host range, ecological adaptability, and ability to survive under adverse conditions.

Traditional management strategies, including soil fumigation and fungicide application, have offered short-term control but are increasingly constrained by environmental concerns, rising costs, and the emergence of fungicide resistance. Moreover, chemical approaches often disrupt beneficial soil microorganisms, weakening the natural suppressive capacity of soils. These limitations have encouraged a shift toward soil-centered disease management strategies that emphasize long-term resilience rather than immediate pathogen elimination.

Biochar has emerged as one such strategy. By introducing stable carbon back into soil systems, biochar alters fundamental soil processes and creates conditions that favor plant health while reducing pathogen success. The concept of "turning carbon into control" reflects this transition—from chemical suppression to ecological regulation of soil-borne diseases.

Biochar and Its Functional Role in Soil Systems

Biochar is produced by heating organic biomass such as crop residues, wood, or organic waste—under limited oxygen conditions in a process known as pyrolysis. This process results in a highly stable, porous, and carbon-rich material that resists microbial decomposition and can persist in soil for decades.

The agricultural relevance of biochar lies in its multifunctional nature. Its porous structure increases soil surface area, enhances water retention, and provides microsites for microbial colonization. The chemical composition of biochar, including surface functional groups and mineral ash content, allows it to interact with soil nutrients and influence ion exchange processes.

Importantly, the properties of biochar vary widely depending on feedstock type and pyrolysis temperature. Low-temperature biochars generally contain more labile carbon and stimulate microbial activity, whereas high-temperature biochars tend to be more alkaline, structurally stable, and effective in modifying soil pH. These variations strongly influence how biochar affects soil-borne pathogens and plant health.

Biochar-Driven Mechanisms of Disease Resistance

Biochar does not function as a fungicide or biocide. Instead, it suppresses soil-borne diseases through multiple, interconnected mechanisms that reshape the soil–plant–pathogen relationship.

Modification of Soil Physicochemical Properties: One of the most consistent effects of biochar amendment is the alteration of soil pH, particularly in acidic soils. Many biochars exhibit alkaline properties, and their application can shift soil pH toward neutral levels that are less favorable for pathogens such as *Fusarium* and *Phytophthora*. Soil pH also governs nutrient availability and microbial activity, indirectly influencing disease development.

Biochar improves soil structure by reducing bulk density and increasing aggregation and porosity. These changes enhance aeration and water infiltration, which are especially important for managing *Phytophthora* diseases that thrive under waterlogged conditions. Improved regulation of soil moisture creates an environment that supports root growth while restricting pathogen movement and survival.

Restructuring of Soil Microbial Communities: Soil health is closely linked to microbial diversity and functional balance. Biochar provides protected microhabitats within its pore networks that support beneficial microorganisms, including plant growth-promoting rhizobacteria, arbuscular mycorrhizal fungi, and antagonistic fungi such as *Trichoderma* spp.

The enrichment of beneficial microbial communities enhances competition for nutrients and space, limits pathogen colonization, and increases the production of antimicrobial metabolites. Over time, these changes can lead to the development of disease-suppressive soils in which pathogen activity is naturally regulated rather than chemically controlled.

Regulation of Rhizosphere Chemistry: Biochar influences the chemical environment of the rhizosphere by adsorbing organic compounds, toxins, and signaling molecules released by pathogens. This adsorption reduces the bioavailability of harmful metabolites and interferes with pathogen infection processes.

In addition, biochar alters root exudation patterns, modifying plant–microbe communication in the rhizosphere. These changes can reduce pathogen attraction while strengthening beneficial plant–microbe interactions that support nutrient uptake and defense activation.

Induction of Plant Defense Responses: Beyond its effects on soil, biochar has been shown to prime plant immune systems. Biochar-amended soils can activate systemic resistance pathways mediated by salicylic acid and jasmonic acid signaling. This priming enables plants to respond more rapidly and effectively when challenged by soil-borne pathogens.

Rather than preventing infection entirely, this induced resistance reduces disease severity and slows disease progression, contributing to more stable and resilient crop performance.

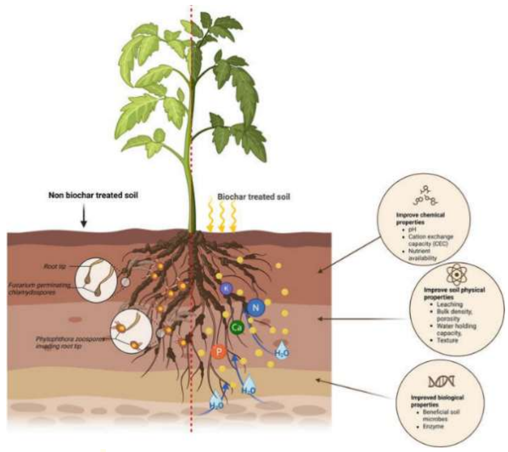

Figure 1. Biochar effects on soil-borne pathogens.

Biochar-Mediated Suppression of Major Soil-Borne Pathogens

***Fusarium* Diseases:** *Fusarium* species are among the most persistent soil-borne pathogens due to their ability to produce long-lived survival structures. Biochar has shown consistent potential in reducing *Fusarium*-induced wilts and root rots across a range of crops.

Disease suppression is associated with improved soil pH balance, reduced survival of fungal propagules, enhanced microbial antagonism, and improved plant vigor. Biochar often performs best when integrated with composts or biological control agents, highlighting its role as a component of integrated disease management rather than a standalone solution.

***Phytophthora* Diseases:** *Phytophthora* species differ fundamentally from true fungi and are highly dependent on soil moisture for dispersal and infection. Biochar's ability to improve soil drainage and aeration makes it particularly effective against these pathogens.

Although research on biochar-based control of *Phytophthora* is still limited compared to *Fusarium*, available studies indicate reduced disease severity and enhanced host resistance, especially under controlled conditions. Field-scale validation remains an important research need.

Table 1. Biochar Alone and Integrated Approaches for Soil Pathogens

Pathogen class	Pathogen name	Host	Treatments (Biochar or supplemented with other agents)	Application Rate	Quantitative Outcome
Fungi	*Fusarium virguliforme*	Soybean	Biochar	Variable	Disease reduction observed
Fungi	*Fusarium solani*	Cassava	Biochar + microbial inoculant	Variable	Enhanced suppression with integration
Fungi	*Fusarium oxysporum f.sp. radicis lycopersici*	Tomato	Biochar + microbial inoculant	Variable	Synergistic disease reduction
Fungi	*Fusarium oxysporum* f. sp. *vasinfectum*	Cotton	Biochar	Up to 9% w/w	Substantial disease index reduction
Fungi	*Fusarium oxysporum* f.sp. *lycopercisi*	Tomato	Biochar	1–2% w/w optimal	Decreased FOL abundance; 3% increased pathogen
Fungi	*Fusarium oxysporum* f.sp. *asparagi*	Asparagus	Biochar	Variable	Disease suppression observed
Fungi	*Fusarium oxysporum* f.sp. *radicis lycopersici*	Tomato	Biochar + phosphate-mobilising bacteria	Variable	Enhanced nutrient uptake and disease resistance
Fungi	*Fusarium oxysporum* f.sp. *lycopersici*	Tomato	Biochar + either compost, Arbuscular mycorrhizal fungi	Variable	Synergistic effects on suppression
Fungi	*Fusarium proliferatum*	Asparagus	Biochar	Variable	Reduced disease incidence
Fungi	*Fusarium oxysporum* f.sp. *asparagi*	Asparagus	Biochar	Variable	Reduced disease incidence
Fungi	*Fusarium solani*	Asian ginseng	Biochar	Variable	Improved plant health and reduced disease
Fungi	*Fusarium verticilloides*	Maize	Biochar	Variable	Improved plant health and reduced disease
Fungi	*Fusarium equiseti*	Grapevine	Biochar + *Trichoderma* spp.	Variable	~53% leaf, ~56% root severity reduction
Oomycetes	*Phytophthora capsici*	Pepper	Biochar + beneficial microbes	Variable	Enhanced disease suppression
Oomycetes	*Phytophthora infestans*	Tomato	Biochar + microbial inoculants	Variable	Reduced late blight severity
Oomycetes	*Phytophthora infestans*	Potato	Biochar + *Streptomyces* strains	Variable	Synergistic suppression
Oomycetes	*Phytophthora nicotianae*	Tobacco	Agricultural waste biochar	Plot amendment	62.34% population reduction; 53.91% sporangia reduction
Oomycetes	*Phytophthora cinnamomi*	Northern red oak	Biochar	Variable	Reduced root rot severity
Oomycetes	*Phytophthora cactorum*	Red maple	Biochar	Variable	Improved plant survival
Oomycetes	*Phytophthora capsici* L.	Sweet bell pepper	Biochar + beneficial microorganisms	Variable	Enhanced disease control

Limitations and Research Gaps

Despite its promise, biochar is not a universal remedy for soil-borne diseases. Its effectiveness depends on multiple interacting factors, including biochar type, application rate, soil properties, climate, crop species, and pathogen biology. Inconsistent outcomes across studies reflect the absence of standardized biochar formulations and application guidelines.

Most existing evidence is derived from greenhouse and pot experiments, with relatively few long-term field trials. Economic considerations, including production and transport costs, also influence the feasibility of large-scale adoption.

Future Perspectives: From Soil Amendment to Disease-Resilient Systems

The greatest potential of biochar lies in its integration into broader soil health and disease management frameworks. Future progress will require:

- Long-term field evaluations across diverse agro-ecosystems
- Standardization of biochar quality and application rates
- Integration with biological control agents and organic amendments
- Economic assessments tailored to different farming systems

High-value cropping systems, nurseries, and greenhouses represent immediate opportunities where biochar-based disease suppression can be effectively implemented.

Conclusions

Turning carbon into control represents a fundamental shift in how soil-borne plant diseases are managed. Biochar demonstrates that durable disease suppression can be achieved not by directly targeting pathogens, but by reshaping soil environments to favor beneficial microbes and resilient plants.

By linking carbon sequestration with soil restoration and plant protection, biochar offers a pathway toward sustainable agriculture in which productivity, environmental health, and disease resistance are mutually reinforcing rather than competing goals.