Journal of Pharmaceutical and Medical Research
ISSN: 2663-1962
DOI: https://doi.org/10.61784/jpmr3035

COMMON SOIL-BORNE PATHOGENIC DISEASES IN AMERICAN GINSENG (PANAX QUINQUEFOLIUS) CULTIVATION AND INTEGRATED CONTROL APPROACHES

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Abstract: American ginseng (*Panax quinquefolius* L.), a high-value medicinal crop, faces persistent threats from soil-borne diseases (e.g., root rot, rusty root). Conventional chemical controls risk disrupting soil microecology and inducing pathogen resistance. This study advocates ecological regulation-centered strategies, emphasizing intercropping (e.g., maize, onion) and soil amendments (e.g., biochar) to reshape rhizosphere microbiomes and suppress pathogens. Maize secretes phenolic acids to reduce Fusarium abundance, while biochar enriches beneficial microbes (e.g., *Burkholderia*) and enhances soil health and ginsenoside content. These approaches synergize disease control, carbon sequestration, and economic benefits but require avoiding crop competition and improper biochar application. Future research should prioritize the application of intercropping and biochar in American ginseng cultivation, investigate the synergistic disease resistance mechanisms between plants and microbes, and drive the sustainable transition of the American ginseng industry.
Keywords: American ginseng; Intercropping; Biochar; Rhizosphere microbiome; Sustainable agriculture

1 INTRODUCTION

American ginseng (*P. quinquefolius* L.), also known as Huaqishen or Western ginseng, is the dried root of a perennial plant belonging to the Araliaceae family, Panax genus. Native to North America, it was introduced to China in the 1980s and is now widely cultivated in northern and northeastern regions. With a cool nature and sweet-bitter taste, it is traditionally used to replenish qi, nourish yin, and clear heat, particularly for treating fatigue, thirst, and respiratory disorders. Modern research reveals that its bioactive compounds (e.g., saponins, polysaccharides, amino acids) exhibit antioxidant [1], anti-fatigue [2,3], hypoglycemic [4], and immunomodulatory effects [5]. Despite its high market demand, American ginseng faces severe disease challenges during cultivation, sharing susceptibility to pathogens with related species (e.g., *Panax ginseng*, *Panax notoginseng*). Soil-borne diseases such as root rot (33%-41% incidence in Shandong Wendeng, 2016-2019) [6] and anthracnose (>20% yield loss in Jilin Fusong, 2021) [7] critically threaten yield and quality, underscoring the urgency of disease management for sustainable production.

2 COMMON DISEASES IN THE CULTIVATION OF AMERICAN GINSENG

American ginseng (*Panax quinquefolius*) cultivation is threatened by two categories of infectious diseases: soil-borne diseases and airborne diseases. Soil-borne pathogens (e.g., *Fusarium* spp., *Cylindrocarpon* spp.) invade root systems through contaminated soil, causing rot, wilting, and plant death. These pathogens exhibit dual ecological strategies—parasitic adaptation and saprophytic survival—with their virulence modulated by soil properties, organic matter content, and microbial community dynamics [8]. Airborne diseases, transmitted via wind or rain splash, target aerial plant parts (e.g., *Alternaria panax*-induced leaf spots, *Botrytis cinerea*-mediated gray mold), impairing photosynthesis and growth. Notably, soil-borne diseases dominate the threat profile in American ginseng cultivation (Table 1). For instance, root rot (caused by *Ilyonectria mors-panacis* and *Fusarium* spp.) exhibits a 33%-41% incidence in Shandong Province [6], while anthracnose (*Colletotrichum panacicola*) caused > 20% yield loss in Jilin Province [7]. Integrated management of both disease types is critical for sustainable production.

Table 1 Common Diseases of American Ginseng Corresponding Pathogenic Fungi and Disease Occurrence Periods

Disease	Pathogen(s)	Symptoms	Occurrence Period
Root Rot	*Ilyonectria mors-panacis* [9], *Fusarium oxysporum*, *Fusarium redolens*, *Fusarium solani*[10]	Root decay, chlorosis and yellowing of leaves, wilting of aerial parts	Year-round occurrence, peaks in April-June and September-October; thrives in high temperature and humidity
Fusarium Wilt	*F. oxysporum* [11]	Leaf yellowing, wilting, and root rot	Predominantly in June-August under high-temperature conditions

Sclerotinia Rot	*Sclerotinia sclerotiorum*[12]	Root and stem rot with formation of rodent feces-shaped sclerotia, leading to plant death	Severe in spring and autumn under moderate temperatures and high humidity
Rusty Root	*Cylindrocarpon destructans* [13], *C. panicicola*, *I. mors-panacis*, *I. robusta*, *I. vredehoekensis*, and *I. communis* [14]	Rusty brown lesions on roots, stems, and buds; tissue disintegration and epidermal rupture	Prevalent during late spring to summer in warm and humid environments
Phytophthora Blight	*Phytophthora cactorum* [11]	Leaf and root rot, plant wilting, and mortality in severe cases	Frequent in early spring
Anthracnose	*Colletotrichum panacicola*	Necrotic lesions on leaves, stems, and fruits with black conidial pustules in later stages	Common during spring-summer and summer-autumn transitions under hot and rainy conditions
Damping-off	*Pythium debaryanum*	Water-soaked lesions at the base of seedlings, leading to lodging and death	Primarily occurs in April-June during seedling stage
Black Spot	*Alternaria panax* [9,15]	Circular dark brown leaf spots, desiccation of expanded lesions, stem lodging, and growth retardation	Year-round occurrence, exacerbated in humid and rainy seasons
Gray Mold	*Botrytis cinerea*	Tissue maceration, plant collapse, and gray-green sporulation on infected fruits	Initial onset in April-May, incidence increases with rising temperatures

3 PREVENTION AND CONTROL OF SOIL-BORNE DISEASES

The prevention and control of soil-borne diseases in American ginseng (Panax quinquefolius) require a synergistic approach targeting pathogen invasion pathways, environmental factors, and host resistance, establishing an ecology-centered integrated strategy. Optimizing planting patterns (e.g., rational intercropping and crop rotation), improving soil physicochemical properties, and breeding disease-resistant cultivars can effectively disrupt pathogen transmission chains and reduce disease risks.

3.1 Intercropping

As a representative agroecological practice, intercropping suppresses soil-borne pathogen proliferation and enhances soil microenvironments through allelopathic interactions and rhizosphere microbial modulation. For instance, maize/onion intercropping systems inhibit *Fusarium* activity via root exudates such as phenolic acids in maize [16] and sulfur compounds in onions [17], while maize/pepper intercropping reduces viral disease incidence by 56.9% [18]. Post-cucumber monoculture soils rotated with onions exhibit significant declines in *Fusarium* abundance [19]. Deep tillage combined with intercropping accelerates organic matter decomposition, promoting beneficial microbial colonization (e.g., Actinobacteria) and reshaping rhizosphere community structures [20]. Companion plant selection should prioritize growth promotion or pathogen suppression over yield objectives [21].

Proper intercropping enhances nutrient uptake and secondary metabolite synthesis: *P. notoginseng*/taro intercropping increases leaf area and seedling vigor by 19.67% and 28.13%, respectively, while elevating soil available phosphorus and potassium [22]; maize/*Cynanchum auriculatum* intercropping reduces downy mildew and brown spot incidence by 14.2–15.6% and enhances flavonoid/polyphenol accumulation [23]. Maize intercropped with lilies or Atractylodes macrocephala modulates rhizosphere microbiomes (e.g., suppressing *Fusarium* while enriching *Streptomyces* and *Rhizobia* [24, 25]), improving stress resistance and medicinal compound biosynthesis. However, improper combinations may yield negative effects, such as inhibited biomass accumulation in *Angelica sinensis*/oat systems [26] or reduced microbial diversity in grape/crepis intercropping. Thus, intercropping design must avoid same-family rotations and prioritize plants with validated antimicrobial activity. For American ginseng, ryegrass (*Secale cereale* L) or red clover (*Trifolium pratense* L) intercropping significantly enriches beneficial rhizobacteria (e.g., Acidobacteria, Chloroflexi), stimulates ginsenosidesynthesis, and suppresses pathogens [27], providing empirical support for ecological disease management.

3.2 Breed Disease-Resistant Varieties

Breeding disease-resistant cultivars serves as the genetic foundation for pathogen control, providing intrinsic resistance. Genetic modification or screening of American ginseng enables the development of cultivars adapted to specific environmental conditions to enhance overall stress tolerance. Systematic breeding efforts have yielded successful examples, such as the *Salvia miltiorrhiza* cultivar ‘Dankang 1,’ which exhibits high levels of bioactive compounds and resistance to root rot and root-knot nematode disease [28], and the hybrid cultivar ‘Longliangyou 1019’ with a comprehensive blast resistance index of 2.7 [29]. However, prolonged development cycles, genetic uniformity risks, and pathogen-specific efficacy limit the practical application of such cultivars, necessitating multi-year trials. Currently, no widely adopted disease-resistant cultivars of American ginseng are commercially available.

3.3 Scientific Fertilization

Scientific fertilization effectively mitigates disease occurrence by optimizing organic or composite microbial fertilizer applications to restructure soil microbial communities and suppress pathogen proliferation. Studies have demonstrated that rational application of organic compound fertilizers and biogas slurry significantly enhances *P. ginseng* growth and resistance to rust rot disease [30]. Field trials confirmed that bio-organic fertilizer application in continuous *P. ginseng* cropping soils improves rhizosphere microenvironments, elevates microbial diversity, adjusts soil pH, and increases organic matter content, boosting yield by 10%–30%. Wang et al. [8] reported that high-dose calcium oxide (4.5 g/kg) reduces root rot incidence caused by *F. solani* and *I. mors-panacis* in American ginseng, whereas 0.5 g/kg exacerbates symptoms. However, fertilization strategies face challenges including high costs, delayed efficacy requiring long-term commitment, and technical precision. Improper practices may aggravate diseases, as exemplified by nitrogen-sensitive American ginseng trials showing excessive nitrogen fertilization induces soil acidification, facilitating pathogen invasion and intensifying soil-borne epidemics [31].

3.4 Soil Disinfection

Soil disinfection serves as a critical measure to block pathogen reinfestation, offering direct and efficient pathogen eradication with rapid short-term efficacy. Common methods include physical approaches (solarization, steam sterilization, hot water irrigation), chemical treatments (fumigants, drenching agents), biological strategies (microbial inoculants, plant-derived disinfectants), and emerging technologies (flame disinfection, ozone treatment, electro-chemical techniques). Chemical disinfection remains the most prevalent: Li et al. [32] demonstrated that 98% dazomet granule application in 5-year-old *P. ginseng* soils significantly reduced pathogenic fungi (*Fusarium*, *Cylindrocarpon*) via dilution plate assays, while Han et al. [33] reported chloropicrin fumigation (25–35 kg/667 m^2) suppressed *P. ginseng* rust rot by 54.78–70.07%. However, prolonged use of chemical agents (e.g., carbendazim, fenaminosulf) risks microbial diversity loss and drug resistance development [34]. In contrast, reductive soil disinfestation (RSD) exhibits dual functionality—inactivating pathogens while reshaping soil microecology to favor antagonistic microbial colonization [35]. Notably, chemical residues (e.g., formaldehyde) may persist, impairing subsequent crop growth and environmental safety, and excessive application disrupts beneficial microbial equilibria, exacerbating pathogen resilience.

3.5 Soil Improvement

Soil amendments establish trinity ecological regulation mechanisms by modulating soil physical structure, chemical properties, and microbial community functions, thereby suppressing soil-borne pathogens and enhancing crop resistance. Common amendments include organic compost, biochar, humic acid, lime, and water-retaining agents, with biochar—a porous carbonaceous material derived from pyrolyzed agricultural residues (e.g., straw, wood chips)—emerging as a research focus due to its high surface area and pore structure. These characteristics improve soil water/nutrient retention, adsorb pathogen-derived toxins and salts via surface functional groups, and provide microhabitats for antagonistic microbes (e.g., *Burkholderia* spp.) and arbuscular mycorrhizal fungi (*Glomeromycota*), inhibiting pathogens like *Fusarium* spp. and *Phytophthora* spp. Biochar enhances systemic disease resistance by regulating soil pH, releasing bioactive organic compounds, and activating soil enzymes (e.g., urease, phosphatase). For instance, tomato fields amended with biochar exhibited 61-78% control efficiency against *Ralstonia solanacearum* [35], while long-term application promotes soil aggregate formation and microbial-driven carbon/nutrient cycling [36].

Biochar enhances plant development and suppresses soil-borne diseases by improving soil nutrient conversion efficiency and enzymatic activity. In field trials comparing three biochar types (manure-derived (PB), wood-derived (WB), and corn stover-derived (MB)) with traditional compost (MC) on continuous *P. ginseng* cropping, MB and WB significantly increased survival rates (21% and 14%, respectively) and root quality (56% improvement with MB), while PB only enhanced root biomass. Biochar reduced total rhizosphere phenolic acids (35–56% reduction) and modulated microbial communities: enriching beneficial taxa like arbuscular mycorrhizal fungi (*Glomeromycota*) while suppressing pathogens (e.g., *Fusarium* spp.). MB notably increased total fungal and bacterial abundance (200% and 38%, respectively) and amplified fungal network complexity. These results demonstrate that corn stover biochar suppresses soil-borne diseases primarily by reconstructing rhizosphere microbial interaction networks and enhancing plant immunity rather than solely improving soil fertility [37]. MB and WB also outperformed MC in soil health restoration, increasing soil fertility by 39% and 23%, root biomass by 27% and 25%, and root quality by 18% and 6% after two-year application. Pathogenic fungi (e.g., *Fusarium*) declined by 19–35%, while beneficial bacteria (e.g., *Burkholderia*) and mycorrhizal fungi proliferated, with MB elevating total fungal abundance by 384% and network complexity. Biochar synergistically improved ginseng quality (e.g., ginsenosides) and soil ecological functions through microbial optimization and pathogen suppression [38]. However, sustained efficacy requires long-term application with dosage adjustments tailored to soil conditions to mitigate potential risks.

4 CONCLUSION AND PROSPECT

American ginseng, a high-value medicinal crop, faces persistent threats from soil-borne diseases such as root rot and rust rot, which severely compromise yield and quality through soil-transmitted pathogens. This review systematically outlines the etiological characteristics, epidemiological patterns, and integrated management strategies for major soil-borne diseases in American ginseng cultivation, with emphasis on the potential of intercropping systems and soil amendments. While conventional chemical control offers short-term efficacy, it risks destabilizing soil microbiomes and inducing pathogen resistance. In contrast, ecology-driven approaches—including optimized intercropping (e.g., maize/onion systems) and biochar application—synergistically suppress pathogen proliferation and enhance soil health by reshaping rhizosphere microbial communities. For instance, maize intercropping reduces *Fusarium* abundance through phenolic acid exudation, whereas biochar adsorbs toxins and enriches beneficial bacteria, significantly lowering disease incidence while boosting ginsenoside content and soil carbon sequestration. These eco-friendly strategies reduce chemical inputs and demonstrate dual ecological-economic benefits.

Current disease management should transition toward an "ecology-centered, multi-technology integration" framework. Interventions like intercropping and soil amendments fundamentally reinforce plant-microbe-soil interactions to restore agroecosystem self-regulation. Although more sustainable than chemical reliance, their efficacy depends on regional conditions, crop combinations, and application techniques. For example, intercropping species must avoid intra-family competition, and biochar feedstock/pyrolysis temperatures require soil-specific optimization to prevent adverse effects. Further research is needed to refine their implementation in American ginseng systems. By integrating technological innovation with ecological principles, this approach can drive the industry toward green, high-quality transformation.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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