Advances in Occurrence and Control of Root Rot Disease in Tuber Crops

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Abstract Root rot is a highly threatening soil-borne root disease in the production of tuber crops, severely constraining crop yield and quality. This paper summarizes the dominant pathogens and typical symptom characteristics of root rot in tuber crops, systematically reviews the research progress on agricultural control, chemical control, and biological control of this disease, and proposes the need to strengthen the monitoring of pathogen population structure and the construction of synergistic multi-functional microbial agent systems. This study provides a theoretical reference for the green and sustainable control of root rot in tuber crops.

Key words Tuber crop; Root rot; Pathogen diversity; Biological control

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Tuber crops such as potato, sweet potato and cassava are important food sources in many developing countries. At the level of economic production, tuber crops have significant economic benefits and have become an important means for farmers to increase their income. In the field of medicinal resources, tuberous medicinal materials including *Polygonatum cyrtonema*, *Atractylodes macrocephala*, *Pinellia ternata*, *Gastrodia elata* and *Bletilla striata* are recorded in the *Chinese Pharmacopoeia*, and are widely used in clinical prescriptions and the manufacture of Chinese patent medicines. With the rapid development of the big health industry, the market size of medicinal and edible tuber crops has maintained a relatively high average annual growth rate, and they have become an important industrial carrier for rural revitalization. Root rot is a common soil-borne disease that occurs during crop growth, characterized by easy transmission, substantial losses, and difficult control. For example, root rot in Huangjing is widespread and causes severe damage, and has become one of the main diseases restricting the yield and quality of *P. cyrtonema*. Studies have shown that the field incidence of root rot in *P. cyrtonema* is typically around 25%, and can exceed 50% in severe cases, causing enormous economic losses[1]. The field incidence of root rot in *A. macrocephala* is generally around 30%, and can reach 60% - 70% in severe cases, or even result in total crop failure[2]. Root rot in Chinese yam mainly causes root necrosis, with yield reductions of 30% - 50%. The widespread occurrence of root rot has seriously limited the yield and quality of tuber crops.

At present, the control measures for root rot mainly include three categories: agricultural control (crop rotation, soil improvement, *etc.*), chemical control, and biological control. Among them, biological control has become a research hotspot in the field of root rot prevention and control due to its advantages of being safe and efficient, resistant to drug resistance, and environmentally friendly. This paper reviews the research progress on root rot in tuber crops from three aspects: pathogenic factors, pathogenic mechanisms, and integrated control technologies, and analyzes the existing problems in current control practices, aiming to provide a theoretical reference for the green control of root rot in tuber crops.

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Disease Characteristics and Pathogen Diversity of Root Rot in Tuber Crops

Typical disease symptoms

Root rot is a root disease caused by single or complex infection by various soil-borne pathogens. Generally, pathogens invade through wounds on plant roots or stems, and seedlings and mature plants are more susceptible to infection. Most plants experience a latent development period after infection by pathogens. In the early stage, there are no abnormal manifestations in the aboveground parts, and the roots do not immediately show typical symptoms such as black rot. However, as the rot intensifies, the upper part of the plant cannot absorb nutrients and water, affecting normal physiological metabolic processes. Subsequently, the aboveground leaves turn yellow and fall off, and eventually the plant wilts and dies[3]. After different plant species are infected with root rot, their underground parts, such as roots, tuberous roots, tubers, and dormant buds, all rot and become necrotic. For example, plants such as potato, *A. macrocephala*, *G. elata*, and *B. striata* exhibit yellow to brown dry rot; plants such as *P. cyrtonema*, *P. ternata*, and lily exhibit yellow, brown, or black water-soaked rot; and plants such as *Panax notoginseng* exude white bacterial ooze from the diseased parts[4].

Main pathogen species

Fungal pathogens *Fusarium* spp. are the most widely distributed and most damaging pathogen group in root rot of tuber crops. Among them *Fusarium oxysporum* and *Fusarium solani* are the most common. *F. oxysporum* has a wide host range and strong pathogenicity, and can cause rot and necrosis in various tuber

crops such as *P. cyrtonema*[5], *A. macrocephala*[6], ginger[7], *Polygonatum odoratum*[8], *G. elata*[9], and potato[10]. *F. solani* is also a major pathogen of root rot, often forming complex infections with *F. oxysporum*, thereby exacerbating the severity of the disease. It is worth noting that the pathogen composition of root rot exhibits significant regional differences in the same tuber crop. Taking Chinese yam as an example, the main pathogens in Yuyang District, Yulin City, Shaanxi Province are *Humicola fuscoatra*, *Fusarium avenaceum*, and *F. oxysporum*[11]. *Colletotrichum alatae* is predominant in Sanming, Fujian Province. while *Fusarium chlamydosporum* and *F. solani* represent the main pathogenic species in Ya'an, Sichuan Province[12]. Similarly, the main pathogen of root rot in *A. macrocephala* in Guizhou, Chongqing, Hebei, and other regions is *F. oxysporum*. However, *Ceratobasidium* sp. was identified as a new pathogen in Enshi, Hubei Province[13], and *Fusarium lateritium* was reported as a new pathogenic species in Baoxing, Sichuan Province[14]. For root rot in ginger, reports in China indicate that *Pythium myriotylum* is predominant, whereas *Fusarium* spp. are the dominant pathogens in reports abroad. The pathogen composition of root rot in *G. elata* is more complex. In specific, the pathogen community in Zhaotong, Yunnan Province includes various pathogenic fungi such as *Ilyonectria robusta*, *Trichoderma hamatum*, *Clonostachys rosea*, *F. oxysporum*, *F. solani*, and *Rosellinia necatrix*[15], whereas in Kunming, Yunnan Province, *Verticillium albo-atrum* is predominant[16]. It can thus be seen that the differences in pathogenic fungi among production regions and the ubiquity of complex multi-pathogen infections further increase the difficulty of effective control of root rot in tuber crops.

Bacterial pathogens Compared with fungal diseases, there are relatively few reports of pathogenic bacteria causing root rot in tuber crops. However, bacteria often form complex infections with fungal pathogens, exacerbating the severity of disease occurrence. Among the reported bacterial diseases, *Pectobacterium carotovorum* subsp. *carotovorum* is the main pathogen of soft rot in *P. ternata*. This disease occurs commonly and seriously threatens the large-scale production of *P. ternata*. In the *P. ternata* production areas of Guizhou, this bacterium often forms complex infections with *F. oxysporum* and *F. solani*, accelerating root and tuber rot by degrading the pectin components of plant cell walls[17]. In addition, studies have shown that root rot of *P. ternata* in Qingshui, Gansu Province, is infected by *Erwinia* sp.[18]. *Dickeya dadantii* can cause stem base rot in sweet potato[19]. The mechanisms of complex infection between bacterial and fungal pathogens still require further systematic research.

Research Progress on Control Technologies for Root Rot in Tuber Crops

At present, the control of root rot in tuber crops mainly includes agricultural control, chemical control, and biological control. Among them, biological control is a method that has comparable control efficacy while causing little environmental pollution, and is consistent with the plant disease and pest control principle of "prevention first, integrated control". The occurrence of root rot is the result of the combined action of multiple factors. Therefore, reasonable plans must be formulated according to the specific causes of the disease, so as to effectively control the disease and produce safe, effective, stable, and controllable crops.

Agricultural control technologies

Agricultural control is a fundamental measure in the integrated management of root rot. It can reduce the risk of disease occurrence by optimizing the crop growth environment and reducing the pathogen population in the field.

Soil microecological regulation is an effective means of reducing the soil pathogen population. At present, commonly used soil disinfectants include chloropicrin, dazomet, and metam sodium. Dazomet fumigation of soils used for cultivating medicinal materials such as *P. notoginseng* and *Codonopsis pilosula* can reduce the proportion of pathogens, increase the abundance of beneficial bacteria, improve soil physicochemical properties, and promote plant growth and development[20-21]. However, due to constraints such as regional limitations, uncontrollable rainfall, and the high cost of large-scale soil disinfection, the application scope of soil fumigation is limited.

Optimizing the cropping system is a core measure of agricultural control. Crop rotation regulates the structure of soil microbial communities and effectively reduces the proportion of pathogenic fungi such as *Fusarium* through the enrichment of rhizosphere antagonistic microbial communities or the inhibitory effects of root exudates, thereby reducing disease occurrence. Studies have shown that *B. striata* rotation can recruit rhizosphere antagonistic bacteria against pathogens[22]. Rotation of *Astragalus membranaceus* with *Avena nuda* can inhibit the growth and reproduction of pathogens through antimicrobial substances in the root exudates of naked oat[23]. *P. cyrtonema* rotation can significantly reduce the abundance of pathogenic fungi such as *Fusarium* and *Ilyonectria* in the soil, while increasing the proportion of beneficial microbial groups such as *Bacillus* and *Lysobacter*, thereby optimizing the composition of the microbial community[24]. Optimizing the cropping system (such as crop rotation and intercropping) reshapes the rhizosphere microecological environment and continuously suppresses pathogen accumulation, making it the most fundamental and sustainable measure in agricultural control. However, constrained by climatic conditions, it is difficult to thoroughly control severely diseased fields merely by agricultural measures. Integrated application with chemical and biological control is urgently required to establish a comprehensive prevention and control system.

Chemical control technologies

At present, chemical control is the main means of preventing and controlling root rot. Commonly used chemical agents include carbendazim, thiram, mancozeb, hymexazol, and triazole fungicides. In terms of in vitro antifungal activity, the inhibition rates of 100 mg/L mancozeb against *F. solani* and *F. oxysporum* were 90.23% and 84.37%, respectively[25]. Carbendazim, flusilazole

· prochloraz and fludioxonil exhibited varying degrees of inhibitory effects against *F. solani*, *Fusarium equiseti*, *Fusarium acuminatum*, and *Fusarium virguliforme*[26]. Agents such as chlorothalonil, mancozeb, triadimefon, thiophanate-methyl, and metalaxyl all exhibited varying degrees of inhibitory effects on the growth and spore germination of the pathogen causing yellow stunt and root rot in *Astragalus adsurgens*[27]. In terms of compounded agents, 300 g/L difenoconazole · propiconazole showed good control efficacy against *F. oxysporum*[28], and propiconazole and iprodione · fluazinam have also been reported in the control of root rot in crops such as *A. macrocephala*, lily, *P. cyrtonema*, and potato.

However, current studies mostly focus on agent screening under in vitro conditions. There is often a notable discrepancy between in vitro bacteriostatic rates and actual field control efficacy, while less attention has been paid to field application performance and the optimization of pesticide application strategies. In addition, long-term single use of chemical agents can easily lead to problems such as pathogen resistance, deterioration of soil physicochemical properties, reduction of beneficial microorganisms, and environmental pollution. Therefore, although chemical control has advantages such as rapid efficacy and ease of operation, it does not meet the long-term needs of green ecological cultivation. Future research should shift toward high-efficiency, low-toxicity and environmentally friendly fungicides, and explore strategies for their synergistic application with biocontrol.

Biological control technologies

Biological control mainly uses beneficial microorganisms such as antagonistic bacteria, fungi, and actinomycetes to prevent and control plant diseases. Due to its advantages of being environmentally friendly and residue-free, it has become an important resource for the green control of root rot.

Antagonistic bacteria Biocontrol bacteria have advantages such as strong environmental adaptability, rapid reproduction, strong rhizosphere colonization ability, and sustained control efficacy. Among them, *Pseudomonas* and *Bacillus* are the most extensively studied genera. *Bacillus* is widely distributed and highly stress-tolerant, can stably colonize the plant rhizosphere, and exhibits both antifungal and growth-promoting effects. The endospore-forming trait renders it an optimal biocontrol strain[29-30]. Currently, the more extensively studied species include *Bacillus subtilis*, *Bacillus velezensis*, *Bacillus polymyxa*, and *Bacillus amyloliquefaciens*. *B. subtilis* can produce antibacterial substances such as bacteriocins, lipopeptides, and peptides, as well as volatile antifungal substances, inhibiting spore germination and mycelial growth. Meanwhile, it synthesizes plant growth hormones such as indole-3-acetic acid (IAA), thus possessing dual functions of antifungal activity and growth promotion[31-32]. In the disease control of tuber crops, Li *et al.*[33] found that *Bacillus kausophilus* and its crude lipopeptide extract can inhibit *F. oxysporum*, the pathogen of root rot in *P. cyrtonema*. Wang *et al.*[34] showed that when the fermentation broth concentration of *B. amyloliquefaciens* and *B. velezensis* was 200 ml/L, the inhibitory effects on mycelial growth of *Polygonatum* pathogens reached 33.05% and 33.52%, respectively. *B. subtilis* can inhibit the root rot pathogens of tuber crops such as *Polygonatum*, *A. macrocephala* and *P. odoratum*.

In addition, *Pseudomonas* is another important group of plant growth-promoting rhizobacteria. It possesses nitrogen fixation and phosphate-solubilizing functions, which can promote plant growth and inhibit pathogen activity[35]. *Pseudomonas putida* exhibited an inhibition rate as high as 71.27% against *Fusarium semitectum*, the pathogen of root rot in *A. macrocephala*[36].

In summary, antagonistic bacteria have broad application prospects in the prevention and control of root rot in tuber crops. However, current studies mostly focus on the screening of in vitro antibacterial activity, and further exploration is still needed in aspects such as large-scale fermentation processes, field colonization ability, and the stability of control efficacy.

Antagonistic fungi Antagonistic fungi are important microbial resources for the biological control of root rot, among which *Trichoderma* spp. are the most extensively studied and most widely applied. *Trichoderma harzianum*, *Trichoderma viride*, *Trichoderma koningii*, *T. hamatum*, and *Trichoderma longibrachiatum* exhibit good antagonistic activity against various plant pathogens[58]. *Trichoderma* can synergistically inhibit pathogens through multiple mechanisms such as competition for nutrients and space, mycoparasitism, and induction of plant resistance[59].

The wettable powder formulation of *T. harzianum* chlamydospores (applied by root drenching) achieved a field control efficacy of 70.32% against potato dry rot[60]. Zheng[62] *et al.* reported that *Penicillium oxalicum* and *Trichoderma asperellum* exhibited inhibition rates of 87.84% –93.14% against the root rot pathogens of *P. cyrtonema*. Among them, *T. asperellum* mainly inhibited pathogens through the dual effects of competition and antagonism, whereas *P. oxalicum* primarily relied on nutrient competition. In the prevention and control of root rot in tuber crops, Jiang *et al.*[62] showed that *T. harzianum* had a significant inhibitory effect on the pathogenic mycelium of ginger, with an inhibition rate of 86.33%, and could significantly promote the plant height growth of ginger. In addition, *Penicillium funiculosum* exhibited inhibitory effects against *Fusarium* pathogens of potato root rot[63]. In addition, endophytic fungi, as an important class of microbial resources, are rich in species and possess multiple functions for plants such as nitrogen fixation, growth promotion, and resistance to pests and diseases[64]. In recent years, they have also attracted widespread attention in the biological control of root rot in tuber crops. The endophytic fungi *Penicillium citrinum* and *Penicillium canescens* isolated from the rhizomes of *P. cyrtonema* exhibited inhibition rates of 73.2% and 70.2%, respectively, against root rot pathogens[65-66]. The endophytic fungus *Phomopsis* sp. from *A. macrocephala* showed inhibition rates of 77.5%, 74.3%, and 70.4% against *F. oxysporum*, *F. solani*, and *Fusarium incarnatum*, respectively[67] (Table 3).

In summary, antagonistic fungi show good potential in the prevention and control of root rot in tuber crops. Among them, the

industrial application of *Trichoderma* is the most mature, while the resource exploration and functional verification of endophytic fungi are still in the initial stage. Compared with bacterial biocontrol agents, fungal biocontrol agents still face challenges in formulation development and field stability.

Table 1 Antagonistic bacteria for controlling root rot of rhizome and tuber crops

Crops	Antagonistic bacteria	Pathogen	References
Polygonatum spp.	*Bacillus cabrialesii*	*F. oxysporum*	[33]
	B. velezensis, *B. amyloliquefaciens*	*F. oxysporum*	[34]
	B. subtilis	*F. oxysporum*	[37]
	B. velezensis	*F. oxysporum*	[38]
A. macrocephala	*Serratia* sp. *FS14*	*F. oxysporum*	[39]
	B. velezensis	*F. oxysporum*, *F. solani*	[40]
	B. subtilis	*Ceratobasidium* sp.	[41]
	B. subtilis	*F. oxysporum*	[42]
	P. putida	*F. oxysporum*, *F. incarnatum*	[36]
Ginger	*B. velezensis*	*Neocosmospora rubicola*, *Fusarium fujikuroi*	[43]
	B. amyloliquefaciens	*F. solani*	[44]
	Bacillus paralicheniformis	*P. myriotylum* Drechsler	[45]
	Paenibacillus polymyxa, *B. vallismortis*	*P. myriotylum* Drechsler	[46]
Chinese yam	*Bacillus tequilensis*	*F. solani*, *F. arcuatisporum*	[47]
P. odoratum	*B. subtilis*	*F. oxysporum*, *F. redolens*	[48]
P. ternata	*Brevibacillus brevis*	*Pectobacteriumcarotovorum* subsp. *carotovorum*, *F. oxysporum*, *F. solani*	[49]
	Pantoea ananatis, *Myroides odoratimimus*, *P. putida*	*Pectobacteriumcarotovorum* subsp. *carotovorum*	[17]
	Bacillus megaterium	*Pectobacteriumcarotovorum* subsp. *carotovorum*	[50]
Potato	*P. polymyxa*	*Fusarium sambucinum*, *F. solani*, *F. oxysporum*, *F. acuminatum*, *Fusarium dimerum*	[51]
	Bacillus siamensis	*F. solani*	[52]
	Bacillus methylotrophicus	*Alternaria solani*, *Botrytis cinerea*, *F. sambucinum*, *Rhizoctonia solani*, *Alternaria alternata*	[53]
	Bacillus vallismortis, *B. amyloliquefaciens*, *Bacillus methylotrophicus*	*F. solani*	[54]
	Halobacillus trueperi	*F. acuminatum*, *F. solani*	[55]
	Bacillus pumilus	*F. acuminatum*, *F. solani*	[56]
	Bacillus atrophaeus	*F. sambucinum*, *F. solani*	[57]

Table 2 Antagonistic fungi for the control of root rot in tuber crops

Crops	Antagonistic fungus	Pathogen	References
Polygonatum spp.	*Trichoderma virens*, *Phlebiopsis gigantea*	*F. oxysporum*	[34]
	P. citrinum	*F. oxysporum*	[65]
	P. oxalicum, *T. asperellum*	*F. oxysporum*, *F. solani*, *Colletotrichum* sp.	[61]
	P. canescens	*F. oxysporum*	[66]
Potato	*P. funiculosum*	*F. oxysporum*, *F. sambucinum*, *F. solani*, *F. equiseti*, *F. acuminatum*	[63]
	Chaetomium globosum, *C. funicola*	*F. oxysporum*	[68]
	T. harzianum	*F. solani*, *F. sambucinum*	[60]
Ginger	*T. harzianum*	*F. oxysporum*	[62]
	T. harzianum, *T. viride*, *Penicillium* spp.	*P. myriotylum* Drechsler	[69]
A. macrocephala	*Trichoderma brevicompactum*	*F. oxysporum*	[70]
	Phomopsis sp.	*F. oxysporum*, *F. solani*, *F. incarnatum*	[67]

Antagonistic actinomycetes Actinomycetes are one of the microbial groups richest in active secondary metabolites, with approximately 70% of known microbially derived antimicrobial active substances originating from actinomycetes[71]. In the biological control of plant root rot, the genus *Streptomyces* has been studied the earliest and applied the most widely. *Streptomyces* mainly inhibits pathogens through the following mechanisms: ① secreting chitinase and β-1,3-glucanase to degrade fungal cell walls; ② producing siderophores to compete for rhizosphere iron nutrition; and ③ inducing systemic defense responses in host plants. Some

strains can also secrete growth-promoting substances such as indole-3-acetic acid (IAA) and ACC deaminase, and exhibit dual functions of antifungal activity and growth promotion[72].

Li *et al.*[73] showed that *Streptomyces globisporus* exhibited inhibition rates of 31.36%, 25.41%, and 19.32% against *F. solani*, *R. solani*, and *A. solani*, respectively. Although it possessed antifungal activity, the activity was relatively weak. *Streptomyces hygroscopicus* JY-22SFB showed inhibition rates of 74.5% and 100% against mycelial growth and spore germination of the potato dry rot pathogen, respectively[74]. *S. globisporus* exhibited a significant inhibitory effect against the potato dry rot pathogen. The inhibition zone was 5.03 cm in primary plate screening, and the inhibition rate of fermentation filtrate reached 54.45% in secondary screening. Its fermentation broth could suppress lesion expansion on potato tubers, with a control efficacy of 65.45% against potato dry rot[75]. In addition, *Streptomyces polychromogenes*, *S. globisporus* subsp. *globisporus* and *Streptomyces rubiginosohelvolus* possess both disease-resistance and growth-promoting effects, making them potential biocontrol resources for the control of potato dry rot[76].

In summary, actinomycetes show good application prospects in the prevention and control of root rot in tuber crops. However, current research still focuses mainly on in vitro screening for antifungal activity, and further exploration is still needed in aspects such as large-scale fermentation processes, soil colonization ability, and field control efficacy stability. It is worth noting that existing studies are mostly concentrated on potato, and the exploration of actinomycete biocontrol resources in other food tuber crops (such as cassava and sweet potato) and medicinal tuber crops (such as *P. cyrtonema* and *A. macrocephala*) still needs to be strengthened. Compared with bacterial and fungal biocontrol agents, the industrialization process of actinomycetes is relatively lagging, and the development and application strategies of their formulations will be important directions for future research.

Table 3 Antagonistic actinomycetes for the control of root rot in tuber crops

Crops	Antagonistic actinomycetes	Pathogen	References
Potato	*S. globisporus*	*F. solani*, *R. solani*, *A. solani*	[73]
	S. hygroscopicus	*F. solani*	[74]
	S. globisporus	*F. solani*	[75]
	S. polychromogenes 1, *S. globisporus* subsp. Globisporus, *S. rubiginosohelvolus*	*F. solani*	[76]
Cassava	*Streptomyces malaysiensis*	*Phytophthora* sp.	[77]

Conclusions and Prospects

Root rot in tuber crops is a highly destructive soil-borne disease caused by fungi such as *Fusarium* spp. and a small number of bacteria. Among them, *Fusarium* spp. are the most widely distributed and most damaging, with *F. oxysporum* and *F. solani* being the dominant pathogenic species in this genus. However, the pathogen composition varies significantly among different crops and production regions, and complex multi-pathogen infections are widespread, significantly increasing the difficulty of control. At the level of control technologies, agricultural control serves as the foundation and has the advantage of being environmentally friendly, but single measures have limited efficacy. Although chemical control takes effect quickly, long-term single use of chemicals can easily lead to resistance and ecological problems, which is not consistent with the direction of green agriculture. Biological control has enormous potential, but its field efficacy stability and degree of industrialization still need to be improved. Among them, biological control has become the most promising direction in root rot prevention and control research due to its advantages of being environmentally friendly, highly targeted, and not prone to inducing resistance. Particularly, antagonistic microorganisms such as *Bacillus*, *Trichoderma*, and *Streptomyces* have shown good application prospects in inhibiting pathogens and promoting plant growth. However, there are still the following shortcomings in existing research. (1) There is insufficient systematic monitoring of the pathogen population structure of root rot in tuber crops, and most studies focus on a single production region or a single pathogen. Studies concerning pathogen distribution and succession patterns at the national scale are scarce. (2) Biocontrol strains mostly remain at the stage of laboratory screening and in vitro activity evaluation. Their colonization ability, control efficacy stability and large-scale application technologies in complex field ecological environments are not yet mature, and the degree of industrialization is relatively low. (3) Chemical control research is dominated by in vitro fungicide screening. Systematic studies on field application strategies, timing optimization and fungicide combination technology are relatively insufficient. And (4) the integration of comprehensive control technologies is insufficient, and regionspecific "agricultural + chemical + biological" collaborative management schemes and standard operating procedures are unavailable. Looking ahead, the sustainable management of root rot in tuber crops should focus on the following directions. First, efforts should be made to strengthen dynamic monitoring and succession pattern research on the population structure of root rot pathogens in major producing areas, so as to provide scientific support for precise disease control. Second, the industrial development of biocontrol agents should be promoted. Key technical bottlenecks including large-scale strain fermentation, formulation processing and enhanced field colonization need to be addressed. Third, a regional integrated disease management system centered on biocontrol should be established on the basis of agricultural control and supplemented by chemical control. Corresponding standard operating procedures should be

formulated. Fourth, the exploration of disease-resistant germplasm resources and disease resistance breeding research should be enhanced. The inherent disease resistance of varieties can be improved at the genetic level to reduce the risk of disease occurrence at the source. Fifth, research on the interaction mechanism between pathogens and hosts should be deepened. Key pathogenic factors and plant immune response pathways need to be clarified to offer theoretical support for discovering new biocontrol targets and designing disease resistance strategies. Through multidisciplinary integration and technological innovation, the prevention and control of root rot in tuber crops should be promoted toward green, precise, and sustainable development. This provides solid support for ensuring food security, promoting the healthy development of cash crop industries and maintaining the sustainable supply of traditional Chinese medicinal resources.

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