

REVIEW ARTICLE

POTATO DRY ROT DISEASE: SYMPTOMS AND ETIOLOGY, PATHOGEN DIVERSITY, ASSOCIATED MYCOTOXINS AND THEIR IMPACT ON HUMAN AND ANIMAL HEALTH

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Abstract: The world's potato crop is seriously threatened by *Fusarium* species that cause potato dry rot (PDR) disease. The crop stand is impacted by this soil- and seed-borne diseases because the pathogens inhibit potato sprouts development and cause severe tuber rots. Dry rot is indicated by sunken, wrinkled brown to black tissue areas with concentric rings on tubers. The pathogens infect potato tubers through the wounds. Although soil contaminated with *Fusarium* spp. is also a source of inoculum, the seed tuber is thought to be the primary source of inoculum. The diversity of the globally recognised, PDR causing 18 *Fusarium* species varies depending on the climate and geographic location. The pathogens produce different mycotoxins and the mycotoxins associated with PDR possess a serious threat to human and animal health when entered body through consumption of toxin contaminated food. This review provides a comprehensive overview of potato dry rot disease, covering its symptoms and etiology, pathogen diversity, mycotoxins associated with the disease and the impact of mycotoxins on human and animal health. The information detailed herein aims to improve the understanding about the current status and the significance of potato dry rot disease.

Keywords: *Fusarium* diversity, Mycotoxin toxicity, Post harvest disease, Potato tuber rot

INTRODUCTION

The potato (*Solanum tuberosum* L.), which comes in fourth place among food crops worldwide after rice, wheat, and maize, is a significant non-cereal crop for human consumption. Potato cultivation as a cash crop in areas with high rates of hunger and malnutrition, combined with their diverse distribution pattern, make potatoes a global crop for sustainable food availability (Haverkort *et al.*, 2013). In addition to being a wealth of macronutrients like carbohydrates and dietary fiber and a great source of micronutrients like vitamins and minerals, potatoes are also a significant source of antioxidants for people's diets and contribute significantly to preserving food security in developing nations (Liu *et al.*, 2022, FAOSTAT 2022). In 2023, India, the second-largest potato grower in the world, produced 59.74 million metric tons of potatoes. The nation's output has been increasing every day due to the expanding human population and their greater demand for food. However, biotic agents are the main barrier to the development of healthy seeds. The line of healthy potato seed development has significant biotic factor hurdles as a result of increased potato output to meet the growing population food demand. There are currently around 40 pathogens including bacteria, viruses, nematodes,

fungi, and insects known to cause significant harm in various potato-growing regions and their infections pose a significant threat to the quality of potato tubers, which can lead to up to 22% of potato losses in the production system, either directly or indirectly (Kumar *et al.*, 2020).

However, bacterial pathogens are the main causes of potato soft rots, potato dry rot is caused by the fungal pathogens belonging to the genus *Fusarium*. In contrast to soft rot, dry rot causes non-slimy lesions and causes the potato tuber to shrivel and shrink, exposing interior tissue and leaving a dark, depressed spot on the outside. During storage, fungal infections can spread up to 60% and potato sprout development is impeded, leading to losses of up to 25% (Wharton *et al.*, 2007; Al-Mughrabi 2010). At least 18 species of *Fusarium* have been reported globally to be associated with the potato dry rot (PDR) disease and they produce diverse groups of mycotoxins which impart a serious threat to human and animal health when entered the body through food chain (Kumar *et al.*, 2020; Xue *et al.*, 2023).

Symptoms and etiology of potato dry rot disease: Sunken tissue with a dry, leathery look and a wrinkled, dark appearance are the predominant signs of *Fusarium* spp. infection on potato tubers (Xue *et al.*, 2023). Roots and tubers are the main parts of potato plants that are affected directly by dry rot

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pathogens. It is typical for tubers and roots to exhibit a pattern of shrivelling and shrinkage coupled with the formation of lesions on their exterior (Tiwari *et al.*, 2020). After about a month of storage, the first signs of *Fusarium* dry rot on tubers manifest as shallow, little brown lesions at the wound sites. The periderm gradually sinks and may wrinkle in concentric rings as the underlying dead tissue desiccates, causing the lesions to expand in all directions (Bojanowski *et al.*, 2013). The internal tissues also experience the brown or black decay at the same time. The pathogens enter the tubers mainly through the wounds, where internal tissue starts rotting that ultimately results in whitish, brick orange, brownish or blackish tissue. Necrotic lesions on the damaged roots of potato indicate the indirect influence of infection (Tiwari *et al.*, 2020). When dry rot disease is severe, the potatoes may entirely decompose, giving them a mushy texture and an unpleasant smell. In order to stop potato dry rot from

spreading further and to save financial losses, it is crucial to recognize and treat the condition (Xue *et al.*, 2023).

Being hemi-biotrophs, the majority of *Fusarium* species live in soil as resistant spores or inside decaying plant tissues. In the field, soil and seed-borne inoculum may infect the plants, but storage is where most damage occurs and the seed tuber is thought to be the primary source of inoculum (Dean 1994, Bojanowski *et al.*, 2013). Only when the potato skin is punctured can the pathogens infect the potato tuber, as they are incapable of doing so through the lenticels or in the absence of wounds. The pathogen gets entry into the tuber through wounds and penetrates through intercellular spaces; some may kill the host cells and grow in the intracellular region. While the pathogens are mesophilic in nature, some may survive below 5°C and cause dry rot during storage at low temperature (Bojanowski *et al.*, 2013).

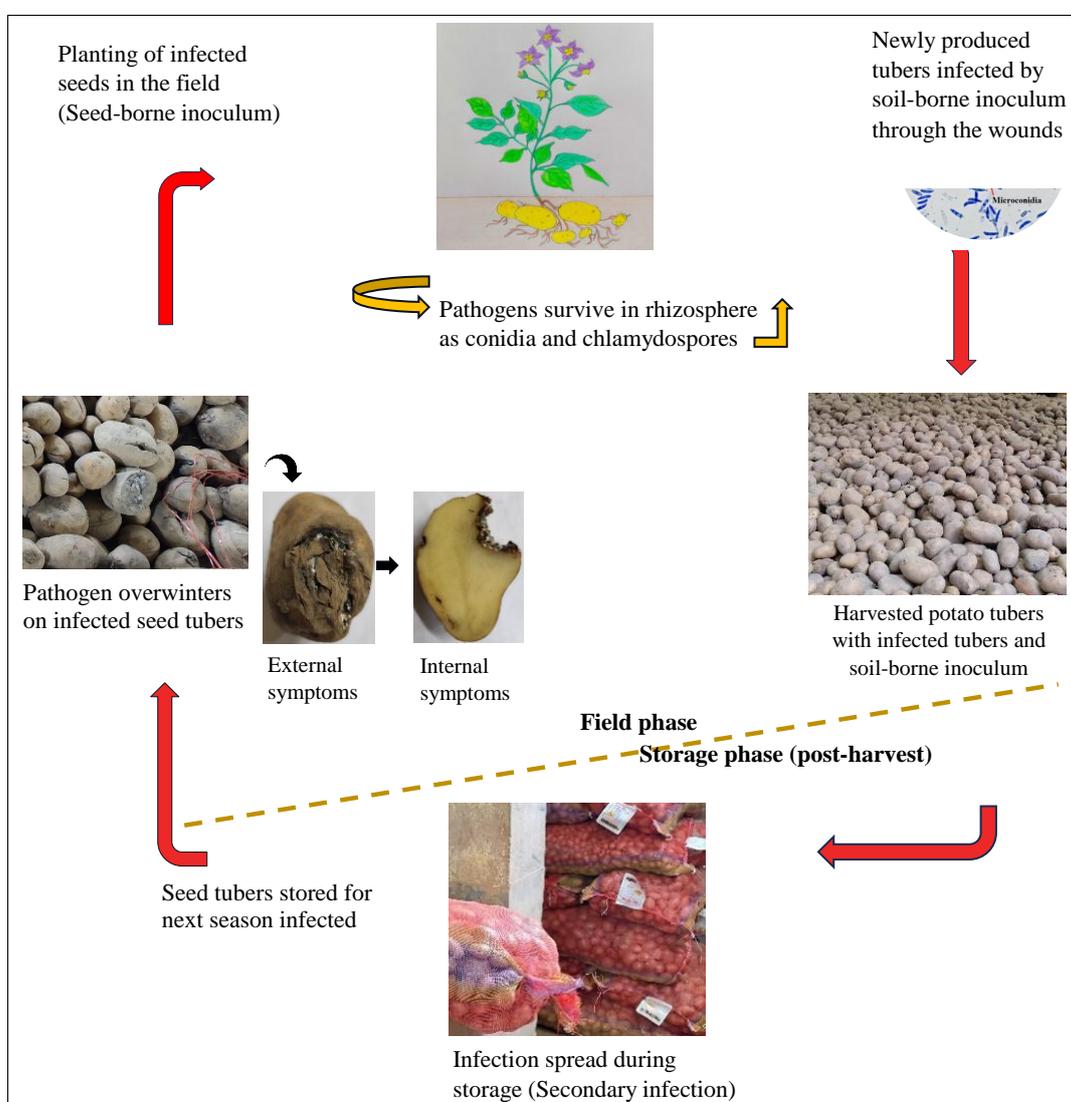


Figure 1. Disease cycle of potato dry rot disease consisting of field phase and post-harvest storage phase. Soil-borne inoculum (conidia and chlamydo spores) infects the newly produced potato tubers. In post-harvest phase, inoculum from infected tubers infects the healthy tubers during storage and causes severe rot.

Diversity of *Fusarium* species causing potato dry rot:

One of the most destructive phytopathogenic fungus in the world is certainly *Fusarium* species which affects almost every crop that is farmed, including potatoes. There are at least 18 *Fusarium* species known to be responsible for potato dry rot (PDR) disease globally which include *F. oxysporum*, *F. sambucinum*, *F. avenaceum*, *F. graminearum*, *F. solani*, *F. acuminatum*, *F. proliferatum*, *F. equiseti*, *F. culmorum*, *F. crookwellense*, *F. coeruleum*, *F. incarnatum*, *F. sulphureum*, *F. semitectum*, *F. sporotrichioides*, *F. scirpi*, *F. vertical* and *F. tricinctum*. To find new species implicated in the disease, more surveys and sampling are required as this number is still not all-inclusive (Tiwari *et al.*, 2020; Xue *et al.*, 2023).

Based on geographic area and prevailing climatic conditions, *F. oxysporum*, *F. solani*, and *F. sambucinum* are the most common and damaging species of *Fusarium* responsible for potato dry rot (Stefańczyk *et al.*, 2016). *F. sambucinum* and *F. coeruleum* are the two most common fungi responsible for potato dry rot in the USA (Secor and Salas, 2001) and Great Britain (Peters *et al.*, 2008) respectively. *F. avenaceum* and *F. culmorum* are minor rot-causing fungi. Still, according to a number of reports, *F. sulphureum* is the most common fungus in North America and Europe (Recep *et al.*, 2009, Gachango *et al.*, 2012). In South Africa the main fungi responsible for the dry rot in potato are *F. solani* and *F. oxysporum* (Theron and Holz, 1990). Iran's most common potato cultivars have been shown to be more prone to dry rot by *F. sulphureum* and *F. solani*. Fascinatingly, reports indicate that the predominant dry rot agent in North Dakota, Tunisia, and Canada is the cereal fungus *F. graminearum* (Daami-remadi *et al.*, 2012; Tiwari *et al.*, 2020). More recently, in our previous study, five fungal isolates of *Fusarium* (*F. oxysporum*, *F. sambucinum* and *F. avenaceum*) and a fungal isolate of *Geotrichum candidum* have been reported as the causal agent of potato dry rot in West Bengal state of India (Ahammed and Datta, 2025; Ahammed and Datta, 2026).

Mycotoxins associated with potato dry rot:

Mycotoxins produced by phytopathogenic fungi are secondary fungal metabolites that interfere with metabolism and cellular processes and ultimately to kill living host cells by rupturing membrane integrity. The host tissue may experience morphological, physiological, and metabolic changes as a result of these mycotoxins. The accumulation of several mycotoxins is linked to *Fusarium*-induced dry rot of potatoes. The mycotoxin fusaric acid inhibits the host tissue's peroxidase and polyphenol oxidase activities and decreases periderm growth by

inhibiting steroid glycoalkaloids, which contributes to the start of potato dry rot disease (El-Hassan *et al.*, 2007, Ismaiel and Papen brock 2015). Under the condition of suitable temperature and humidity, toxigenic fungi can produce several mycotoxins that could be harmful to human and animal health (Xue *et al.*, 2023). These *Fusarium* mycotoxins, which fall into two categories—trichothecene and non-trichothecene—have been found in a variety of host plants infected by this pathogen. The trichothecenes are sesquiterpenes, which are responsible for phytotoxicity in host plants and mycotoxicosis in both humans and animals (Bojanowski *et al.*, 2013; Nagaraja *et al.*, 2016). More than 190 known trichothecenes have been identified till date. Based on variations in their chemical structures, trichothecenes are categorized into four groups: A, B, C, and D. The non-macrocytic trichothecenes, produced by *Fusarium* species that infect potato and cereal crops, are mostly classified as type A (which contains diacetoxyscirpenol [DAS] and T-2 toxin) and type B (which includes nivalenol [NIV] and deoxynivalenol [DON]) (Delgado *et al.*, 2010). As has been previously reported, a large number of *Fusarium* species that cause dry rot (*F. oxysporum*, *F. sambucinum*, *F. graminearum*, *F. coeruleum* and *F. equiseti*) produce trichothecenes NIV, T-2 toxin, DON and DAS in the tissues of rotting potato tubers (Bojanowski *et al.*, 2013; Eranthodi *et al.*, 2020).

The main non-trichothecene mycotoxins produced by *Fusarium* in dry rotted potato tubers are zearalenones (ZEA), beauvericin (BEA), fumonisins (FUM), sambutoxin (SAM), fusaric acids (FA), fusarin C (FUS), and enniatins (ENN) (Song *et al.*, 2006; Bojanowski *et al.*, 2013; Tiwari *et al.*, 2020; Eranthodi *et al.*, 2020; Hadjebar *et al.*, 2024). Dry rotting potato tubers infected with *F. oxysporum* were shown to contain beauvericin (BEA) and enniatins (ENN), which have antibacterial, insecticidal, phytotoxic, and cytotoxic qualities (Song *et al.*, 2006). Potato tubers infected with *F. sambucinum*, *F. solani*, and *F. oxysporum* showed contamination of Zearalenone (ZEA) and Fusarin C (FUS) (Golinski *et al.*, 1998). When Potato tubers are dry rotted due to infection by *F. oxysporum*, *F. equiseti* and *F. sambucinum*, fumonisin (FUM) toxin accumulation has been found. Fusaric acid (FA) is produced in potato tubers infected with *F. oxysporum*, and there is a positive correlation between the incidence of dry rot and FA content (El-Hassan *et al.*, 2007). In our recent study, potato dry rot causing *F. avenaceum* has reported for the first time to produce the trichothecene mycotoxin Deoxynivalenol (DON) and non-trichothecene mycotoxins like zearalenones (ZEA), sambutoxin (SAM), Fusaric acid (FA) and Fusarin C (FUS) (Ahammed and Datta, 2025).

Table 1. The major trichothecene and non-trichothecene mycotoxins produced by *Fusarium* species associated with potato dry rot disease

Toxins	Chemical formula	<i>Fusarium</i> species	References
Trichothecene toxins			
T-2 toxin	C ₂₄ H ₃₄ O ₉	<i>F. oxysporum</i> , <i>F. equiseti</i> , <i>F. graminearum</i> , <i>F. sambucinum</i> , <i>F. sporotrichiodes</i> , <i>F. langsethiae</i>	El-Hassan <i>et al.</i> , 2007; Eranthodi <i>et al.</i> 2020
HT-2 toxin	C ₂₂ H ₃₂ O ₈	<i>F. coeruleum</i> , <i>F. sambucinum</i> , <i>F. sporotrichiodes</i> , <i>Fusarium langsethiae</i>	Desjardins and Gardner, 1989
Nivalenol	C ₁₅ H ₂₀ O ₇	<i>F. culmorum</i> , <i>F. equiseti</i> , <i>F. graminearum</i> , <i>F. sambucinum</i> , <i>F. crookwellense</i> , <i>F. sporotrichiodes</i>	Nielsen and Thrane, 2001; Delgado <i>et al.</i> , 2010; Eranthodi <i>et al.</i> , 2020
Deoxynivalenol	C ₁₅ H ₂₀ O ₆	<i>F. culmorum</i> , <i>F. coeruleum</i> , <i>F. sambucinum</i> , <i>F. graminearum</i> , <i>F. oxysporum</i> , <i>F. sporotrichiodes</i> , <i>F. equiseti</i> , <i>F. avenaceum</i>	Delgado <i>et al.</i> , 2010; Eranthodi <i>et al.</i> 2020; Ahammed and Datta, 2025
3-acetyldeoxynivalenol	C ₁₇ H ₂₂ O ₇		
15-acetyldeoxynivalenol	C ₁₇ H ₂₂ O ₇		
Neosolaniol	C ₁₉ H ₂₆ O ₈	<i>F. sambucinum</i> , <i>F. sporotrichiodes</i>	Nielsen and Thrane, 2001
Fusarenone	C ₁₇ H ₂₂ O ₈	<i>F. culmorum</i> , <i>F. equiseti</i> , <i>F. graminearum</i> ,	Nielsen and Thrane, 2001
4-acetyl-monoacetoxyscirpenol, 15-acetyl-monoacetoxyscirpenol Diacetoxyscirpenol	C ₁₇ H ₂₄ O ₆ C ₁₇ H ₂₄ O ₆ C ₁₉ H ₂₆ O ₇	<i>F. equiseti</i> , <i>F. sambucinum</i> <i>F. sulphureum</i> , <i>F. solani</i>	Nielsen and Thrane, 2001; El-Hassan <i>et al.</i> , 2007; Xue <i>et al.</i> , 2013; Eranthodi <i>et al.</i> , 2020
Non-trichothecenotoxins			
Beauvericin	C ₄₅ H ₅₇ N ₃ O ₉	<i>F. sambucinum</i> , <i>F. equiseti</i> , <i>F. oxysporum</i> , <i>F. acuminatum</i> , <i>F. avenaceum</i>	Song <i>et al.</i> , 2006
Enniatins	C ₃₃ H ₅₇ N ₃ O ₉	<i>F. acuminatum</i> , <i>F. avenaceum</i> , <i>F. oxysporum</i> , <i>F. sambucinum</i> , <i>F. scirpi</i>	Song <i>et al.</i> , 2006
Zearalenones	C ₁₈ H ₂₂ O ₅	<i>F. crookwellense</i> , <i>F. equiseti</i> , <i>F. solani</i> , <i>F. graminearum</i> , <i>F. oxysporum</i> , <i>F. sambucinum</i> , <i>F. sporotrichiodes</i> , <i>F. avenaceum</i>	Golinski <i>et al.</i> , 1998; El-Hassan <i>et al.</i> , 2007; Alwan <i>et al.</i> , 2020; Ahammed and Datta, 2025
Sambutoxin	C ₂₈ H ₃₉ NO ₄	<i>F. sambucinum</i> , <i>F. oxysporum</i> , <i>F. avenaceum</i>	Kim and Lee, 1994; Ahammed and Datta, 2025
Fumonisin	C ₃₄ H ₅₉ NO ₁₅	<i>F. sambucinum</i> , <i>F. equiseti</i> , <i>F. oxysporum</i>	El-Hassan <i>et al.</i> , 2007
Fusaric acid	C ₁₀ H ₁₃ NO ₂	<i>F. sambucinum</i> , <i>F. crookwellense</i> , <i>F. solani</i> , <i>F. oxysporum</i> , <i>F. avenaceum</i>	Venter <i>et al.</i> , 1998; El-Hassan <i>et al.</i> , 2007; Ahammed and Datta, 2025
Fusarin C	C ₂₃ H ₂₉ NO ₇	<i>F. sambucinum</i> , <i>F. sulphureum</i> , <i>F. solani</i> , <i>F. crookwellense</i> , <i>F. oxysporum</i> , <i>F. avenaceum</i>	Golinski <i>et al.</i> , 1998; Stefańczyk <i>et al.</i> , 2016; Ahammed and Datta, 2025

Impact of mycotoxins on human and animal health:

Mycotoxins build up on distant, seemingly healthy tissues in addition to the decaying tissues of the infected potato tubers and these mycotoxins could be harmful to human and animal health. DON is the most common mycotoxin found in the rotting tissues of potato tubers. Since DON is enzymatically transformed into NIV in the rotten potato tissue, it is typically found in conjunction with NIV (Delgado *et al.*, 2010). While trichothecene mycotoxin DON, commonly called vomitoxin, is a strong protein synthesis inhibitor that suppresses the immune system and results in dysphagia. Ingestion of DON mycotoxin can result in both immediate and long-term damage. Abdominal pain, intestinal damage, nausea, dizziness, headache, anorexia, diarrhea, increased salivation, vomiting, and malaise are examples of acute symptoms. Anorexia, weight loss, and changes in dietary efficacy are the most frequent

consequences of long-term DON exposure. It causes epithelial cell cycle arrest at G₂/M and G₀/G₁ phase, micronucleus induction, DNA damage (Kamle *et al.*, 2022). Mycotoxin NIV has cytotoxic and immunotoxic effects, destroys thymus and bone marrow cells, and lowers peripheral blood lymphocyte counts by apoptosis (Kumar *et al.*, 2022). T-2/HT-2 toxin produces oxidative damage, aberrant immunoglobulin alterations, mitochondrial malfunction, and teratogenic, cytotoxic, and hematotoxic effects (Meneely *et al.*, 2023). Zearalenone inhibits the synthesis of follicle stimulating hormones, suppresses ovarian follicle maturation, and results in reproductive abnormalities by competitively binding to estrogen receptors. Through the G protein-coupled estrogenic receptor, a low dose of zearalenone increased the proliferation of colon cancer cells (Lo *et al.*, 2021). Sambutoxin has hematotoxic effects, causes apoptosis and cell cycle halt, and alters mitochondrial respiration

(Kimet *et al.*, 1994). Fusarin C, a polyketide mycotoxin generated by PDR pathogens, has a mutagenic effect and disrupts mammalian chromosomes. Due to its carcinogenic effects, Fusarin C stimulates Breast cancer *in-vitro* and is associated with esophageal cancer (Sondergaard *et al.*, 2011). Fumonisin is a polyketide mycotoxin that causes esophageal carcinoma, kidney and liver tumors, neurotoxic, hepatotoxic, and immunotoxic effects, deregulates calcium homeostasis, and interferes with sphingolipid metabolism (Kamle *et al.*, 2019).

CONCLUSION

Fusarium dry rot is one of the most damaging forms of potato decay that lowers tuber quality, causes financial losses, and contaminates tubers with mycotoxin. There are 18 species of *Fusarium* that cause potato dry rot worldwide, and the genetic diversity varies depending on the geographical regions and climatic variations. The frequency and aggressiveness of *Fusarium* strains that cause dry rot in a location-specific manner are also influenced by the dominant cultivars and environmental conditions. The mycotoxins associated with the potato dry rot impart a serious threat to human and animal health when entered the body through food chain.

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