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SUSTAINABLE POTATO PEST AND DISEASE MANAGEMENT: GLOBAL INNOVATIVE PRACTICES WITH A FOCUS ON ROMANIA

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Abstract

Potato crops worldwide face significant challenges from pests and diseases that impact yield, quality, and economic value. This paper provides a comprehensive overview of current pest and disease pressures on potato production, focusing on both global and Romanian contexts. Key pests and pathogens, including the late blight, early blight, dry rot, potato virus Y or Colorado potato beetle are addressed, with discussions on their biology, epidemiology, symptomatology, and economic impacts. For each pest and disease, various control strategies are explored, emphasizing cultural practices as effective, low-cost preventive measures. Detailed tables summarize successful biological, chemical, and plant extract-based treatments. Additionally, the review highlights the importance of selecting resistant varieties and identifies proven chemical treatments for effective management. Through an integrated approach combining cultural, biological, and genetic methods, this paper underscores the critical role of sustainable practices and ongoing innovation in managing pests and diseases in potato crops.

Key words: *potato crop, pest, disease, IPM, Romania.*

INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the world's most vital staple crops, playing a crucial role in global food security. It ranks worldwide as the sixth most significant food crop (0.9 billion tons – roots and tubers) after cereal crops, sugar crops, vegetables, oil crops and fruit (FAO, 2023). Potatoes are a primary source of carbohydrates, vitamins, and minerals, particularly vitamin C, potassium, and dietary fiber (Górska-Warsewicz et al., 2021). Due to its adaptability to diverse climates and soils (Chun-ling et al., 2015), the potato is cultivated in over 150 countries, making it a cornerstone of both subsistence farming and commercial agriculture, serving also as a vital alternative to major cereal crops in feeding the global population (Haas et al., 2009). Its versatility extends beyond direct consumption, contributing to various processed foods and industrial products, thereby supporting economies and livelihoods across the globe. The crop's importance is underscored by its ability to produce high yields in a relatively short growing season, making it a key player in addressing global challenges related to food availability and agricultural sustainability.

Potato crop production is constantly put under pressure by pests and diseases, which can cause annual losses of up to $6.7 billion due to late blight disease, caused by *Phytophthora infestans* (Haas et al., 2009). While pesticides can pose environmental risks, their careful and precise use, through targeted application, integrated pest management (IPM) strategies, and adherence to best practices, can significantly minimize these impacts. However, social pressure on pesticide use in agriculture has been growing due to increasing awareness of the environmental and health impacts associated with chemical pesticides. Concerns about soil degradation through affecting community of organisms (Tripathi et al., 2020), water contamination (Syafrudin et al., 2021) loss of biodiversity (Sánchez-Bayo & Wyckhuys, 2019), and the health risks to farmers (Islam et al., 2022) and consumers (Ssemugabo et al., 2023) have led to a demand for more sustainable farming practices. This societal push necessitates the adoption of new Integrated Pest Management (IPM) approaches, which emphasize reducing chemical use through a combination of biological controls, cultural practices, and technological innovations.

The area required for producing seed potatoes in Romania initially included 5 regions: Hărman and Râşnov in Braşov County, Ciuc and Lăzarea in Harghita County, Suceava in Suceava County, Târgu Secuiesc in Covasna County, and Neamţ in Neamţ County (Figure 1).

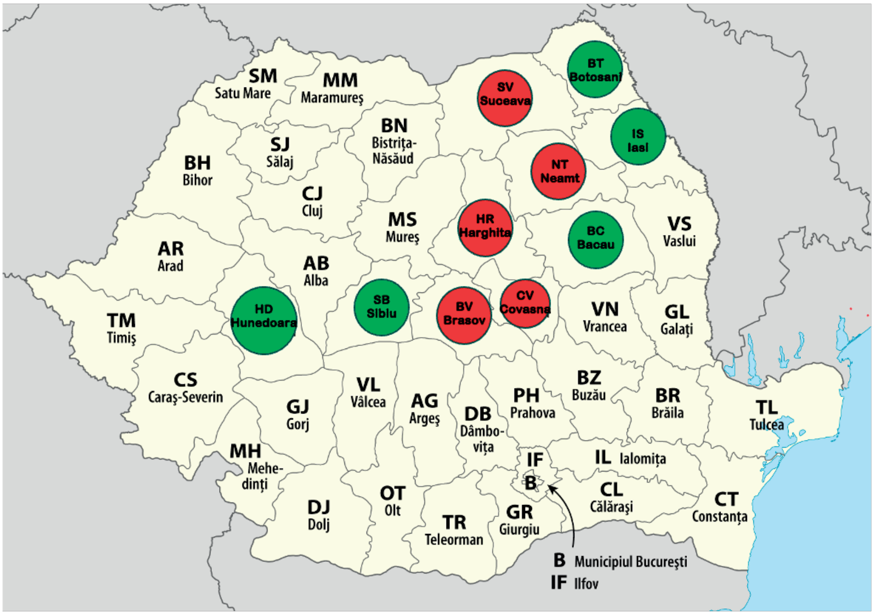

Figure 1. Most important regions in Romania for potato seed production

Subsequently, it expanded to include areas in Botoşani, Bacău, Iaşi, Sibiu, and Hunedoara counties, particularly in moist and cold regions. Yet, in the past two decades, Romania's potato production has seen a significant decline, with output dropping from 3.5 million tons in 2000 to just 1.34 million tons in 2022. This dramatic decrease in production is mirrored by a substantial reduction in the area harvested, which fell from 281,466 hectares to 80,770 hectares over the same period.

These statistics reveal a stark reality: potato farming in Romania is contracting both in terms of yield and cultivated area. Despite this downturn, potatoes continue to be a vital crop for Romania, ranking sixth among the country's top 10 commodities in 2022 (FAO, 2023). The correlation between the decreased production and the reduced harvested area suggests several underlying issues. It points to potential factors such as declining profitability, changes in agricultural policy, higher impact of pests and disease, variations of imports/exports or shifts in farmer preferences toward other crops. This context highlights the need for innovative approaches to revitalize potato farming in Romania.

The objective of this review paper is to explore advanced methods for managing pests and diseases in potato cultivation. The study aims to address the following areas: current pest and disease challenges in potato crops, fungicides, insecticides and biological control used, examples of best practices in integrated pest management potato production, emerging global and local challenges related to pests and diseases in potato crop, particularly in Romania.

CURRENT CHALLENGES AND CONTROL STRATEGIES OF PESTS AND DISEASES IN ROMANIA AND BEYOND

Potatoes are a staple crop globally, providing essential nutrition and economic value. However, their cultivation faces significant challenges from pests and diseases, which can severely impact yield and quality. The prevalence and impact of these issues vary across different regions, with specific pest and disease threats emerging in diverse climatic and geographic contexts. In potatoes, due to vegetative propagation, the quality of the planting material greatly determines the phytosanitary status of the crop, as well as the level and quality of the yield. This is because most diseases and pests are transmitted from one year to the next primarily through infected planting material. Potato crops face significant threats from various pathogens, attacking both in field and storage, including early blight (*Alternaria solani*) (Ivanović et al., 2022), dry rot (*Fusarium* spp.) (Prasetyo et al., 2024), late blight (*Phytophthora infestans*), (Guenthner et al., 2001) Potato Virus Y (PVY), and Potato Virus X (PVX) (Verchot, 2022), each of which can cause severe damage, reducing yields and quality.

In Romania, among the diseases that cause significant damage to potato crops are late blight (*Phytophthora infestans)* and early blight (*Alternaria solani)*, with the former being important in cooler, wetter areas and the latter in warmer, lowland regions. In spring, the incidence of tubers infected with various pathogens, particularly the most harmful ones like potato blight, dry rot, and wet rot, ranges from 3 to 20%, and occasionally even higher (Berindei, 2009). While general control strategies such as crop rotation, use of resistant varieties, and proper sanitation are essential in managing key potato diseases and pests, including early blight, late blight, dry rot, potato virus Y, and the Colorado potato beetle; targeted treatments play an equally significant role in mitigating their impact. These treatments include fungicides, biological control agents, botanical oils, and other specialized approaches. Each method has been thoroughly studied, showing varied levels of effectiveness depending on the active substances used and application conditions.

Controlling viral diseases is a crucial step in the multiplication process of planting material, potato growers only need to ensure they procure guaranteed, virus-free seed. A special attention should be paid to the significant importance of monitoring aphid populations in seed potato production to understand their structure, seasonal activity, and the risk of viral transmission.

Pests are a major threat to potato crops, with significant impacts on yield and quality. Among the most damaging is *Leptinotarsa decemlineata*, commonly known as the Colorado potato beetle. This pest is notorious for its ability to rapidly defoliate potato plants, leading to substantial reductions in crop yields. The beetle's larvae and adults feed aggressively on potato foliage, and their widespread resistance to many chemical insecticides further complicates control efforts. As a result, managing *L. decemlineata* has become a critical challenge in potato cultivation.

1. *Alternaria solani* – Early blight

Symptoms and Impact. Pathogenic species of the *Alternaria* fungus can lead to significant economic losses in crops (Berca & Cristea, 2015). On potato crop, early blight caused by the fungus *A. solani*, manifests as dark brown to black spots on the leaves, often surrounded by a yellow halo (Agrios, 2005; Dhaval et al., 2021). These lesions can expand, causing the leaves to wither and die prematurely, in some cases disease causing total defoliation (Zhao et al., 2023). This disease not only restricts the photosynthetic area of the plant (Horsfield et al., 2010), leading to smaller and fewer tubers but also makes the crop more susceptible to other stresses. The disease can harm both the foliage and tubers of potato plants, yield losses being recorded from 5% to 50% (Chaudhary et al., 2021), up to 40% in India (Suganthi et al., 2020), or high as 20-30% across U.S., due to severe epidemics (Shtienberg et al., 1990). Recent research highlights even more severe impact of *A. solani* on potato crops. One study (Meno et al., 2021) reveals that the Frisia and Daifla varieties, when subjected to early blight in control plots, exhibited substantial susceptibility, with nearly 75% of plants affected. Complementarily, another study reports a maximum Disease Severity Index

(DSI) of 24.95% recorded on the 13th day, which reflects the intensity of disease manifestation (Soni et al., 2023).

In all potato production areas, weather conditions favor the development of early blight disease. Epidemics can occur at any stage of potato growth but are more severe during the later stages of growth. In Romania the disease progresses rapidly when wet and dry weather alternate, a situation that is created in the southern part of the country under drought conditions through irrigation, national authorities warning that losses can reach from 20% up to 50% (MADR, 2018).

To develop effective strategies for controlling this disease, it is essential to first correctly diagnose and identify the pathogen affecting the potatoes (Borca & Carmen, 2013).

Pathogen Biology and Epidemiology. *Alternaria solani* is a fungal pathogen that thrives in warm, humid conditions (Kapsa, 2004; Batista et al., 2006). Sporulation occurs within a temperature range of 2-4°C to 28-30°C, with optimal conditions between 15 to 25°C (Saha & Das, 2013), more precisely at presented 20 °C (Chaudhary et al., 2021). This process requires a relative humidity (RH) above 90% or the presence of wet leaves. The germination of *A. solani* conidia is a critical factor in the onset and severity of early blight in potato crops. Research has demonstrated that *A. solani* conidia can germinate across a broad temperature range,. as low as 4°C to as high as 34°C, with initiation of germination occurring within 30 minutes under these favorable conditions, while optimum being recorded at 25°C (Thomidis et al., 2023). The fungus produces large-spores that are dispersed by wind and rain, infecting potato plants through natural openings or wounds, infection occurring usually after one week. Moreover, the pathogen can persist in the soil for prolonged periods, either as mycelia or as conidia on infected plant debris (Runno-Paurson et al., 2015).

Control Strategies. To effectively manage early blight caused by *A. solani*, it is crucial to understand the environmental conditions that favor disease development and the pathogen's life cycle. Insight into these factors can inform the development of comprehensive and sustainable approaches to reduce the impact of the disease on potato crops.

Across both Romania and worldwide, various cost-free and smart methods and practices have been developed to limit the occurrence and development of early blight. A sensitive point is the precision with which we analyze signs of primary infection. Initially, many of the lesions caused by early blight on potato leaves are less than 1 mm in diameter, making them difficult to observe with the naked eye. It is recommended to use a magnifying glass with appropriate magnification for monitoring. In the absence of warnings, when climatic conditions favor disease development, the potato crop should be inspected daily, given that the incubation period of the disease is 5-7 days.

Cultivation is appropriate in fields with good drainage and aeration, in which nutrients deficiencies are prevented. Application of chemical fertilizers must be carefully monitored, as high doses of phosphorus make plants more susceptible to this disease, while nitrogen increases resistance (MADR, 2018; Abuley et al., 2019). Implement a crop rotation plan, rotating to non-host crops for a minimum of three years, ideally three to four years, to reduce disease risk.

During cool, cloudy weather conditions it is advised to avoid irrigation.

During harvest, take care to avoid injury and skinning of the tubers. Post-harvest, ensure that all plant debris, remains of solanaceous crops, and weeds are thoroughly plowed under or collected.

Regarding varieties, there are no immune ones to early blight; however, early varieties are known to be more sensitive than mid-maturity or late-maturity varieties (Abuley et al., 2018). It is also recommended not to plant both early and late varieties in the same field (Wharton & Kirk, 2007).

The following table provides a detailed overview of these specific control strategies, summarizing key studies, their findings, and references (Table 1).

Table 1. Overview of control methods for *Alternaria solani*

Category/ Control method	Active substance	Results/Efficiency	References
Fungicides	combined use of difenoconazole, boscalid and pyraclostrobin	lower severity of the disease	Odilbekov et al., 2019
	azoxystrobin	did not improve disease control/ limited activity	Landschoot et al., 2017; Odilbekov et al., 2019
	dithiocarbamate mancozeb	the effectiveness of the dithiocarbamate mancozeb was high	Landschoot et al., 2017
	boscalid	completely inhibited disease development when applied one day before inoculation	Horsfield et al., 2010
Biological	*Trichoderma viride* (10^7 CFU/ml)	27.52% PDI (percent disease index)	Varma et al., 2008,
	Trichoderma spp.	"a significant reduction of early blight in the field was only observed in one out of four years of field trials"	Metz & Hausladen, 2022
	Bacillus amyloliquefaciens, B. cereus, Stenotrophomonas rhizophila	a) detached tomato leaflets – reduced lesion development by over 30% b) greenhouse - reduced early blight severity by over 50% c) field - slowed early blight disease progress and reduced disease severity	Riaz et al., 2024
	Bacillus velezensis SEB1	decrease of disease severity form 52.47 ± 3.8% to 9.59 ± 2.1%	Gorai et al., 2021
	Bacillus subtilis (alone or in combination with other treatments)	90% reduction in lesion size	Stridh et al., 2022
	Clonostachys chloroleuca, C. pseudochroleuca, C. rhizophaga	reduced disease severity from 88.7% to 92.9%	Da Silva et al., 2021
	Pseudomonas gladioli B25	controlled the early blight disease by 60.2%	Jagadeesh & Jagadeesh, 2009
Plant extracts	Clerodendron leaf extract	minimised PDI (23.22%)	Varma et al., 2008,
	Active extract of marine algae *Chaetomorpha antennina*	Affects *A. solani* spore germination (92.13%)	Chanthini et al., 2023
Oil extracts	Carnation, caraway, thyme oils	carnation oil had the strongest and most extensive inhibitory effect on fungal growth.	El-Mougy, 2009;
	Citronella essential oil	100% inhibition of *A. solani* mycelial growth at 2417 µL/L concentration	Hendges et al., 2020
Combined methods	Clerodendrum leaf extract + mancozeb	22.73% PDI	Varma et al., 2008,
	Bacillus subtilis (BS-01) + selective plant nutrients (NPK and Zn)	Relative fungal load reduced significantly by ~90%.	Awan et al., 2022

2. *Fusarium* spp. - Dry rot

Symptoms and Impact. Potato fusarium dry rot, caused by the fungus *Fusarium solani*, is one of the most damaging diseases affecting potatoes worldwide. Previously, 13 species of *Fusarium* were reported to cause dry rot (Cullen et al., 2005). This list has been updated to 17 species (Tiwari et al., 2020), indicating that these pathogens evolve and increasingly affect potato crops. This pathogen primarily targets the tubers, where the initial symptoms manifest as dark depressions, that internally continues with dark-brown necrotic areas (Wharton et al., 2007). Recent research (Gavrilova et al. 2024) reported that some *Fusarium* strains cause tissue necrosis ranging in size from 12.9 to 33.9 mm, confirming the aggressiveness of these new strains and their potential impact on potato crops.

Dry rot does not alter the shape of potato tubers in the initial weeks following infection, being visible only 3-4 weeks after (Hooker, 2001). Symptoms manifest later as slightly sunken areas. The affected tissues are distinctly separated from healthy ones by a layer of dark-coloured cells. As the disease progresses, the centre of the tubers decays, causing extensive rotting. Eventually, the affected areas dry out and harden, leading to significant loss of quality and marketability. Indirect symptoms have been reported, with primary and secondary roots also being affected (Tiwari et al., 2020). However, the most severe damage to potato crops occurs postharvest (Monjil et al., 2021). Since it was first recorded, dry rot has caused significant losses to potato crops, ranging from lower percentages observed in surveys across various districts of Bangladesh:

0.91% in Mymensingh, 0.96% in Dhaka, and 0.99% in Rajshahi (Masum et al., 2011), to broader estimates of 6.25% to 25%, with losses reaching up to 60% under certain conditions, particularly in injured tubers (Fan et al., 2021). Higher losses were recorded across the world, like 88% of total post-harvest potato losses were attributed to *F. sambucinum* and *F. solani* infections in China (Du et al., 2012), while another record indicated that *Fusarium species* infected 50% of tuber lots in Michigan storage units (Merlington et al., 2014).

Pathogen Biology and Epidemiology. Dry rot, mainly caused by *Fusarium* species, manifests as a dry, internal decay within potato tubers. This rot can range in colour or appearance at the surface or beneath the skin. Initial coluors of the rot can range from light brown (Xue et al., 2021) to dark black and typically begins at injury sites, such as bruises or cuts, which often occur during harvesting or transportation. These injuries serve as entry points for dormant spores on the tuber's surface. Once the pathogen penetrates the tuber, it often rots out the central portion, causing the tissue to shrink and collapse (Aydin et al., 2016). This leads to dark, sunken spots on the tuber's surface and internal cavities. Additionally, the rot may be accompanied by yellow, white, or pink mold (Vatankhah et al., 2019).

Regarding environmental conditions, even low temperatures of 3°C and 10°C ensure the survival of the fungus. Dry rot fungi thrive at temperatures of 20-25°C for mycelial growth, while growth slows down at 30°C and completely stops at 35°C or 40°C (Tiwari et al., 2020; Gavrilova et al., 2024). On the other side, some scientific results (Mejdoub-Trabelsi et al., 2012; Stefańczyk et al., 2016), showed that pathogenity is higher and varieties are highly susceptible to dry rot pathogen at 15-16°C than 20°C, for *Fusarium* strains tested, causing larger average lesions. While temperatures above 10°C in cold stores promote fungal growth, being reported to produce large tuber rots (Peters at al., 2008), the temperatures below 5°C reduce infection rates.

Control Strategies. Since symptoms of dry rot become visible only 3-4 weeks after infection, selecting high-quality tubers and planting resistant varieties are crucial steps in management. Using resistant varieties reduces the risk of infection, while high-quality, healthy tubers minimize initial disease presence, ensuring better storage outcomes and crop resilience. The reaction of different potato varieties to various *Fusarium* species reflects in differing degrees of susceptibility and resistance (Wastie et al., 1989). This variation is due to the genetic makeup of each potato variety, which influences its ability to fend off or succumb to specific *Fusarium* pathogens.

As *in vitro* tests have shown, some varieties possess inherent resistance traits, reducing the incidence and severity of dry rot, while others may be more vulnerable, leading to more significant disease impact and post-harvest losses. Moreover, no variety has been found to be fully resistant to dry rot. Among the highly resistant varieties, some have been reported: Atlantic, Barvin, Belmando, Bella Rossa, LaBelle (German selection), Glazurny, Cimmeria, Flooding, Tiras (Ukrainian selection), Russet Norkatah, Carrera, Marlene (Dutch selection), Snowden and Sorai (Belgian selection) (Bomok, 2019). Some tested cultivars exhibited partial tolerance to inoculation treatments; for instance, cultivars Spunta and Oceania demonstrated lesser susceptibility (Mejdoub-Trabelsi et al., 2012).

Similarly, no cultivars were entirely resistant to all *Fusarium* isolates, with only one cultivar, Broke®, displaying reduced susceptibility (Aydin & İnal, 2018).

Specific genotypes also demonstrated varying levels of resistance to different *Fusarium* species; for instance, Seuminar was highly susceptible to *F. sulphureum*, while Saturna, Desiree, and Ariana exhibited resistance. Conversely, Panda, Fregate, Folva, Ariana, and Saturna were resistant to *F. solani*, whereas Scort and Monalisa were more susceptible (Esfahani, 2005). Managing Fusarium diseases effectively requires a multi-faceted approach, incorporating fungicides, biological control agents, plant extracts, oil extracts, and combined methods (Table 2).

Table 2. Overview of control methods for *Fusarium* spp.

Category/ Control method	Active Substance	Results/Efficacy	References
Fungicides	Fludioxonil	effectively control tuber seed disease and sprout rot	Malyuga et al., 2022
	Azoxystrobin and fludioxonil	disease incidence decreased to 50%	Tiwari et al., 2020
	Metalaxyl hemexazol at 100 ppm	reduction of dry rot disease incidence by 82.5%	Awad et al., 2020
	Imazalil and thiabendazole (40 and 5 ppm respectively)	completely stopped the mycelia growth and reduced *F. solani* FPO-67 development by 68 and 71.69% respectively (tuber treatment).	Vatankhah et al., 2019
	Benomyl	suppressed growth of *F. sambucinum* and *F. solani* strains by an average of 76 ± 4%	Orina et al., 2024
	Azoxystrobin	least effective – 35 ± 5% averaged inhibition of *Fusarium* growth	Orina et al., 2024
	Carbendazim/ Benomyl/ Thiophanate methyl/ Triadimefon	carbendazim and benomyl significantly inhibited the fungal growth (86.72 and 87.03 respectively), even at its lower concentration (100 ppm), compared to thiophanate methyl and triadimefon (43.73% and 46.87%)	Sandipan et al., 2017
Biological	*Serratia grimesii* 4-9 and *S. plymuthica* 5–6	a) potato tuber slice assay - diameter of the infection sites was reduced 91 and 96%, compared to control b) potato tubers - suppressed development of *Fusarium* dry rot by 60 and 77%, respectively, at 15°C	Gould et al., 2008
	Burkholderia cepacian	*in vitro* antagonism test revealed inhibition zone expanded to 47.37 mm	Recep et al., 2009
	Pseudomonas fluorescens and *Enterobacter cloacae*	dry rot reduction in tubers averaged over the two years (35% and 26.5%, respectively)	Al-Mughrabi, 2010
	Clonostachys rosea IK726	45% reductions in the mean number of rot compared to the non-treated ones	Jima, 2013
Plant extracts	Garlic extract in 3%, 5% and 10% concentration	fungal growth inhibition	Awad et al., 2020
	Punica granatum L. (peels extract) 20 mg/ml	methanol extract exhibited 75.5% inhibition on *F. sambucinum* mycelial growth, and complete inhibition of spore germination	Elsherbiny et al., 2016
Oil extracts	*Beta vulgaris* essential oil (1000 µl)	inhibition rate of 29.1% on *F. sambucinum,* and 27.3% on *F. solani*	Zöngür, 2024

Most of the methods tested, both in vitro and in the field, begin with managing symptoms from the pre-plant phase and continue through to storage. This comprehensive approach is essential because *Fusarium* dry rot can infect potatoes at multiple stages of production and storage.

Managing *Fusarium* dry rot starts with the selection of high-quality, disease-free seed potatoes. Certified seed potatoes are less likely to harbour *Fusarium* pathogens. Certified seed potatoes must meet the stringent standards set by a certification agency. This entails that the seeds were produced, inspected, graded, and handled in compliance with the agency's regulations (Bohl at al., 1992).

European law mandates that all seed potatoes must be officially inspected and certified before they can be marketed. This ensures they meet the EU's quality and health standards. Member states (including Romania) are required to comply with the Plant Health Regulation Regulation (EU) 2016/2031 and Directive 2002/56/EC for seed potato marketing. Seed treatment with fungicides before planting can further reduce the risk of initial infection. Good results have been reported from pre-treating tubers with various fungicides before planting. This practice not only reduced disease occurrence but also led to a noticeable improvement in yield and quality (Duellman & Olsen, 2019; Udalova et al., 2021). In addition to these measures, other strategies can also be effectively utilized. Use healthy seed and maintain strict hygiene when handling and planting tubers, including sterilizing tools and cleaning equipment. Employ proper storage and treatment practices, such as gradual temperature adjustment and timely planting, while ensuring long crop rotations and applying registered fungicides to minimize disease spread and soil contamination. Ensure tubers have a good skin set before harvest, and adjust harvester speed to minimize damage. Avoid wet conditions during harvest, keep tubers out of direct sunlight, and dry them quickly to aid in soil removal.

3. *Phytophthora infestans* - late blight

Symptoms and Impact. Since its devastating role in the Irish Potato Famine of the 1840s, late blight caused by *P. infestans* has remained one of the most economically damaging diseases affecting potatoes, causing annual losses of up to $6.7 billion worldwide. Once infected, entire foliage can collapse within a few days, and under favourable conditions, the disease can lead to complete crop loss if left unchecked, within 7 to 10 days (Yuen, 2021). Additionally, all asexual and sexual forms of the disease, such as mycelium, oospores (which can survive for up to four years), zoospores, and sporangia, can cause infection, making it even more dangerous to potato crops (Alrudainy & Mshari, 2022). The widespread distribution of the two mating types, A1 mating type before 1980, along with the emergence and rapid spread of the A2 mating type from Mexico to other regions, has enhanced the pathogen's capacity for sexual reproduction (Al Harethi et al., 2023). Late blight first symptoms usually begin 3 days after infection with small, brown lesions on the lower leaves and stems (Kool & Evenhuis, 2023) which quickly develop into brownish-green blotches or black lesions. Under high humidity conditions, these lesions can spread rapidly, with white mildew growth often appearing on the abaxial surface of the leaves (Al Harethi et al., 2023). The disease typically spreads across all parts of the plant. Infected tubers, due zoospores penetration through lenticels exhibit irregular, copper-dry brown or reddish lesions that can lead to secondary bacterial infections, leading mostly to a soft rot (Ristaino et al., 2018).

Pathogen Biology and Epidemiology. Late blight in potatoes, caused by the oomycete *Phytophthora infestans* (de Bary, 1876) is one of the most devastating diseases affecting this crop globally. The pathogen is highly adaptable, with a complex life cycle that includes both asexual and sexual reproduction. Mycelium, which is non-septate, can survive through winter, making it a primary cause of potato plant infections. Meanwhile, sporangia, typically found on the lower leaf surface, have the ability to germinate when water is present and temperatures range between 18-24°C (Ristaino et al., 2018). Alternatively, if temperatures drop below 16°C, sporangia can release zoospores (6-8), which are also capable of causing infection (Ristaino et al., 2018). The pathogen can sporulate on infected tubers in inadequately managed storage areas with excessive humidity. Moisture from condensation forms droplets on the tuber surfaces, prompting sporangia formation, which can then infect nearby tubers, potentially leading to the entire stock being devastated by soft rot bacteria.

Control Strategies. Effective management of late blight, a serious disease affecting potatoes, requires a multifaceted approach due to the pathogen's aggressive nature and ability to spread rapidly under favourable conditions. Key strategies include the use of resistant potato varieties, which can reduce the impact of the disease. So far, no immune potato cultivar has been reported, yet resistance to late blight has been observed in tetraploid breeding clones, cultivars, and wild diploid relatives of potatoes (Xue et al., 2021), or obtained by transferring resistance genes (*Rpi* genes) from wild potato relatives (Paluchowska et al., 2022). Research on potato cultivars' resistance to late blight has been conducted globally, typically highlighting cultivars that are highly susceptible to the disease, while susceptible cultivars got foliage distructed in less than 15 days. Runno-Paurson et al. (2019) tested twelve potato cultivars and found that only two of them, Anti and Toluca, exhibited resistance. In contrast, Xue et al. (2021) tested over 200 cultivars, both new and old, and found that 32 cultivars showed moderate resistance.

Given that the pathogen can survive for many years in the soil due to oospores, crop rotation becomes a crucial component of integrated management strategies. This includes avoiding other host crops, such as tomatoes or ornamental plants, and ensuring that potatoes return to the same plot only after a two- to three-year interval, two years being the minimum needed to delay disease onset (Abuley et al., 2019), while a three-year rotation can enhance the crop's resistance to pathogen attack (Peters et al., 2005).

Irrigation methods play a crucial role in limiting late blight in potatoes by influencing the moisture levels on plant surfaces and in the soil, which are key factors in the development and spread of the disease. Irrigation methods play a crucial role in limiting late blight in potatoes by influencing the moisture levels on plant surfaces and in the soil, which are key factors in the development and spread of the disease. While some studies (Olanya et al., 2007), showed no significant difference between different irrigation methods, other studies highlight importance of timing, frequency and duration in diseases emergence (Bohl et al., 2003), values up to 87.77% in disease incidence being observed with more frequent irrigations (Peerzada et al., 2013).

Planting potato tubers at the correct depth is vital in managing late blight, as it influences soil moisture and temperature, which are critical for both plant health and disease prevention. Proper depth helps maintain stable soil conditions around the tubers, promoting vigorous plant growth and reducing stress, which can make plants more resistant to late blight. Deeper planting, not more than 6 inches (Bohl et al., 2003), also minimizes the exposure of foliage to excessive moisture and pathogens that can accumulate at the soil surface, thereby lowering the risk of infection. Furthermore, it protects tubers from direct exposure to rain and irrigation, which can carry pathogen spores, and supports better water management by preventing waterlogging around the tubers. Overall, correct planting depth contributes to a more resilient plant and enhances the effectiveness of integrated disease management strategies.

Proper management of soil moisture through careful irrigation scheduling can also limit late blight. Avoiding excessive watering and maintaining consistent moisture levels without over-saturating the soil can reduce the likelihood of creating conditions favourable to the pathogen.

Fertilization significantly influences the emergence and severity of late blight in potatoes by affecting plant growth and susceptibility. Adequate fertilization promotes strong, healthy plants with robust foliage and root systems, which can better withstand disease pressure. However, excessive or imbalanced fertilization, particularly with high nitrogen levels, can lead to lush, dense foliage that creates a moist environment favourable for the pathogen *P. infestans* (Juárez et al., 2000). Properly balanced fertilization enhances plant resistance and reduces the likelihood of late blight outbreaks by avoiding conditions that support pathogen proliferation. Additionally, research has shown that potassium and calcium can play a significant role in disease management. Higher applications of phosphorus have been associated with smaller leaf lesions caused by late blight, while spraying calcium nutrients has been found to lower the incidence of late blight (Seifu, 2017).

Scouting is essential for managing late blight in potatoes as it facilitates early detection of disease symptoms, allowing for prompt intervention before the disease spreads extensively. Regular inspections help monitor disease progression, enabling timely adjustments to treatment strategies. Additionally, scouting provides critical information for targeted interventions, focusing resources on the most affected areas and reducing unnecessary treatments.

By maintaining consistent scouting practices, growers can effectively manage late blight, improving overall crop health and yield. The following table (Table 3) summarizes the most effective curative methods for managing dry rot.

Table 3. Overview of control methods for *Phytophthora infestans*

Category/ Control method	Active Substance	Results/Efficacy	Reference
Fungicides	Dimethomorph, fenamidone + mancozeb	area under disease progress curve (AUDPC) was consistently reduced by dimethomorph (90%) fenamidone + mancozeb (68%)	Khadka et al., 2020
	Mancozeb	lowest disease severity (38.50%) recorded on Belete variety	Teshome et al., 2022
	Mancozeb 75% WP (0.2%) + dimethomorph 50% WP (0.2%)	Applying mancozeb 75% WP (0.2%) before disease appearance, followed by two additional sprays with mancozeb 75% WP (0.2%) combined with dimethomorph 50% WP (0.2%) at 7-10 day intervals,	Lal et al., 2017

Category/ Control method	Active Substance	Results/Efficacy	Reference
		resulted in lower terminal disease severity (24.55%).	
	Mancozeb 640 g/kg + cymoxanil 80 g/kg	suppressed blight symptoms by 54%	Kilonzi et al., 2024
	Metalaxyl	failed to protect the potato crop from late blight in temperate highlands, resulting in 40–70% crop losses.	Lal et al., 2018
Biological	*Streptomyces* sp. FXP04	inhibition of colony of *P. infestans* was reduced by 32.4% and 58.2%	Fu et al., 2022
	Willaertia magna C2c Maky lysate	a) greenhouse - up to 80% disease reduction b) 77% protection in field in the case of low infestation (28%)	Troussieux et al., 2022
	Trichoderma spp.	in dual-culture assays – inhibited *P. infestans* growth with 53 to 95%	Alfiky et al., 2023
	Penicillium aurantiogriseum, P. viridicatum, Trichoderma viride and *Acremonium strictum*	all the four bio-agents significantly reduced *P. infestans* sporangial germination, *T. viride* and *P. viridicatum* being better than the others	Gupta et al., 2004
Plant extracts	*Syzygium cumini* leaves extract	very effective in controlling the late blight disease incidence and severity (up to 58 days after sowing (DAS) and increased the potato yield by 71.29%	Islam et al., 2021
	Garlic (*Allium sativum*), Neem (*Azadirachta indica*), Turmeric (*Curcuma longa*), Mint (*Mentha* sp.) at 5, 10, and 15% concentrations	a) *in vivo* test - *A. sativum* and *A. indica* at 15% concentration were found to be more effective in inhibiting *P. infestans* mycelial growth by 58.4% and 43.9%, respectively b) greenhouse trials – minimum potato late blight disease incidence (5.81%), due to *A. sativum extract*	Mehmood et al., 2022
Oil extracts	Juniper, tea tree, clove, thyme, cinnamon, turmeric, pepper and rosemary essential oils (EO), in 0.41, 0.83, 1.66, 3.33 and 6.66 µL/mL concentrations	rosemary, thyme EO and Timbor® (*Thymus vulgaris*) were the most effective compounds in reducing late blight with more than 80%	Najdabbasi et al., 2020; Gheorghe et al., 2022
	Cinnamaldehyde, carvacrol, and eugenol	Inhibited *P. infestans* by hindering its mycelial radial growth, zoospore release, and sporangiospores germination	Tian et al., 2024
Combined methods	Biochar + *Streptomyces* strains	decreased the disease index by 10 % to 26 %, in field trial, exhibiting better disease control than the use of either agent alone	Jin et al., 2023

4. Potato Viruses – Potato Virus Y

Plant viruses are widely recognized for their significant impact on crops worldwide, causing detrimental effects on major agricultural products and resulting in substantial losses, up to $60 billion (Sinha et al., 2024). Among the most dangerous viruses affecting potatoes, Potato virus Y (PVY) poses a widespread problem in potato-growing regions (Onditi et al., 2022). While its molecular structure is well studied, there is still limited understanding of the virus's evolutionary pathways (Gao et al., 2020).

Symptoms and Impact. PVY can significantly impact potato crops with a range of symptoms (depending also on the virus strain) that often start with the appearance of mosaic patterns on the leaves. These mosaic patterns typically present as alternating light and dark green areas, creating a mottled effect. As the infection progresses, the leaves may begin to curl either upwards or downwards, leading to noticeable deformities. This curling is often accompanied by chlorosis, where the leaves turn yellow and eventually become necrotic, which can result in premature leaf drop. Infected plants may also exhibit stunted growth, with a noticeable reduction in size compared to healthy plants. Several other more specific symptoms have been reported during virus-plant interactions, including significant metabolic changes such as alterations in fatty acids, amino acids, and energy pathways (Manasseh et al., 2023), lower concentrations of sugar metabolites (Kogovšek et al., 2016), a general reduction in photochemical efficiency (Stare et al., 2015) or decreased starch content and dry matter (Ospankulova et al., 2023). Tubers from affected plants can show various deformities, including necrotic ringspots (Chikh-Ali et al., 2020), irregular shapes or smaller sizes, and may have fewer eyes. Additionally, the overall yield of the potato crop can be markedly reduced, as the virus impacts the plant's ability to produce healthy tubers.

Due to the limited resistance in many potato cultivars, PVY has become one of the most economically significant viruses affecting potato crops. The widespread susceptibility of these cultivars allows PVY to easily infect and damage plants, leading to significant losses in yield and quality across Europe, with annual economic losses estimated at 187 million euros (Dupuis et al., 2024) or up to 80% of the entire yield (de Bokx & Huttinga, 1981).

Pathogen Biology and Epidemiology. PVY is a member of the *Potyvirus* genus in the *Potyviridae* family. Its virions are filamentous, measuring 730 nm in length, 11 nm in diameter, and contain a single-stranded RNA genome approximately 9.7 kb in length (Urcuqui-Inchima et al., 2001). PVY is a member of the *Potyvirus* genus, which is one of the largest groups of plant viruses (Wylie et al., 2020). It can infect a minimum of 495 species across 31 families (Abd El-Aziz, 2020). Three main strains have been initially reported for PVY: O (ordinary), N (necrotic), and C (common) (Wani et al., 2021; Samarskaya et al., 2023), but recombinant strains have been recently reported such as $PVY^{N:O}$, $PVY^{N\text{-}WI}$, and PVY^{NTN} (Karasev & Gray, 2013).

PVY is primarily transmitted mainly by mechanical actions (Fegla et al., 2001; Hamza et al., 2018), infected tubers (Rahman & Akanda, 2009), or aphid vectors (see Table 4), in a non-persistent manner, meaning the virus does not replicate within the aphid but can be transmitted rapidly during brief feeding periods.

Table 4. Reported aphid species transmitting Potato Virus Y (PVY)

PVY strains	Host range	Aphid species	References
PVA	Potato	*Aphis fabae, Metopolophium dirhodum, Sitobion avenae, Acyrthosiphon pisum* and *Cavariella aegopodii*	Fernández-Calvino et al., 2006; Fox et al., 2017
PVY	Potato, pepper	*C. aegopodii*	
PVY^{O}/ PVY^{N}/ PVY^{NTN}/ PVA	Potato	*M. persicae*	
PVY^{N-Wi}	*N. benthamiana*	*M. persicae*	Kamangar et al., 2019
PLRV and/or PVY.	Potato	*M. persicae*, *M. euphorbiae, A. gossypii*	Machado-Assefh et al., 2023
PVY^{O}/$PVY^{N\text{-}WI}$	Potato	*Myzus persicae*	Mello et al., 2011
PVY^{NTN}/PVY^{NW}	*Physalis floriana*	*Myzus persicae*	Kostiw & Trojanowska, 2011
PVY	Tobacco	*Brachycaudus helichrysi, Myzus persicae, Phorodon humuli*	Harrington et al., 1986

Control strategies. Effective control of PVY in potato crops requires a comprehensive, multi-faceted approach due to the virus's genetic diversity and the complex dynamics of its transmission.

A key component of this strategy is the use of diagnostic tools like ELISA (enzyme-linked immunosorbent assay), widely employed for detecting and differentiating PVY strains using commercially available polyclonal and monoclonal antibodies, although it has limitations. While serological assays can distinguish different serotypes of the virus, they are not capable of identifying recombinant isolates. This requires the integration of more advanced molecular techniques, such as RT-PCR, for precise detection (Baebler et al., 2020).

In addition to accurate diagnostics, breeding for PVY-resistant potato cultivars is a cornerstone of disease management. However, the constant evolution of the virus, particularly the emergence of recombinant strains that can overcome existing resistance, underscores the importance of ongoing research and development of new resistant varieties. Yet, some varieties showing moderate resistance (Villetta Rose, Eva, Rio Grande), have been reported (Schramm et al., 2011). In addition to genetic resistance achieved by transferring resistance genes like Ry_{chc} (Li et al., 2022), effective control of aphid vectors through IPM strategies is crucial. Although insecticides are commonly used, their efficacy is limited because they do not act quickly enough to prevent aphids from probing and transmitting the virus to healthy plants. Additionally, establishing thresholds for aphid populations is vital for the effective management of insecticide use (DiFonzo et al., 1996).

Therefore, integrating cultural practices such as crop rotation, the use of reflective mulches, and the regular removal of infected plants is essential for reducing aphid populations and minimizing virus spread. Dupuis et al. (2017), presents some promising new cultural methods of controlling or reducing spreading of PVY, using mulching, oil spraying and intercropping. Additionally, the use of certified virus-free seed potatoes plays a critical role in reducing the initial inoculum, further strengthening the overall control strategy. By combining these diverse approaches, farmers can more effectively manage PVY, mitigating its impact on potato yields and quality.

5. Leptinoptarsa decemlineata **- Colorado potato beetle**

Symptoms and Impac. *Leptinotarsa decemlineata* L., or the Colorado potato beetle, is a highly destructive pest that significantly impacts potato crops. In Romania, the Colorado potato beetle was first reported in Săpânța, Maramureș, in the years 1952, 1953, and 1954, and in Uivar, Timiș, in 1955, in the form of isolated outbreaks that were eradicated. However, in 1956, it became permanently established, being discovered in numerous locations in the southwest of the country (the counties of Timiș, Arad, and Bihor), entering in large numbers by flight from Serbia and Hungary. Currently, the Colorado potato beetle is found throughout the entire country.

The symptoms of infestation begin with the presence of small, yellow eggs laid on the underside of leaves, which soon hatch into larvae that voraciously consume the foliage. As the larvae mature, they cause extensive leaf damage, up to 40 cm^2 of potato leaves during larval stage (Ferro et al., 1985), leading to defoliation (Figure 2), that severely impairs the plant's ability to photosynthesize. Even though the plant's photosynthetic rate is not affected, the attack on the plants stunts their growth and can result in significantly lower tuber yields (Hoback et al., 2015). In severe infestations, entire fields can be defoliated, with defoliation levels exceeding 75% often leading to total crop loss. The beetle's ability to develop resistance to multiple insecticides, up to 52 compounds so far (Alyokhin et al., 2008), further exacerbates its impact, making it one of the most challenging pests to control in potato farming.

Adults of the Colorado potato beetle are 10 mm long, 7 mm wide with an oval, convex body that is yellow-orange in colour (Alyokhin et al., 2022). The head is yellow-red with a triangular median spot and two black lateral-posterior spots. The pronotum has 11 black spots of varying sizes, with the central ones forming a "V" shape. The elytra are marked with 5 black stripes, bordered laterally by rows of dots. One female can lay from 500 eggs (Radcliffe & Lagnaoui, 2007), up to 800 during its lifetime (Sablon et al., 2012). The egg is 1.2-1.5 mm long, oval-shaped, and yellow-orange in colour. The larva in its final stage, is 8-10 mm long and orange, with black spots along the sides. The head is black, and the legs are dark brown.

Figure 2. Combined attack of adults and larvae of Colorado potato beetle on potato plants grown in Dolj County, Romania

Life cycle. The Colorado potato beetle overwinters as an adult in the soil (EFSA Panel on Plant Health, 2020) at depths ranging from 10 to 90 cm, depending on the soil type, and sometimes for as little as 30 days (Capinera, 2001). In the conditions of Romania, in alluvial soils, the overwintering depth of adults is between 10 and 50 cm, while in sandy soils, it ranges from 30 to 90 cm. In spring, after a period of 10-12 days with average daily temperatures above 10°C, usually in the second half of March, the emergence of adults begins, continuing until the end of May. The peak flight period typically occurs at the end of April or the beginning of May, when average temperatures range between 14-21°C. After an intense feeding period necessary for sexual maturation, mating and egg-laying occur. The eggs are laid in clusters of on the underside of potato leaves.

Control strategies. Colorado potato beetle populations can be effectively managed through a variety of cultural and physical control methods. Cultural practices such as crop rotation, manipulation of planting time, the use of mulches, and the incorporation of trap crops have proven successful in reducing beetle populations. Crop rotation, first recommended in 1872, remains a key strategy, as it not only reduces beetle populations but also helps manage potato pathogens and weeds. Research has shown that rotated fields (with distance rotations >400 m), can experience a significant decrease in beetle adult infestations in the spring (Sexson & Wyman, 2005). Additionally, when potatoes are planted following non-host crops like rye or wheat, early-season beetle densities can be reduced by nearly 96% (Wright, 1984).

Trap crops can attract beetles away from the main crop, effectively intercepting both over-wintered beetles in the spring and those moving from senescing crops later in the season (Hoy et al., 1996). Mulching, particularly with straw, has been shown to significantly reduce larval populations and delay their peak by one to two weeks, while also decreasing defoliation and increasing the beetles' predation risk (Stoner, 1993; Brust, 1994).

CONCLUSIONS

In conclusion, alternative methods for disease and pest control in potato cultivation are showing promising potential. Integrated approaches, including the use of low-input pesticides, biological control agents, and resistant crop varieties, offer effective solutions while minimizing environmental impact. Continued research and field trials are essential to optimize these strategies, ensuring sustainable, long-term protection against key pathogens and pests. Adopting these methods can contribute to healthier crop yields and promote resilience in agricultural systems.

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