Chapter

Impact and Management of Diseases of *Solanum tuberosum*

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Abstract

Solanum tuberosum (Potato) is one of the essential economic crops with the potential to reduce hunger due to its high yield per unit area of land compared with many economic crops. However, its yield losses due to pest and disease attacks could be as high as 100%, depending on its tolerance level and pest and disease. Over the years, several disease management strategies have been researched, ranging from synthetic pesticides to the formulation of biopesticides as disease control measures. Moreso, recent breakthroughs in genetic engineering have simplified plant disease management strategies by developing techniques for conferring resistance on plants. Potato is a vital food crop worldwide, and with the struggle to suppress world food insecurity, effective disease management strategies must be employed for high production of quality and quantity potato, enough to feed the ever-increasing world population. Therefore, attention must be given to how disease-free potatoes can be produced to meet the unending demand for food by the continually increasing world population.

Keywords: Potato, Disease-free, Crops, Pathogens, Biocontrol, Resistance

1. Introduction

Potato (*Solanum tuberosum* L.) is the most popular vegetable crop of great importance worldwide and follows only wheat and rice as a food crop [1]. It is a source of carbohydrate being a starchy vegetable; it is, however, as a vegetable a very significant source of vitamin C, potassium, and dietary fibre as well as magnesium, vitamin B6, iron, carotenoids, and phenolic acids [2, 3]. It grows in a wide range of climates and is adopted by a broad range of cultures [4]. Potato is a critical alternative to the major cereal crops for feeding the world's population [5]. However, its production has two main challenges: disease and nutrient management [6]. Pathogens such as bacteria, fungi, viruses, nematodes, and phytoplasmas attack potato plants, causing diseases, which result in a significant loss of yield [7]. Naming a pathogen that negatively affects the host's health is the primary means to define any disease [8]. For instance, potato plays host to heterothallic species, *Phytophthora infestans* [9], which causes late blight disease. This single pathogen caused severe devastation in the late 1840s in Europe [10] and cost Ireland 25% of its population in just four years [11]. Potatoes still have many diseases, but many other alternative crops make most countries not depend on potatoes like Ireland in the 1800s [12]. In recent time, potato crop loss due to late blight disease alone is estimated at $6.7 billion annually worldwide [5]. A significant challenge to the management of *P. infestans* is the rate at which it adapts to control strategies [5]. More research on epidemiology and the host-pathogen interaction is needed to devise the most appropriate management strategy [7]. Also, insight into pathogen population dynamics offers an essential input for effective disease management [13].

Meanwhile, effective management of the disease requires implementing an integrated disease management approach [14]. Guchi [7] proposed investigating several control options and implementing an integrated management strategy based on local needs [7]. Therefore, this chapter aims to discuss the general/overall impact of the diseases of *Solanum tuberosum* as well as their management. This would increase awareness and awaken researchers' intervention to develop globally effective control or management strategies.

2. Some host pathogens and diseases of potato

Diverse host-pathogens are associated with the different diseases of potatoes, among which are bacteria and fungi. Plant pathogens responsible for diseases in potatoes include viruses, fungi, oomycetes, and bacteria [15]. A pathogenic bacterium known as *Ralstonia solanacearum* is responsible for the devastating bacterial wilt of potato and other solanaceous plants [16, 17]. The bacterium, *Ralstonia solanacearum,* is a gram-negative, non-spore-forming, aerobic, soil-borne motile pathogen that hinders tuber production resulting in economic losses [16–18]. It is distributed worldwide, affecting more than 200 economically essential crops, including potato [19]. The pathogen, usually disseminated by infected seed tuber, soil, water, and farm machinery [20], penetrates to infect the roots through wounds or natural openings and rapidly propagates within the host to attack the plant's vascular system. Consequently, it forestalls the translocation of nutrients and water, culminating in wilt, collapse and complete deadening of the plant and its decay [21, 22]. The ubiquitous plant pathogenic fungus of *Colletotrichum coccodes* is responsible for the blemish disease of potatoes called black dot [23].

The typical characteristic of black dot disease is the microsclerotia on infected tissue present in all potato parts. These microsclerotia, which usually survive in the soil for lengthy periods, lead to high disease incidence when soil inoculum levels increase [24]. Sequel to fungal colonisation of roots are colonisations in the stems, stolons, and tubers [25], and fungal contamination of tubers with *C. coccodes* leads to the development of lesions on the epicarp and loss of water during storage [26, 27]. The potato late blight disease is caused by *Phytophthora infestans* [28]. It affects the potato foliage and tubers. The foliage symptoms begin with brown to black, water-soaked lesions on leaves and stem that produce visible white spores at the lesion margins under humid conditions. This may result in the rapid collapse of the entire plants and orchards. Sporangia in the soil from the foliage initiate the tuber infection that starts from the wounds, eyes, or lenticels. The lesions appear as copper brown, red, or purplish, and white spores appear on tuber surfaces in storage.

Streptomyces spp. is the bacterial pathogen responsible for common scab in potato, and characteristic tan to dark brown, circular or irregular lesions rough in texture are produced. The scab may be superficial (russet scab), slightly raised (erumpent scab), or sunken (pitted scab). Its lesion type is determined by potato cultivar, maturity of tuber at infection, soil organic matter content, pathogen strain, and the environment [29]. Another disease caused by the bacterium is soft rot, which is the most destructive of all storage diseases caused by *Erwinia carotovora*. The disease symptoms include tan- to brown-coloured water-soaked areas of granular, mushy tissue often outlined by brown to black margins. During storage periods, soft rot bacteria penetrate tubers already infected with other potato diseases. The rottening from bacterial penetration is accelerated by the heat generated from the intense respiration in the storage environment.

Early blight of potatoes, caused by *Alternaria solani*, usually affects its leaves, but tuber infections can also occur. The lesions found in the tubers are dark, sunken, and circular, usually surrounded by purple to grey raised tissue. Its underlying tissues are void of moisture, leathery and these brown lesions may have increased during storage with shrivelled tubers [29]. *Fusarium sambucinum* or *F. coeruleum* is responsible for dry rot that causes inner light to be dark brown or black dry crumbly rot of potato with collapsed tissue often lined with secondary white other-coloured fungal growth. This rot may commence at an injury site (bruise or cut), and the fungus penetrates the tuber to rot out its centre. In furtherance, the extensive rotting results in the shrinking and complete collapse of tissue and usually leaves a dark sunken area outside the tuber and internal cavities [29]. The silver scurf, caused by *Helminthosporium solani*, infects only the uber periderm (skin). The lesions appear first at the stolon end as small pale brown spots that may be difficult to detect at harvest but continues development during storage. While in storage, these lesions darken, sloughing off the skin occurs with many small circular lesions coalescing to form large lesions. The potato tubers tend to dry out and become wrinkled from excessive moisture loss during storage [29]. The fungus *Rhizoctonia solani* causes the black scurf disease, which does not reduce yield, even in storage. Fungal sclerotia develop in irregular, black hard masses on the tuber surface that harvesting tubers may reduce immediately after vine-kill and skin set. Sclerotia allow the pathogens to survive in the soil. Inside wet soils, *R. solani* may induce dark, sunken lesions on underground sprouts and stolons with consequent deprivation of nutrients, the complete killing of the potato tubers, reduction in transfer of starches (results to reduced sizes) [29].

Pink rot infections caused by *Phytophthora erythroseptica* commence at the stolon end and culminates in rotten, internal rubbery skin that turns pink after about 15 to 20 minutes of exposure to warm air (with a clear delineation between healthy and diseased tissue). On exposure to air, the tuber flesh turns pink and then brown-black. The fungal pathogen *Pythium* spp. is responsible for leak infections, penetrates tubers through harvest wounds, and continues to grow in transit and storage. Its infections develop into internal watery, grey, or brown rot, but the outer cortex remains intact, with well-defined red-brown lines demarcating healthy and infected tissue [29].

Viruses are among the predominant phytopathogens that cause approximately 50% of all emerging plant diseases [15]. Potato virus Y (PVY) is one of the most harmful viruses infecting potatoes across the globe since the 1980s [30].

3. The impacts of diseases on the yield (quality and quantity) of potato

In 2013, more than 368 million tonnes were produced from 19.4 million hectares [31]. Though hundreds of varieties of potato are grown in temperate and sub-tropical areas, its diversification in various agroclimatic conditions leads to a decrease in its production and productivity due to its low genetic base and various biotic factors, which makes it susceptible to many devastating diseases. The crop infection due to fungi, viruses, bacteria, and viroids alters its metabolism. These pathogens affect the crop's morphological, physiological, and biochemical characteristics leading to altered distribution of photoassimilates, with resultant effects on its quality ad quantity.

Viral diseases of potatoes are devastating because they are tough to manage and transmitted via the tubers to subsequent generations. Viruses have the potential to alter the physiology of potato plants drastically, causing disorders. These disorders of growth processes cause stunting, leaf deformation, dwarfing, and reduction in the yield of potato tubers and product quality up to 88% [32–34]. Tens of potato viruses have been discovered and characterised, and the most cataclysmic are: Potato virus M (PVM): Potato virus S (PVS); Potato virus X (PVX); Potato virus Y (PVY); and Potato leaf roll virus (PLRV, virus L). PVX can debilitate 10–40% of potato in a single infections cycle and possess enormous devastating effects when combined with other potato viruses; due to its synergistic interaction with potyviruses, tuber losses yield close to 80% [33]. For example, the yield of potato simultaneously infected with PVM and PVX will decline to 60%, and when it is a complex infection of PVM + PVX + PVY, it will decline by 83.7%, i.e., total loss of yield [35]. In potato tubers infected with viral diseases, the content nutrients become reduced compared to healthy ones. Other biochemical and physiological changes also occur, resulting in a decrease in the quantity and quality of starch grains in the debilitated tissues, the acidity of starch, and amylase content [36]. There are varying losses in potato production from viruses; they are determined by the variety's resistance, the viral pathocomplexity, the level of spread of a specific virus, and their combinations with other viruses [37].

Bacterial diseases are one significant biotic constraint of potato production in the subtropical and tropical regions. Several bacterial diseases devastate potato, resulting in severe damages, especially on tubers, leading to economic losses. The most acute diseases are bacterial wilt caused by *Ralstonia solanacearum* [38] and the backleg caused by *Pectobacterium atrosepticum, P. carotovorum* subsp. *brasiliensis, P. wasabiae, Dickeya solani* and *D. dianthicola* [39, 40]. Loss of yield in potato crop is due to bacterial diseases that could be direct and indirect. There are specific facets: short-term impacts like yield loss and unvendability, and others with long-term impacts with environmental, economic, and social effects [39].

To date, potato late blight is still one of the most devastating diseases in potato-producing regions worldwide and causes substantial economic losses of about 25–57%. Pathogenic fungus, *Phytophthora infestans,* are responsible for late blight disease in potato. Late blight disease is highly destructive and one of the diseases threatening global food security [41]. Its outbreak in Ireland resulted in famine, which led to millions of people's starvation and eventual death and subsequent continuous significant losses of potatoes worldwide. Therefore, it remains the most debilitating disease of the food crop, which causes annual potato losses sufficient enough to feed several millions of people [42]. Despite the apparent debilitating potential of late blight, it is tough to estimate losses because of other environmental factors that simultaneously affect potato yield.

Meanwhile, the economic impact of potato late blight in the USA was appraised to be around 210 million US dollars, while a worldwide assessment of potato loss by late blight in the second world countries based on an average production was about 15%. This represents approximately 2.75 billion US dollars loss in developing countries. However, a critical method of estimating the economic impact of potato late blight is by determining the usage of fungicide. With this method, the estimated fungicide currently used in developing countries stands at 750 million US Dollar. Therefore, about 1 billion US Dollar is spent on fungicides yearly to manage fungal disease worldwide [43].

4. Management strategies of the diseases of potato

Potato is among the high-income-yielding crops globally and can contribute to poverty reduction in developing regions [44]. However, Potato cultivation is beset with several diseases caused by diverse pathogens in the field and during storage, accounting for 50 to 60% of annual losses [45–47]. Control strategies that have been deployed to manage diseases in potato include the application of chemical fungicides, biological control agents, and cultural practices involving crop rotation.

4.1 Chemical control

Diseases caused by fungi are critical in potato production and require several synthetic fungicide options to reduce them to tolerable economic levels. Fungicides are preparations of different organic and inorganic compounds which can inhibit or destroy phytopathogenic fungi. These chemicals exert their effects by disrupting cell membranes of their targets or instigating catalytic enzymes in plant host tissue to suppress fungal growth and proliferation [48]. Practically, conventional management of potato diseases relies on the timely application of preventive fungicides [48, 49]. To control black rot disease, seed tubers are immersed in the fungicides thiabendazole, captofal, chloramizol sulphate, prochloraz, or a combination of each before field planting. Pencycuron and thiabendazole have also been documented to control black scurf and silver scurf effectively, respectively [26, 27]. Rahman et al. [50] demonstrated the effectiveness of Filthane M-45, Melody Duo, Secure, Metaril, and Ridomil gold to minimise Phytophthora infestans-induced late blight improve the yield of potato. More so, the application of dimethomorph, mancozeb, and fenamidone + mancozeb can significantly reduce the severity of late blight and increase potato yield [51]. The application of the antagonist *Trichoderma harzianum* combined with flutolanil seed dressing offers protection against *Rhizoctonia solani* damage throughout the growing season (Wilson et al., [52]. Although fungicides have been shown to manage potato diseases effectively, they are not without their attendant problems. It is now known that continuous application of fungicides results in resistance in many pathogenic fungi of potato. Whereas metalaxyl containing fungicides show good action against *Phytophthora infestans*, prolonged applications have resulted in resistant *P. infestans* [53]. Several metalaxyl-insensitive genotypes of *P. infestans* have been reported in different regions of the world. For example, in 1980, phenylamide resistant isolates of *P. infestans* were detected on field-grown potatoes in Netherlands, Switzerland, and Ireland [48, 49, 54]. In addition to fungicide resistance, the harmful consequences on non-target organisms, risk to soil environment, and carcinogenic potentials have discouraged the use of synthetic fungicides, thereby prompting the search for efficient, safe, and eco-friendly disease management options [55, 56].

4.2 Biological control

Disease management using biological control agents is touted as efficient alternatives to chemical fungicides as they are more eco-friendly and reduce the risk of the emergence of fungicide-resistant strains of plant pathogens [57, 58]. A biological control refers to the application of microbial antagonists or their by-products to inhibit plant diseases. Organisms that antagonise plant pathogens are known as biological control agents (BCAs). Such organisms are highly specific in their action against target pathogens, their products are biodegradable, and their mass production requires low cost [59, 60].

Here, we discuss the biological control strategies – microbial inoculants (beneficial, non-pathogenic single-strains of microorganisms that antagonise plant pathogens), microbial consortium (combination of different genera or species of symbiotically living microorganisms) isolated from the natural environment, and the application of phytoextracts [61–63].

4.3 Microbial inoculants

These are single strains of active beneficial microorganisms that offer protection against diverse pathogens or promote crop productivity and health when applied to crops or incorporated into the soil [63]. Microbial inoculants are an effective and cheap alternative strategy to reduce the severity of plant diseases [64–66]. *Agrobacterium*, *Pseudomonas*, *Bacillus*, *Alcaligenes*, *Streptomyces,* and others have been reported as effective bacterial control agents [16, 17, 60]. These organisms suppress bacterial and fungal pathogens by releasing active compounds, including siderophores, antibiotics, enzymes, and the plant hormone, indole-1,3-acetic acid. *Pseudomonas* strain has been widely investigated for their potential as BCAs because of their active nature and abundance in the rhizosphere [60]. Tariq et al. [67] demonstrated the antagonistic potential of *Pseudomonas* sp. StS3 against *Rhizoctonia solani,* which causes potato black scurf. *Streptomyces violaceusniger* AC12AB promoted growth by 26.8% and significantly reduced potato typical scab disease severity by up to 90% in field trials [66]. In addition to enhancing potato tuber biomass by 33% and 22% in two location field trials, *Bacillus amyloliquefaciens* strain BAC03 considerably reduced the severity of potato scab disease by 17–57% compared to control. BAC03 also enhanced potato tuber weight by 33% and 26% in the two locations [68].

4.4 Microbial consortium

This combination of BCAs consists of various microbial strains that synergistically confer enhanced plant growth activities and superior pathogen inhibition capabilities [69–71]. Compared to single-species microbial inoculants, the microbial consortium is more useful in field applications as it offers a wide range of biocontrol activities that promote inoculant efficiency and, in turn, improve plant growth and disease suppressability [56]. The application of a microbial product comprising a consortium of *Bacillus subtilis* and *Trichoderma harzianum* inhibited common scab disease in potato caused *Streptomyces* spp. by 30.6%–46.1%, and improved yield by 23.0%–32.2% [72]. Inoculation of *Fusaria* infested soil with a bacterial consortium of *Pseudomonas aeruginosa* (B4, B23, B25, and B35), *Alcaligenes feacalis* (B16), and *S. marcescens* (B8) was reported to not only suppress fusarium wilt of potato by 94% but also considerably improved plant biomass by 186.9% (Fresh weight) and 214. 75% (dry weight) [56]. Treatment with a consortium formulation comprising *Enterobacter amnigenus* strain A167, *Serratia plymuthica* strain A294, *Serratia rubidaea* strain H440, *S. rubidaea* strain H469 and *Rahnella aquatilis* strain H145 significantly reduced potato soft rot severity and incidence by 62–75% and 48–61%, respectively, when compared to a positive control with pathogens alone [73]. Also, a combination of rhizobacteria in combination with commercial arbuscular mycorrhiza fungi (AMF) have been reported to effective in abating bacterial wilt of potato [16, 17].

4.5 Phytoextracts

Green plants harbour a plethora of secondary metabolites that could serve as eco-friendly, natural alternatives to chemical fungicides [50, 74, 75]. Phytoextracts are botanicals, natural oils, and plant volatiles that show pest/pathogen control activities. They are usually extracted from fresh or dried plant parts using alcohol, water, or other solvents. Phytoextracts can be fungicidal or fungistatic in action and exert their effects by inducing conditions unfavourable for pathogen growth and proliferation [44]. The application of botanicals can significantly reduce the cost of crop protection and the occurrence of pathogen resistance [44]. Several phytoextracts have been widely tested and reported as effective suppressors of plant pathogens [50, 75]. Dried cheerota plant (*Swertia chirata* Ham.) and jute leaf (*Corchorus capsularis* L.) have been reported to exhibit *in vitro* antibacterial activity against *Erwinia carotovora* subsp. *carotovora* (Ecc) P-138 s, the causative pathogen of soft rot in potato. Under storage conditions, the plant extracts also considerably attenuated bacterial soft rot disease of different potato varieties [50]. Regardless of the mode of application (seed coating or soil inclusion), Canada milkvetch extract (MVE) effectively abated *Verticillium dahlia*-induced wilt by 55–84% in two potato cultivars – Kennebec and Russet Burbank compared to the control under growth room conditions. MVE also significantly reduced vascular discolouration and infection by 55% and 45%, respectively, in two potato cultivars in the first year of the field trial. In the second year, MVE reduced all wilt parameters by 19–31% while increasing yield by 18% on the cultivar Kennebec [76]. Soil drenching with aqueous leaf extracts of *Hibiscus sabdariffa*, *Eucalyptus globulus,* and *Punica granatum* substantially reduced the severity of bacterial wilt disease of potato relative to inoculated control under greenhouse and field conditions. While the reduction in disease severity under field conditions was similar (up to 63.23 to 68.39%) for all the three plant extracts, *E. globulus* leaf extract showed maximum abatement (94% reduction) of disease symptom development under greenhouse condition compared to extracts of *H. sabdariffa* and *P. granatum* [77]. Fumigation of seed tubers of potato with *Allium sativum* – derived essential oils has been shown to manage stem cancer, silver scurf, dry rot, black scurf, and gangrene in small–scale farming systems [78, 79].

4.6 Cultural control

A well-known cultural method to manage the diseases of potato is crop rotation. This refers to cultivating economic plants in recurrent succession and a sequential fashion on the same piece of land [80]. Rotation using different cover crops and suitable fallow periods can contribute to the attenuation of multiple soil-borne pathogens and diseases and enhance the diversity of beneficial soil microflora [81]. Evidence is mounting to show the use of *Brassica* spp. like cabbage, broccoli, cabbage, kale, cauliflower, turnip, rapeseed, canola, radish, different mustards, and other related plants as rotation or green manure crops [82, 83]. These crops produce sulphur-containing glycosinolates degraded as part of a biofumigation process to generate isothiocyanates deleterious to several soil pathogens. *Brassica* spp. have been effectively used to abate populations of soil-borne fungal pathogens, nematodes, and weeds and promote crop yield and soil properties [82]. Other non-brassica crops like ryegrass have good suppression ability over soil-borne pathogens. In several rotation studies, rapeseed and canola crops prior to potato cultivation significantly attenuated (in the range of 25–75%) soil-borne disease due to common scab and *Rhizoctonia* over many seasons to less successful rotations or no rotation [84, 85]. A field trial at a highly infested site with a powdery scab, ryegrass, rapeseed, canola, and Indian mustard grown as rotation crops and green manure suppressed powdery scab in the subsequent potato crop 15–40%. Additionally, rapeseed and canola abated black scurf by 70–80% compared to a standard oats rotation (**Figure 1**) [82].

S/N	Potato Diseases	Associated Pathogens	Pathogen Type
1	Bacterial wilt	*Ralstonia solanacearum*	Bacterium
2	Potato late blight	*Phytophthora infestans*	Fungus
3	Potato virus Y (PVY) disease	Potyvirus Y	Virus
4	Potato scab	*Streptomyces* spp	Bacterium
5	Early blight of potato	*Alternaria solani*	Bacterium
6	Internal blight	*Fusarium sambucinum or F. coeruleum*	Fungus
7	Silver scurf	*Helminthosprium solani*	Fungus
8	Black scurf disease	*Rhizoctonia solani*	Fungus
9	Pink rot	*Phytophthora erythroseptica*	Fungus
10	Soft rot	*Erwinia carotovora*	Bacterium
11	Yellow potato cyst nematode	*Globodera rostochiensis*	Nematode
12	White potato cyst nematode	*G. pallida*	
13	Root-knot nematodes	*Meloidogyne incognita, M.* spp, *Nacobbus aberrans*	Nematode
14	Potato rot nematode	*Ditylenchus destructor*	Nematode
15	Root lesion nematode	*Pratylenchus* spp.	Nematode
16	Stubby-root nematodes	*Trichodorus* spp. and *Paratrichodorus* spp.	Nematode
17	Lance nematode	*Hoplolaimus galeatus*	Nematode
18	Dagger nematode	*Xiphinema* spp.	Nematode

Figure 1.
Management strategies for potato diseases.

5. Methods for raising disease-free potato

Potato is affected by a wide range of fungal, viral, bacterial, and nematodal diseases [86]. These result in colossal yield loss annually. Therefore, it is imperative to exploit strategies for raising disease-free potato to reduce losses caused by pathogens, thus ensuring food security.

Some of the strategies for raising disease-free potato are:

5.1 Conventional plant breeding

The breeding of potato is a huge task due to inherent genetic and biological factors. Breeding for increased resistance to *Phytophthora infestans* (causal agent of late blight) is one of the most critical targets in potato breeding [87]. Plant breeders incorporated resistance against early and late blight disease by crossing hybrid lines with wild species (*S. brevidens* and *S. bulbocastanum*), which exhibited resistance against fungal pathogens [88, 89]. Potato plants resistant to diseases have been produced using conventional plant breeding. However, this process is tedious, and it takes time to achieve success.

5.2 Induced resistance

Resistance in plants can be induced by applying exogenous substances, or agents including living and non-living agents. Resistance to both fungal and viral diseases has been reported in potato. Quintanilla and Brishammar [90] reported systemic induced resistance to late blight in potato by treating with salicylic acid and *Phytophthora crptogea*. In their study, the non-pathogenic fungus *Phytophthora crptogea* and salicylic acid were used as inducer agents. Nadia *et al.*, [91] showed that chemicals under greenhouse and field conditions induced resistance against early and late blight diseases. The inducers used in this study were ascorbic acid, dichloro-iso-nicotinic acid, ethylene diamine tetraacetic acid, and calcium chloride. Chemicals and fungicides (at low concentration) can induce resistance [92]; similar reports include

Andreu *et al*., [93]. Several studies have reported using biological agents as inducers of resistance in potato [94–98] reported mycorrhiza-induced resistance in potato. Induced resistance against potato virus Y (PVY^{NTN}) has also been achieved [99].

5.3 Genetic engineering approach

Genetic engineering has been used to raise-disease free transgenic potato plants. However, this technique requires specialised skill, sophisticated equipment, and technical know-how. However, the problem of acceptance and ethical issues may also arise.

Extreme resistance to late blight disease by transferring 3 *R* genes from wild relatives into African farmer-preferred potato varieties was reported by [100]. Three late blight resistance genes from wild potato species were transferred as a stack into the farmer-preferred varieties, Tigoni and Shangi. *R* gene expression analysis in 18 transgenic events showed different transgenic events exhibiting different expression levels in the three genes. Engineering virus resistance using a modified potato gene has been reported by [101]. They reported that the transgenic expression of the *pvrl*[2] gene from pepper confers resistance to potato virus Y (PVY) in potato. The development of late blight-resistant potato by cisgene stacking was studied by Jo *et al*., [102].

RNA interference (RNAi) is an emerging post-transcriptional technique that has been used to produce crops resistant to diseases. Production of potato lines resistant to *P. infestans* through the RNAi technique has been reported [103]. RNAi technology can be directed to degrade the pathogen's mRNA that enters the host cell or silence endogenous genes of the host cell that aid pathogenicity. RNAi's mechanism of pathogen control is not dependent on producing a foreign protein that could be allergenic or toxic in the host plants. This makes this technology more acceptable than the typical transgenic approaches for disease control [104].

5.4 Plant tissue culture techniques

This technique can be used to produce disease-free pre-basic seeds. Disease-free pre-basic seed potato was produced through tissue culture in Nepal [105]. The use of disease-free seeds can help reduce the transmission of pathogens from propagating materials such as tuber to the field. It has been reported that quality seeds alone can increase yield by 15–20% in Bangladesh [106]. Therefore, micropropagation of potato can help reduce disease transmission through propagating materials; however, little has been achieved on the use of somatic embryos [107], and more researches are required for more remarkable breakthroughs in this regard.

5.5 New/advanced breeding techniques

Genome editing of potato using new technologies such as zinc-finger nucleases (ZFNs), transcription activator-like effector nucleases (TALENs), and clustered regularly interspaced palindromic repeats (CRISPR) associated nuclease 9 is currently been exploited. CRISPR/Cas9 has emerged as a breakthrough in gene editing; however, limited studies have been done on potatoes using this technique [108]. Genome editing using CRISPR/Cas9 has been used to engineer virus resistance in plants by targeting host genes directly involved in host-viral interactions [109–113]. This technique has been used to knock out potato genes/factors like eukaryotic translation initiation factors (*elf4E* and isoform *elf* (*iso*) *4E* that interact with viruses to assist viral infection [114]. Potato varieties resistant to viruses can be produced using this technique. Late blight resistance in potato has also been achieved using CRISPR/Cas9 genome editing. Functional knockouts of *stDND1*, *StCHL1,* and *DMG400000582* (*STDMR6*–1) genes generated increased resistance against late blight in potato [115].

Therefore, holistic and integrated approaches are required for raising disease-free potato in order to overcome the ever-evolving phytopathogens and mitigate losses; including post-harvest losses caused by these pathogens, therefore ensuring food security.

6. Conclusions

This chapter discusses the host-pathogens association of different diseases in potato and their impact on yield. The findings highlight management strategies of these diseases: chemical control, biological control, microbial inoculants, microbial consortium, phytoextracts, and cultural control. In addition, current methods for raising disease-free potatoes to reduce annual yield loss were reported in detail. Based on the presented findings, annual yield loss (pre-and post-harvest) is still high. Thus, the management strategies alone are promising but combining the different methods and exploiting disease-free potato can translate into an integrated management approach of potato diseases.

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Conflict of interest

The authors declare no conflict of interests.

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