Recent Advancements in Integrated Management of Potato Diseases


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Abstract

The sustainable potato production is a major challenge for agriculture professionals worldwide. Disease caused by fungi, bacteria's and viruses are amongst the major biotic constrains affecting quality and yield of potato tubers. With consistent climate change, chances of emergence of new virulent and aggressive races of fungus and biotypes of vectors are also high, which will pose more challenges in future. The successful disease management practices in potato involves cultural management, crop rotations, seed certifications, use of natural and synthetic pesticides, bioagents disease forecasting models, germplasm screening and developments of resistant varieties. With consistent pathogen pressure and emergence of more virulent strains it is mandatory to develop an integrated management approach which is holistic and sustainable along with economic feasibility for the poor farmers. The concern of health and environment deterioration by indiscriminate use of pesticides can also be addressed by implementing an integrated disease management approach in potato. The present

chapter discusses the impact of major diseases in potato production, resultant economic losses and the current management practices along with possibility of designing a suitable integrated disease management approach.

Introduction

Potato (*Solanum tuberosum* L.) is regarded as a future crop to ensure food security in developing countries like India (Haverkort and Struik, 2015). It is a global crop with diverse distribution pattern and extensively grown in areas of hunger, malnutrition and poverty as source of food and income for smallholder families. Currently the potatoes are cultivated on 19 million hectares area with a global production of 378 million tons (FAOSTAT, 2017). Worldwide, this vegetable crop occupies first position as non-cereal food crop for human consumption. In India, the total area of potato cultivation is 2.13 million hectares with annual production of 52.50 million tons. During the last 30 years, the popularity of this crop has extensively increased in Africa and Asia as compared to other staple crops. Any significant innovation based on potato science will be useful factor targeting the small and marginal famers dependent on this crop. Ensuring its sustainability is a major challenge for the agricultural professionals worldwide as many biotic and abiotic factors pose constant threats in potato production system. The biotic factors can cause up to 22% yield loss to the tuber both qualitatively and quantitatively (International Potato Center, Lima, Peru http://www.cipotato.org/; Food and Agriculture Organization, United Nations http://www.fao.org/).Among the biotic factors the diseases caused by viruses, fungi and bacteria's are the most serious threats hampering the potato crop to attain its optimum yield (Kumar et al. 2019; Tiwari et al. 2020a).The oomycete pathogen *Phytophthora infestans* causing potato late blight is still a major biotic constraint worldwide and cause a loss of €6.1 billion in global potato production system (Adolf et al. 2020). The late blight being the oldest disease of economic importance in potato is disastrous because of the rapid evolution of the pathogen and migration from other areas. The early blight on potatoes caused by *Alternaria solani* is found in most of the potato growing countries. The disease cause considerable yield loss in warmer areas during early season of potato growth and with late blight occurrence in late season the crop is devastated completely. The wart disease in potato is another fungal disease which is presently under the strict quarantine regulations across the world. The sporangia of this fungus can survive up to 40 years in soil which makes it a difficult disease to eradicate from the place of its occurrence. The fungal pathogen not only causes infection in field but losses in storage are much more devastating. The high amount of water content in tubers (~70%) makes it prone to rots, skin blemishes and galls during harvesting, transportations and storage (Czajkowski et al. 2011). Earlier, these rots were considered as minor and inevitable losses but in recent past the losses are much rigorous and profound especially for potato processing industries. The rapidly evolving and most virulent dry rot causing fungus, *Fusarium sambucinum* is present in most of the potato growing countries. Dry rot directly damages the crop stand by inhibiting the development of potato sprouts and cause loses up to 25% with infection up to 60% during storage (Wharton et al. 2007). These damages become more serious with infection of disease such as soft rot and late blight accompanying dry rot during storage.

The phytopathogenic bacteria *Ralstonia solanacearum* cause wilt disease in potato is solely responsible for a loss of US$1 billion each year in 80 countries (Elphinstone, 2005). Genus *Ralstonia* is already regarded as second most devastating phytobacteria after *Pseudomonas syringae* (Mansfield et al. 2012). Other bacterial disease like soft rot, black leg and stem rot cause loss of huge capital to the farmer since these diseases occur after farmer has given full inputs to the crop. The common scab caused by gram positive actinomycetes is a disease of worldwide occurrence and great economic importance (Braun et al. 2017). Worldwide, there are more than 50 viruses which infect the potato and some of them cause great economic losses. There are various factors which determine the estimation and yield losses by viruses such as virus strain, variety, season and growing conditions (Kreuze et al. 2020). The most important viruses for major loss in potato cultivation are *Potato virus Y* (PVY), *Potato virus X* (PVX), *Potato leaf roll virus* (PLRV), *Tomato leaf curl New Delhi virus* (ToLCNDV) and *Groundnut bud necrosis virus* (GBNV). The yield reduction is one effect of viral infection but deterioration of potato quality is another factor which is seen in form of internal and surface necrosis on tubers.

The management of fungal and viral diseases in potato is a major challenge is potato production system. The successful disease management practices in potato involves cultural management, crop rotations, seed certifications, use of natural and synthetic pesticides, bioagents disease forecasting models, germplasm screening and developments of resistant varieties. With consistent pathogen pressure and emergence of more virulent strains it is mandatory to develop an integrated management approach which is holistic and sustainable along with economic feasibility for the poor farmers. The concern of health and environment deterioration by indiscriminate use of pesticides can also be addressed by implementing an integrated disease management approach in potato. The present chapter discusses the impact of major diseases in potato production, resultant economic losses and the current management practices along with possibility of designing a suitable integrated disease management approach.

Major pathogens infecting potato

Potato is devastated by a large number of fungal, viral and bacterial pathogens (Table 1). The fungal diseases pose a threat to potato cultivation in Eastern Europe and Russia where millions of people are subsisting on potatoes. Region wise importance of late blight shows that it takes highest toll of potato in Sub-Saharan Africa followed by Latin America, Caribbean, South-East Asia, South-West Asia and Middle East and North Africa. In India it is most severe in temperate highlands followed by tropical highlands and subtropical plains. In the subtropical plains, the disease assumes epiphytotic proportions once in 4 to 5 years. It is somewhat regular in north-eastern plains of Bihar, Assam and Orissa as compared to western plains (Arora et al. 2014). Late blight in recent years has become a serious problem in Karnataka during *kharif* season. Disease symptoms can be seen on leaves (brown to dark water-soaked spots), stem (brown or grey spots) and tubers (depressed cavities with brownish appearance). Under the favorable condition of high humidity and low temperature the disease can destroy whole potato crop in a field within a few days (Perez and Forbes, 2010; Fry et al. 2015). Early blight caused by *Alternaria solani* is prevalent in many countries in Asia, Africa, Australia, Europe, North, Central and South America. In India though the disease occurs wherever potatoes are grown but heavy incidence occurs in central India and plateau regions (Arora et al. 2014). The disease often affects the plants which show loss of vigor. It is particularly severe under alternate dry and wet climate where the annual loss from this disease could range between 10 to 25 per cent. Typical target spot symptoms (dark brown and black spots with concentric rings) of this disease can be observed on the infected leaves (Gannibal et al. 2014). The dark brown and black necrotic lesions which appear on the foliage are mostly limited by veins and those concentric rings are seen in larger lesions. The losses due to this disease are more than 20% of total loss due to disease in Australia (Horsfield et al. 2010). Black scurf of potato is caused by *Rhizoctonia solani.* It is a well-known disease of potato with worldwide distribution. It causes damping off of the seedlings, stem canker in growing plants and black scurf on potato tubers. The disease kills potato sprouts, delay crop emergence, reduce crop stand, affects tuber quality and thus marketability of the produce (Lal et al. 2017). The occurrence of black irregular lumpy encrustations of fungal sclerotia which stick to the surface of the tubers reduce the marketable value of produce. Potato wart has been reported in Asia, Africa, Europe, Oceania, North America, and South America. In India, it is prevalent in Darjeeling hills. Spherical outgrowths or protuberances appear on buds and eyes of tubers, stolons, underground stems, at stem base and occasionally on above ground stem, leaf or flowers. Importance of wart disease can be estimated from the fact that since last 65 years this disease in under strict quarantine and domestic legislations (Anon, 2015). The disease is a potential threat for international trade market and in India itself it is under strict quarantine regulations in Darjeeling hills. The dry rots in potato caused by *Fusarium* sp. is a major disease of potato in field as well as storage. The most predominant fungus causing this rot, *Fusarium sambucinum* is present in most of the potato growing countries (Sagar et al. 2011). An estimated loss due to dry rots in United States is US$100–250 million. More than 50% seed lots in Michigan when inspected were having some level of dry rot infection (Gachango et al. 2012). Presently, silver scurf disease caused by *Helminthosporium solani* is also emerging as major threat in potato cultivation (Tiwari et al. 2020b). The fungus can affect the crop in field as well as in storage. The symptoms include silvery lesions on the surface of infected tubers. However, sometimes the infected tubers do not show symptoms of the disease but on getting favorable conditions in stores may cause heavy loss in potatoes.

In tropics, subtropics and warm temperate regions the losses due to bacterial diseases are pretty high in potato. The losses caused by bacterial disease are more profound as majority of these pathogens directly attack the tubers. The most important bacterial disease is bacterial wilt caused by *Ralstonia solanacearum* (Salgon et al. 2017). The infected plants show wilting during the warmest time of the day and usually sectoral wilting is observe. The whole plant wilts and dies if favourable condition persists for many days. Chlorosis, bronzing and epinasty can also be observed in severely infected plants. Bacterial soft rot of potato occurs wherever potatoes are grown. The disease affects the crop at all the stages of its growth but it is more serious on potato tubers stored under poorly ventilated conditions especially in warm and wet climate. *P. atrosepticum* is the predominant species responsible for black leg on potato while *P. carotovorum* often cause soft rot in storage (Charkowski, 2018). The simultaneous or sequential occurrence of soft rot, black leg and stem rot cause huge economic losses in potato. Another devastating disease called Common scab caused by *Streptomyces* spp. occurs in most potato producing areas in Africa, Asia, Europe, North and South America. Most of the underground parts of potato are affected with necrosis and severe infection kills the seedlings (Han et al. 2008). The symptoms may vary from pitted scab, erumpent scab, to netted scab based on the species involved in the infection. It has spread in many locations in the Indo Gangetic plains due to continuous cultivation of potato in the same land. Another disease called zebra chip is emerging consistently and becoming a disease of worldwide importance. The disease affects both foliage and tubers very severely. Foliage symptoms include leaf curling, shortened internodes, necrosis, aerial tubers and plant death (Buchman et al. 2012). The tubers show brown necrotic streaks with unique pattern giving it a name as zebra chip disease. However, the disease is not causing any significant loss in India.

Viruses are presently the most notorious constraints in potato production. With sub-tropicalization of potato the chances of outbreak of diseases caused by minor viruses are also very high (Jeevalatha et al. 2017; Kumar et al. 2019). The vector dynamics are also changing in the wake of climate change. PVY is one of the most economically important viruses of potato worldwide including India. Depending on cultivars and virus strains, it can cause up to 80 % yield reduction. PVYO occurrence is worldwide. However, PVY^{N} and PVY^{NTN} strains are limited to certain countries, and therefore, are of quarantine significance. PVX is found wherever potatoes are grown. In nature it is largely confined to members of the family *Solanaceae*. Yield losses of 15–20% can occur with widespread infection PVX (Kumar et al. 2019). The virus interacts with PVY and PVA to cause more severe symptoms and still higher yield loss than either virus alone. PVA has worldwide distribution. In India it most often observed as combined infections with PVX and PVY. PVA alone can cause 30-40 % yield reduction while it is still higher in case of co-infections with PVX and PVY. PVS occurs worldwide. It is the most frequently found virus in potato. An incidence of 8.5 to 99.5% has been recorded in Indian potatoes at different locations. Reduction in tuber yield is very low but may go up to 10-20% or more when combined with PVX. Potato leafroll virus (PLRV) is found wherever potatoes are grown. The infected plants may 50% or more reduction in yield. PLRV is probably the most important potato virus worldwide (Kreuze et al. 2020). In India, apical leaf curl disease of potato was observed in 1999 from Northern India. Association of a begomovirus with this disease using immunoelectron microscopy was confirmed and it was found as a strain of *Tomato leaf curl New Delhi virus*. About 40-100 % of infections have been recorded in Indo-Gangetic plains and hisar area of India with heavy yield losses in susceptible varieties (Jeevalatha et al. 2017). The incidence of this virus is also reported from Bihar, West Bengal and warm areas of Himachal Pradesh, Rajasthan and Gujarat, but at lower level. Significant decrease in size and number of tubers lead to marketable yield loss as high as 50% in early planted susceptible cultivars (Chandel et al. 2010). The affected plants show curling/crinkling of apical leaves with a conspicuous mosaic symptom. The symptoms of various diseases affecting potato is shown in Fig. 1.

Table 1. List of the important fungal, bacterial and viral pathogens infecting potato in India

Disease	**Causal agent**
Fungal diseases	
Late blight	*Phytophthora infestans* Mont de Bary
Early Blight	*Alternaria solani* Sorauer
Potato wart disease	*Synchytrium endobioticum* (Schilb.) Perc.,
Powdery Scab	*Spongospora subterranea*
Potato dry rot	*Fusarium* species
Silver scurf	*Helminthosporium solani*
Black scurf	*Rhizoctonia solani*
Bacterial diseases	
Bacterial Wilt of Potato	*Ralstonia solanacearum*
Bacterial Blackleg and Tuber Soft Rot	Genera *Pectobacterium and Dickeya,*
Potato Ring Rot	*Clavibacter michiganensis* Subsp. *sepedonicus*
Common Scab of Potato	*Streptomyces* Species
Zebra Chip of Potato	"*Candidatus* Liberibacter"
Important viral diseases in India	
Potato virus Y (PVY)	*Potyvirus, Potyviridae*
Potato virus A (PVA)	*Potyvirus, Potyviridae*
Potato virus V (PVV	*Potyvirus, Potyviridae*
Potato virus X (PVX)	*Potexvirus, Alphaflexiviridae*
Potato leaf roll virus (PLRV)	*Polerovirus*
Groundnut bud necrosis virus (GBNV)	*Tospovirus, Bunyaviridae*
Tomato leaf curl New Delhi virus (ToLCNDV)	*Begomovirus,* *Geminiviridae*

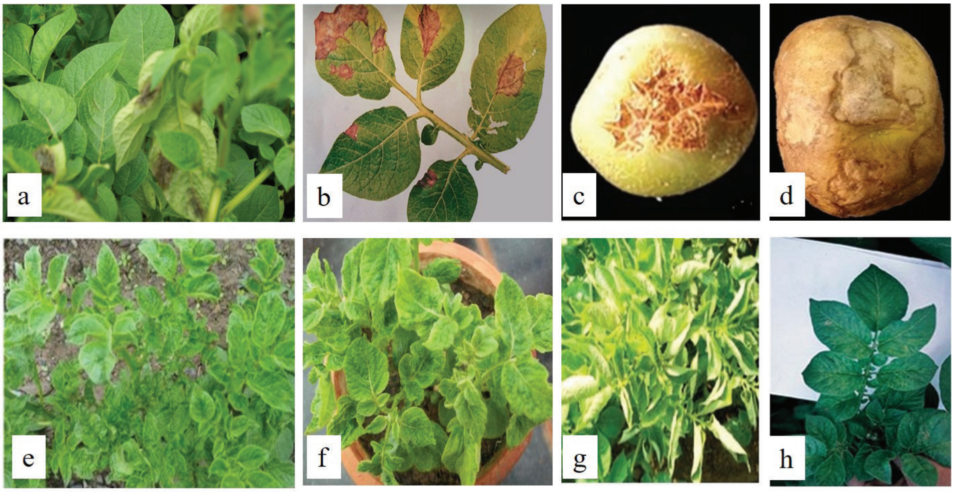

Fig. 1. The disease symptoms of a. Late blight, b. Early blight, c. Common scab, d. Dry rot, e. Potato virus Y, f. Potato apical leaf curl disease, g. Potato Leaf Roll Virus, h. Potato virus X

Integrated Management of potato diseases: Past, present and future

Integrated management is a holistic ecosystem approach for crop production and protection with focus on environment sustainability and economic feasibility. Integrated disease management (IDM) to combat potato pathogens requires the implementation of multiple approaches. A unified management strategy involves the sound seed certification system, appropriate phytosanitary measures, use of resistant cultivars, need based pesticide application and managing the tubers during harvest and storage (Kumar et al. 2019). The increasing intercontinental trade in potato poses a threat for emergence and spread of pathogens worldwide. With advancement in the molecular science and computational technology supplemented with increasing awareness of information technology several advancements have been observed in the management of diseases in potato. The most devastating late blight which is a polycyclic disease capable of causing epidemics under favorable conditions must be managed through an integrated approach. These include, phytosanitary measures to reduce the primary inoculum load, prophylactic sprays of fungicides, judicious curative sprays, use of resistant cultivars and early maturing cultivars to reduce duration of infection etc. The early blight disease is mainly controlled by the use of cultural practices (minimize soil born inoculum), growing tolerant and less susceptible cultivars and the use of fungicides (Volz et al. 2013). Most potato viruses are managed by using three principal methods: cultural practices, clean seed systems, and host plant resistance. This section gives a comprehensive analysis of traditional and modern management practices (which are an integral component of IDM) against major potato pathogens. An iluustration is also made to highlight the IDM principles in potato along with stage specific management strategies (Fig. 2).

Host Plant Resistance

In any disease management program, the development of resistant varieties and utilizing the inherent resistance capacity of the plants is the best possible way of managing a disease. The wild Mexican potato cultivar *Solanum demissum* was an excellent source of disease resistance specifically late blight disease from which 11 resistance genes were incorporated in present day major potato cultivars (Black et al. 1953; Malcolmson and Black, 1966). The gene R8 is still sowing high resistance against the disease (Vossen et al. 2016). More than 50 R genes are reported now against late blight pathogen but only few successful crosses are there because of linkage drag and crossing barriers. The modern genomics approaches must be used in future to reduce the lengthy breeding procedure and due to develop transgenic or non-transgenic resistant varieties. The cultivars showing less susceptibility against early blight are very limited and no resistant cultivar is available. In general, early maturing cultivars are more susceptible than late maturing varieties (Abuley et al. 2017). Initially, the conventional breeding programs proven helpful in manging wart disease in potato using resistant cultivars (Obidiegwu et al. 2014). The pathotype 1(D1) of *S. endobioticum* was successfully restricted using dominant resistant genes. Unfortunately, other pathotypes developed which were very difficult to manage. Currently, researchers identified a locus Sen2 on chromosome XI which proved resistant against seven virulent pathotypes of wart causing fungus pathotypes (Plich et al. 2018).

The available host resistance against bacterial disease in potato is elusive. Conventional breeding has not given suitable resistant varieties. For bacterial disease of solanaceous crops studies have been done in tomato where R gene identified in Arabidopsis and transferred in tomato gave resistance against this disease (Narusaka et al. 2013). Strain specific QTLs showing broad spectrum resistance have been identified in tomato, tobacco and brinjal (Salgon et al. 2017). Similar studies are also required in potato to develop resistant cultivars. The genetic basis of resistance against common scab disease is described as suberization of phellum, thickening of phellum layer, thaxtomin detoxification, expression of defence genes (Thangavel et al. 2016). PVY is now the most widespread viral pathogen in potatoes in most countries. For PVY resistance, breeders have identified and introduced resistant gens in major potato cultivars but these cultivars are show strain specific resistance. A single mutation in helper component gene of PVY^{O} leads to breakdown of resistance (Tian and Valkonen, 2013). Best option here is to stacking many strain-specific PVY resistance genes in popular cultivars. PVX resistance gene Rx, Nx, Nb are identified in Australian, American and European cultivars. ToLCNDV-[potato] resistance in potato cultivars has been observed in India (Jeevalatha et al. 2016).

Cultural management

In any successful disease management program cultural practices play a key role in eliminating the primary inoculum, reducing the chances of survival, minimizing secondary spread etc. The chance of late blight, black scurf and dry rots can be minimized if the infected and rotten tubers are separated from the heaps (Nyankanga et al. 2004; Bojanowski et al. 2013). Removal of dead and decaying tubers and plant debris minimize the survival of oospores of Phytophthora infestans. Additionally, the field sanitation minimizes the chance of survival of virus vectors in the field and viral diseases are also minimized. Making high ridges, limiting irrigation in the field after blight appearance, infected haulm cuttings are some of the key management practices for late blight and early blight diseases (Arora et al. 2014). Solanaceous crops should be avoided near potato field for managing blights. Sprinkler irrigation also favors blights which should be avoided. To manage black scurf the healthy seed being free from sclerotia should be used. Soil solarization using transparent poly sheets reduces the soil borne diseases like black scurf and dry rots and common scab in potato (Lal et al. 2017). A crop rotation with cereals and legumes for two to four years reduces the occurrence of black scurf in potato. A rotation of green manure- potato – wheat crops can reduce soft rot. Biofumigant plants (e.g. white mustard, leaf radish) can reduce the early blight disease progression in the crop (Volz et al. 2013). Some soil amendments are reported to manage the common scab by increasing nonpathogenic Streptomycetes. These include, chelated iron, peat can, or rice bran, which are easily available and can be incorporated in the soil (Sarikhani et al. 2017).

Careful inter cultivation practices and minimizing the bruises during transportation and storage reduces the losses due to dry rots and bacterial soft rots in potato. Alternatively, the delay in harvesting after haulm cutting which allows the bruises to heel may also reduce several soils borne disease in potato (Charkowski, 2018). Planting of whole seed potato in a well-drained soil with temperature around 10 to 13°C at low planting depth can reduce incidence of blackleg. Irrigation management is crucial to manage common scab in potato especially during tuber initiation to maturity stage (Han et al. 2008). Use of Virus free certified seeds is the best approach in managing virus diseases. PVX, PVY, PVA and PVM viruses are readily transmitted through contaminated hands, clothes of workers, farm machineries/ tools (Kumar et al. 2019). It is necessary to disinfect all field equipment's by dipping in or washing them either with 3% trisodium phosphate or calcium hypochloride (1%) solution for controlling sap transmitted viral diseases in potato. Elimination of sources of the virus through rouging of diseased plants in seed crops and killing of volunteer plants reduces the risk of spread of PLRV. The seed plot technique is a successful method of preventing outbreak and spread of vector borne diseases. However, with change in climate and increasing vector pressure there is a need to explore seed production is nontraditional areas (Singh et al. 2014).

Biological management

Biocontrol agents and biopesticides could be a safe option to the use of synthetic fungicides. Antagonism to *P. infestans* by some naturally occurring microorganisms such as *Trichoderma viride*, *Penicillium virdicatum*, *P. aurantiogiseum, Chetomium brasilense*, *Myrothecium varrucaria*, *Penicillium aurantiogriseum, Epiccocum purpuranscens*, *Stachybotrys coccodes*, *Pseudomonas syringae*, *Fusarium graminearum*, *Pythium ultimum, Pseudomonas fluorescens, Pseudomonas* sp. *Aspergillus flavus, A. niger, Penicillium* sp., *Trichoderma virens* and *T. harzianum* have been observed in laboratory and field studies (Yao et al. 2016; Gupta, 2016). The biopreparation Gluticid (*Pseudomonas aeruginosa)* and alirin-B and gamair (*Bacillus subtilis*) have been reported as effective against early blight. A bioformulation developed at Central Potato Research Institute from *T. viride* strain A-7 was found very effective when used as seed treatment applied before planting potatoes. Efficacy of *Trichoderma viride, Bacillus subtilis* and *Bacillus cereus* in consortium further improved the for control of *Rhizoctonia solani.* Combination of biocontrol genera *Enterobacter* and *Pseudomonas* and two chitinolytic enzymes from *Trichoderma harzianum* has been reported to have inhibitory effect on spore germination of *F. solani* (Mawar and Lodha, 2008). *Bacillus subtilis* (strain B5) recovered from rhizosphere soil of potato plants from bacterial wilt infested fields of Bhowali, Uttarakhand controlled tuber borne *Ralstonia solanacearum* under different agro-climate conditions and enhanced the crop yield (Reddy, 2010; Arora, 2011). A bio-formulation of *Bacillus subtilis* (strain B5) has been developed at CPRI and is being promoted for the disease control. Bio-control of common scab using antagonists such as *Bacillus subtilis*, non-pathogenic *Streptomyces* spp. and bio-pesticides such as *Geranium pretense* have shown to be effective against common scab.

Simulation tools to manage major diseases in potato

The better way of integrating management element and implementation is through simulation models and decision support systems (DSS). The disease forecasting and subsequent protection of crops form disease outbreak is very well established in potato against late blight disease. In subtropical plains of India, the late blight prediction model 'JHULSACAST' developed by Singh et al. (2000) is very much effective in preventing the disease epidemics. The model was initially developed for western Uttar Pradesh but now has been modified and used in Punjab and other areas of the country. The developed DSS integrate and organize information related to Phytophthora life cycle, monitoring the inoculum load, weather details, cultivar growth and resistance, fungicide characteristics, etc. DSS can provide very site-specific information to the farmers via telephone, extension officers, e-mail, SMS, and websites (Cooke et al. 2011). Such kind of models and DSS are also needed in managing other diseases.

Chemical based management

Spraying with an effective fungicide has been a standard practice for control of late blight. Mancozeb has been the most common fungicide used worldwide to manage late blight. The first prophylactic spray of the fungicide should be given shortly before the canopy in the rows is about to close. Normally 3 to 4 sprays of mancozeb applied at an interval of 7 to 10 days on a moderately resistant cultivar are sufficient to manage the disease in the Indo Gangetic plains (Arora et al. 2014). In case of susceptible and highly susceptible varieties first prophylactic spray of mancozeb should be followed by a spray of translaminar or partly systemic fungicides such as cymoxanil, dimethomorph or fenomidone in combination of a contact fungicide and the third spray should be mancozeb again. In hills, a prophylactic spray should be followed with mixture of translaminar + contact fungicides followed by fourth spray as mancozeb. Crop sprayed with one percent urea at 45 days of growth improves plant vigor and prevents onslaught of early blight and other leaf spots (Tsedaley, 2014). The use of calcium cyanamide results reduced infection onset of early blight disease, also the degradation of calcium cyanamide can reduce the surviving inoculum in the soil (Volz et al. 2013).

Fungicides such as maneb, zineb, mancozeb, captafol, chlorothalonil provide good control of the disease. First spray should be applied as soon as lower leaves develop the spots which coincide with the secondary spread of the disease. Use of mancozeb and chlorothalonil delays the disease progress. Similarly, the use of Pyton Consento 450SC @ 2l/ha, Zoxamide + mancozeb, fenamidone + mancozeb; potassium or sodium bicarbonate alone or in combination with Nerol and kresoxim-methyl have been reported to be effective against early blight (Arora, 2011; Tsedaley, 2014). Seed treatment with 3% boric acid before storage has been identified as a safe and effective chemical treatment for the control of black scurf. Tuber treatment with 1200 ppm thiabendazole or benomyl can reduce the disease incidence. However, resistance to thiabendazole in *Fusarium* has been reported. Fungicides such as imazalil and mixtures containing TBZ have also found effective for control dry rot. Application of bleaching powder @ 12 kg/h mixed with fertilizer or soil drenching after first earthing up help to reduce incidence of bacterial wilt (Arora and Sharma, 2014). Tuber treatment with 3 percent boric acid or 0.05 percent copper sulphate or 160ppm kasugemycin have also been reported to reduce soft rot. Seed treatment with 3% boric acid as dip for 30 minutes can be used for management of tuber borne pathogen (Singh et al. 2012). The scab disease can also be reduced by use of acidic fertilizers such as ammonium sulfate, single super phosphate; and potassium chloride (Dees et al. 2012). The common fungicide to manage scab includes fludioxonil as a tuber treatment, chloropicrin as a soil fumigant, and pentachloronitrobenzene for in-furrow treatment (Al-Mughrabi et al. 2016). Fluazinam is also reported to provide good control against common scab.

To manage the aphid vectors, treatment with imidacloprid (200SL) @ 0.04% (4ml/10lit) for 10 minutes before planting is recommended. Provide first spray with imidacloprid (200SL) @ 0.03% (3ml/10lit) at the time of emergence of crop and second spray with thiamethoxam (25WG) @0.05% after 15 days of crop emergence (Chandel et al. 2010; Kumar et al. 2019). Phorate (Thimet) 10 G @ 10 kg /ha at earthing provides good protection against vectors. Alternative insecticides such as thiamethoxam (25WG) @0.05% is also helpful in late buildup vector management. Chloronicotinyl, imidacloprid, pyridine azomethine and pymetrozine have been reported to be highly effective in reducing transmission of PLRV from infected to healthy potato plants by *M. persicae*. The synthetic pyrethroid, esfenvalerate, was effective in reducing inoculation of PLRV by virus-infected aphids into potatoes due to its repellent effect, but not virus acquisition by aphids from infected plants (Bholanath and Palash, 2014). Application of mineral and vegetable oils has been found to inhibit virus transmission. This can also help to avoid development of insecticide resistance in whiteflies.

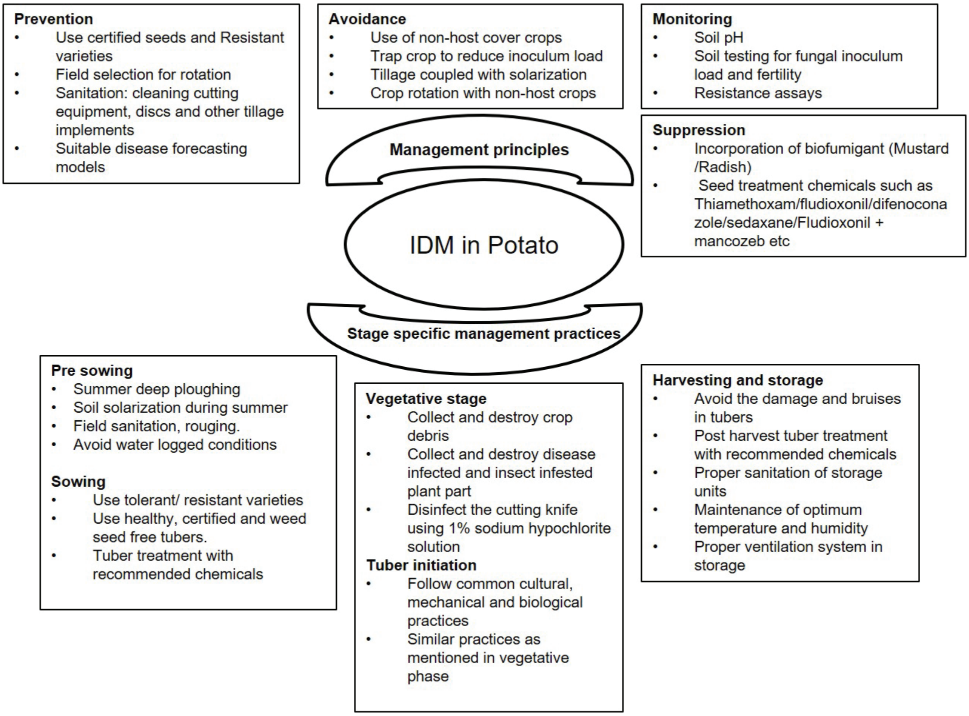

Fig. 2. The principals and practices of Integrated disease management in potato.

Conclusion and future thrust

Potato is the future crop for ensuring global food security and minimizing the losses due to biotic stress is an integral component of sustainable potato production. The formulation, adaptation and utilisation of integrated disease management will be crucial for resilient and profitable potato production worldwide. The emphasis should be given to the use of management approaches which minimize the fungicide burden and promote the environment sustainability. Present research opportunities in managing potato diseases depend on pathogen inoculum studies, fungicide, adoption of resistant cultivars and DSSs. In addition to ongoing research and extension activities, collaboration with the agro-chemical industry is necessary to fully achieve integrated disease management strategies. The improvement of disease management skills of farmers through capacity building program, coupled with use of disease-free tubers and resistant cultivars, novel and rapid diagnostic tools and broad-spectrum low toxicity fungicides have potential for sustainable management of potato diseases.

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