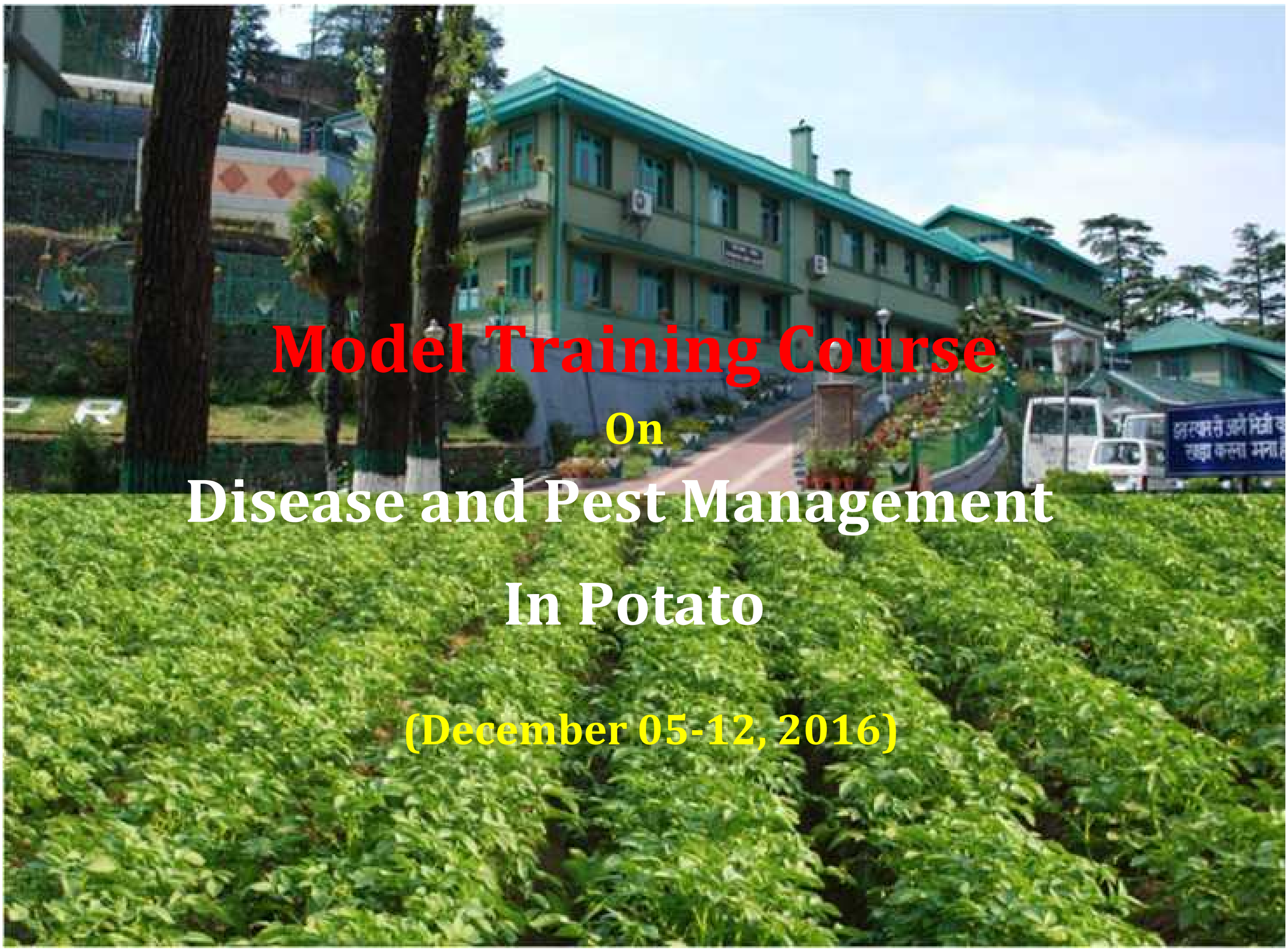

Model Training Course

On

Disease and Pest Management In Potato

(December 05-12, 2016)

SANJEEV SHARMA
VINAY SAGAR
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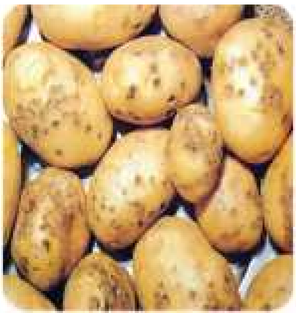

Sponsored by: Directorate of Extension, DACFW, New Delhi
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भा.कृ.अनु.प.-केन्द्रीय आलू अनुसंधान संस्थान
ICAR-CENTRAL POTATO RESEARCH INSTITUTE
शिमला- 171 001, हि.प्र. (भारत)
SHIMLA- 171 001, H.P. (INDIA)

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Foreword

Potato is the third most important food crop in the world after rice and wheat with a record global production of 365 million tonnes. India is the second largest producer after China with a production and productivity of 48 MT and 23.6 t/ha, respectively. However, it is projected that India need to produce 55 and 122 MT by 2025 and 2050, respectively to meet the demand of the growing population. But, often the potential yield of potato is limited by number of biotic and abiotic factors in hills, plains and plateau regions in India. Among the biotic factors, diseases such as late blight, common scab, bacterial wilt, viral diseases (especially PVY, PLRV and ToLCNDV-potato), potato cyst nematodes and insect-pests such as aphids, whiteflies, white grubs, cutworms and PTM etc. cause huge economic losses to potato in India. Besides, new pests and diseases such as new pathotypes of late blight, new strains of PVY, groundnut bud necrosis virus, interception of quarantine viruses, new vectors, thrips, leafhoppers and mites are emerging and posing threat to potato production. Mainly potato viruses have been posing insurmountable problems in production of disease-free quality seed which is the most critical component for potato production. With liberalization in imports, newer pests and pathogens are finding their way into the country which further endangers potato production. Therefore, pests and diseases occupy pivotal role in achieving sustainable potato production and need management strategies. The need of the hour is to sensitize and educate various stake holders such as officials of line departments to disseminate latest technologies to farmers, in identification of different pest and pathogens and equip them with better understanding about integrated management strategies for pests and diseases. This training manual is aimed at providing information, which includes all possible management strategies which could be practiced at field level for the management of potato diseases and pests. I am sure that this training manual will be of great use to technical workers, plant protection officers, farmers and all those who deal with potato crop. I congratulate the contributors and editors of this manual for their efforts in compiling the information with latest updates on integrated management strategies for potato diseases and pests for the benefit of the potato fraternity.

(S K Chakrabarti)

Director
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Chapter 1

Potato in India: Past, Present and Future

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Introduction

Potato (*Solanum tuberosum* L.) is one of the most important food crops after wheat, maize and rice, contributing to food and nutritional security in the world. This tuber crop of the family solanaceae has about 200 wild species. It originated in the high Andean hills of South America, from where it was first introduced into Europe towards the end of 16th century through Spanish conquerors. There the potato developed as a temperate crop and was later distributed throughout the world largely as a consequence of the colonial expansion of European countries. It was introduced to India by early 17th century probably through British missionaries or Portuguese traders.

The potato is an annual, herbaceous, dicotyledonous and vegetatively propagated plant. It can also be propagated through botanical seed known as True Potato Seed (TPS). The potato tuber is a modified stem developed underground on a specialized structure called stolon. It contains all the characteristics of a normal stem like dormant bud (eye) and scaly leaf (eyebrow). Potato tuber is a bulky commodity which responds strongly to its prevailing environment thus needs proper storage. Potato is a highly nutritious, easily digestible, wholesome food containing carbohydrates, proteins, minerals, vitamins and high quality dietary fibre. A potato tuber contains 80 per cent water and 20 per cent dry matter consisting of 14 per cent starch, 2 per cent sugar, 2 per cent protein, 1 per cent minerals, 0.6 per cent fibre, 0.1 per cent fat, and vitamins B and C in adequate amount. Thus, potato provides more nutrition than cereals and vegetables. Keeping in view the shrinking cultivable land and burgeoning population in India, potato is a better alternative to deal with the situation.

In Europe the potato crop is grown in summer having long photoperiod of up to 14 hours and the crop duration of 140-180 days. The potato in Indian plains is, however, grown in completely contrasting situations. Nearly 85 per cent of the crop is grown during winters having short photoperiod (with about 10-11 hours sunshine) and the crop duration is also limited to 90-100 days because of short and mild winter. The mornings usually have fog, which further reduces the sunshine hours posing severe constraints on photosynthetic activity. Besides, the post-harvest period consists of long hot summer, which creates storage problems. All these problems called for suitable varieties and technologies for growing potatoes under the sub-tropical conditions of India. This Potato Scenario-Past, Present and Future necessitated to initiate indigenous potato research and development programmes, and accordingly the Central Potato Research Institute (CPRI) came up in 1949 at Patna. The headquarters was later on shifted to Shimla in order to facilitate hybridization and maintenance of seed health. In 1971 the All India Coordinated Research Project (AICRP) on potato was initiated under the aegis of the Indian Council of Agricultural Research (ICAR) at the CPRI with an objective to coordinate potato research and development in the country across diverse agro-ecological regions. The success story of over five decades of potato research in India is phenomenal. Compared to the area, production and productivity in 1949-50, the increase over this period is 832 per cent, 2963 per cent and 345 per cent, respectively. India now ranks third in potato area (1.99 million ha) and second in production (45.34 million tonnes) in the world with an average yield of 222.7 q/ha. It was only because of indigenously developed technologies that potato in India has shown spectacular growth in area, production and productivity during the last five decades. The major achievements of potato research in India are as under:

Varietal Improvement

So far 53 potato varieties have been bred for different agro-climatic regions of the country with 28 varieties alone for north Indian plains. Varieties have also been developed for north Indian hills and other special problem areas viz. Sikkim, north Bengal hills and south Indian hills. Of the 53 varieties developed, 19 possess multiple resistances to different biotic and abiotic stresses. Besides, ten varieties are suitable for processing purposes. These are Kufri Chipsona-1, Kufri Chipsona-2, Kufri Chipsona-3, Kufri Chipsona-4, Kufri Himsona, Kufri Frysona, Kufri Jyoti, Kufri Chandramukhi, Kufri Lauvkar and Kufri Surya. All these varieties fall in three maturity groups, i.e. early (70-80 days), medium (90-100 days) and late (110-120 days). The potato varieties developed by CPRI are grown not only in India but also in several neighbouring countries. The variety Kufri Chandramukhi is grown in Afghanistan, Kufri Jyoti in Nepal and Bhutan, and Kufri Sindhuri in Bangladesh and Nepal. Besides, five Indian hybrids are also commercially grown in Sri Lanka, Madagascar, Mexico and Philippines.

Seed Plot Technique

This technique was developed in 1970s to enable healthy seed potato production in the sub-tropical Indian plains under low aphid period. This technique aided by bio-technological approaches for virus elimination, micropropagation and effective viral diagnostics has sustained the National Potato Seed Production Programme by producing about 2600 tonnes of breeder's seed annually. This breeder's seed is further multiplied to about 4,32,000 tonnes of certified seed by the State Departments of Agriculture/ Horticulture. Thus, the country saves about 484 million US dollars because most Asian countries like Pakistan, Bangladesh and even China continue to import seed potatoes from Europe. The decentralization of potato breeding from hills to plains in India through the seed plot technique enabled the development of varieties suited to different agro-climatic regions of the country. The area under seed potato production also increased by 12 times and enabled the availability of seed potato throughout the country in proper physiological state. Tissue Culture Efforts are being made to improve seed health standards and reduce the time required for production of breeder's seed by employing *in vitro* techniques of meristem culture and micro-propagation. Presently, about 30 per cent of Breeder's seed production programme is fed annually by hi-tech seed production. It is proposed to produce 100 per cent of breeder's seed through tissue culture propagated material in the years to come.

Agro-techniques

The development of package of practices for potato production in different agro-climatic zones has helped in improving potato productivity in these zones. The potato crop is input intensive and requires optimum cultural practices for achieving higher productivity. Optimum cultural practices depend on delineated phenological phases of crop growth and development viz. pre-emergence, emergence to tuber initiation, tuber initiation to tuber bulking and tuber bulking to termination of bulking. The cultural practices are adjusted in the Indian plains in a way so that tuber initiation and development coincide with the period when night temperature is less than 20^{o}C and day temperature is below 30^{o} C. The phenological phase of tuber initiation to tuber bulking is mainly conditioned by nutrition and moisture. For this purpose, fertilizer and irrigation requirement in different agro-climatic zones have been worked out through multi-locational trials under AICRP (Potato). Termination of tuber bulking coincides with onset of foliage senescence. By manipulating the nutrition and moisture, the foliage senescence is delayed for ensuring continuation of linear tuber bulking phase resulting in higher yield. Several profitable potato-based inter-cropping and crop rotations have also been identified for different regions of the country. Potato can be profitably intercropped with wheat, mustard and sugarcane. These cropping systems have helped in the maintenance of soil fertility and have improved the fertilizer economy, crop yield and gross returns. Besides, potato cultivation has also been mechanized in selected regions through the fabrication and development of cost-effective tools and implements.

Plant Protection

Effective management practices have been devised for the major potato diseases and insect-pests in India. Late blight is the most notorious disease of potato which occurs almost every year in the hills and plains. Besides chemical control measures, several late blight resistant varieties have been developed. Potato varieties have also been bred which possess resistance to wart and cyst nematodes. Cultural and biological control measures have also been developed to control the diseases and insect-pests. The development of late blight forecasting systems for hills and plains has enabled the early warning mechanism for the appearance of late blight disease.

Storage

In European countries, the potato crop is grown in summer and the main storage season is the cold winter. However, in India, 85 per cent of potato is produced in winter and stored during long hot summer. This requires storage of potatoes in cold stores at 2-4^{0}C, which involves substantial cost. It also leads to accumulation of reducing sugar in the potato tubers resulting in sweetening of potatoes. However, there are a number of traditional low-cost and non-refrigerated storage structures (essentially based on evaporative or passive evaporative cooling) in use in India with varying degrees of success. These traditional structures have been studied, validated and popularized for particular regions. In non-refrigerated storages, use of sprout suppressants has also been popularized to prevent excessive weight loss and shrinkage due to sprouting. The CIPC (isopropyl-Nchlorophenyl carbamate) is the most effective sprout inhibitor when applied @ 25 mg a.i. per kg tubers.

Processing and Value Addition

In addition to raw consumption, potatoes can be processed into several products like chips, French fries, cubes, granules and canned products. The primary determinants for potato processing include high dry matter and low reducing sugar content. A dry matter content of more than 20 per cent is desirable for chips, French fries and dehydrated products. Similarly, reducing sugar content in tubers up to 100 mg/100g fresh weight is considered acceptable for processing. Nine varieties viz. Kufri Chipsona- 1, Kufri Chipsona-2, Kufri Chipsona-3, Kufri Jyoti, Kufri Chandramukhi, Kufri Lauvkar, Kufri Surya, Kufri Himsona and Kufri Frysona have been developed for processing purposes. In India, potato processing in organised sector started about a decade ago, and the recent proliferation of this sector mainly results from the development of three indigenous potato processing varieties, viz. Kufri Chipsona-1 and Kufri Chipsona-3 by CPRI. These two varieties are now being used by the industries for processing into chips and French fries.

Computer Applications

Simulation modelling is now widely used in various disciplines to work out tactical decisions. CPRI has developed INFOCROP-POTATO model to simulate the potato growth and development, to determine the best growing period, to optimise management practices under different agro-ecological regions, and to forecast the accurate yield estimates. An expert system (Potato Pest Manager) has also been developed for decision support with respect to identification and management of diseases and insect-pests.

Transfer of Technology

Research achievements alone are not adequate to gauge the success of an agricultural system. The research information needs to be assessed and refined under various bio-physical and socio-economic situations through adaptive research before it is labelled as a technology. In this regard, the multi-locational trials under AICRP (Potato) and the TOT projects undertaken by CPRI such as Operational Research Project (ORP), Lab-to-Land Programme (LLP), Tribal Area Development (TAD) programme and Institution-Village Linkage Programme (IVLP) proved landmark in getting feedback from the field and development of appropriate technologies. Transfer of technology to the end users is a complex task which consists of a number of components and dimensions. One of the important components is proper linkage between technology generating system and the client system. In this regard, innovative approaches like need assessment, participatory planning and implementation, and direct scientist-farmer interface facilitated faster dissemination of technologies and consequent adoption by the farmers/clients. The CPRI has build up linkages with farmers through demonstrations, trainings, Kisan Melas, potato school on All India Radio, supply of literatures and other extension activities. Besides, studies have been conducted to measure the socio-economic impact and constraints in transfer of potato technology.

Potato Export

Although India contributes 12% to the total world potato production, its 0.7% share in world's potato export is quite insignificant. Indian potatoes are truly free from the prohibited disease like wart, and pests like tuber moth and nematodes, which are the barometer for phytosanitary standards. India has also the natural advantage of exporting fresh table potatoes during January to June when supply from European countries dwindles. It can also supply fresh potatoes round the year because India has diverse agro-climates and potato is grown throughout the year in one or the other part of the country. Potato has a good future in India under the changed scenario of global economy. Globalisation has resulted in many developing countries becoming much more integrated into the international potato trade. With the phasing out of quantitative restrictions on agricultural commodities, the imports and exports of potato would be based on the differences in price and production cost between the importing and exporting countries involved. Due to low production cost in the country as a result of availability of cheap labour, India will have competitive advantage in the international potato trade.

Potato in the New Millennium

With the improvement in the living standard of people in India, the dietary habits will shift from cereals to vegetables. Under such a situation it is estimated that India will have to produce 49 million tonnes of potato by 2020. This target could be achieved only by improving the productivity level. The productivity of potato in India is quite low (183.3q/ha) as compared to that of Belgium (490q/ha), New Zealand (450q/ha), UK (397q/ha) and USA (383q/ha). This is due to shorter crop duration in India. There is a wide range of variations in the agro-ecological setting of different parts of the country, which results in wide variations in the productivity levels of different states. Therefore, all our efforts may be put in to develop location specific and problem-specific varieties and technologies. Most of the people in India have either no knowledge or wrong notions about the nutritive value of potato. With low fat (0.1 per cent) and calorie contents, it does not cause obesity. Due to misconception the potato consumption, the per capita consumption of potato in India is only about 16 kg/year. On the other hand, the per capita consumption in Europe is 121 kg/ year and as high as 136 kg/year in Poland. Hence, there is ample scope for improving the consumption of potatoes in India. For this purpose, a publicity compaign like eggs and milk needs to be launched through mass media such as television, radio and newspapers highlighting its nutritional value. Moreover, the possibility of using surplus potatoes as animal feed also needs to be explored. The surplus potatoes in a season are stored in cold stores at 2-4^{o} C in the country. This makes stored potatoes just unfit for processing and loses preference for table purposes due to accumulation of sugar content. To avoid sweetening potato are required to be stored at 10-12^{o}C. Only seed potatoes should be cold stored at 2-4^{o}C. This would release atleast 60 per cent of cold storage space that can be converted to store potatoes for processing and table purposes at 10-12^{o}C with CIPC treatment leading to considerable savings on energy and storage costs. Processing is a fast growing sector in the potato world economy. Due to increased urbanization, rise in per capita income and expanding tourism, the demand for processed potato products in India and international market has risen at a fast pace. However, in India, processing of potatoes constitutes less than 2 per cent of the total annual production as compared to 60 per cent in USA, 47 per cent in the Netherlands and 22 per cent in China. Hence, there is great scope to expand the potato processing industries in India and also to diversify the processing to produce flour, cubes, granules, flakes and starch. Under the changed global scenario, the potato production and utilisation pattern is changing very fast. These changes harbour many opportunities which could be tapped through effective extension system. The use of modern information and communication technologies (ICT) to create awareness is highly pertinent in the contemporary times. This would enable us to reach directly to the end users by eliminating the intermediate channels which create distortion of information. Efforts are also needed to devise market based extension strategies in order to promote entrepreneurship among potato growers with regard to potato production and marketing.

Chapter 2

Biosecurity Issues in Import of Potato

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Introduction

Plant systems are the foundation of food production systems and consequently, among the most important components of a sustainable society. There are many threats to plant systems that put sustainability at risk. Challenges like population growth, globalization, climate change, bioterrorism and changing agribusiness infrastructure hamper plant biosecurity at the local, regional, and global levels. It is important for each nation to develop a plant biosecurity infrastructure that ensures a safe and constant supply of food, feed, and fiber. It is equally important to develop an international framework for cooperation that maintains plant biosecurity without compromising trade.

Biosecurity is a set of preventive measures designed to reduce the risk of transmission of infectious diseases, quarantined pests, invasive alien species and living modified organisms. It has direct relevance to the sustainability of agriculture, food safety, and the protection of the environment, including biodiversity. Emerging, re-emerging and endemic plant pathogens continue to challenge the biosecurity of plants. Today these organisms often cause little noticeable damage to their host plants, having developed a natural balance through co-evolution. However, major problems may arise if a pathogen escapes – or is introduced – to another region where the native plants have little resistance and the pathogen has eluded its natural enemies. Such events can trigger damaging disease episodes that may also have long-term negative impacts on the environment, economy and cultural heritage.

The devastating effects resulting from diseases and pests introduced along with international movement of planting material, agricultural produce and products are well documented. The historical Irish famine of 1845, caused by late blight of potato introduced from Central America; coffee rust introduced in Sri Lanka in 1875 and its subsequent introduction in India in 1876; fluted scale on citrus introduced from Sri Lanka in 1928; San Jose scale in apple introduced into India in 1930s; bunchy top of banana introduced from Sri Lanka in 1943; the dreaded Golden nematode infesting potatoes introduced in 1960s from the UK and the noxious weed *Lantana camara* introduced in 1809 from Central America are glaring examples that clearly demonstrate that introduction and establishment of quarantine pests including weeds into new areas can severely damage the crop production and economy of a region/country. Movement of plants and plant products between bio-geographical zones by human activities is now generally accepted to be the primary mode of introduction of exotic pathogens and pests. A recent US study showed that invading species cause losses up to almost $120 billion per year nationwide. Climate change has led to evolution in pathogens and vectors contributing increase in the incidence and severity of diseases, emergence of new diseases and altered host range of pathogens. The effect of climate change is also reflected at the genomic level of pathogens leading to new races/biotypes or species with change in virulence and host range.

After the Second World War, FAO convened an International Plant Protection Convention (IPPC) in 1951, to which India became a party in 1956. This convention helps in developing international cooperation among various countries to prevent the introduction and spread of regulated pests that may accompany international movement of plants and planting material (http://www.ippc.org). The IPPC requires that each country establish a national plant protection organization to discharge the functions specified by it. The Government of India legislated the Destructive Insects and Pests (DIP) Act in 1914. This Act has been amended through various notifications issued from time to time and also has provision for domestic quarantine to restrict the movement of certain planting material from one state to another state. In 1984, a notification was issued under this Act, namely Plants, Fruits and Seeds (Regulation of Import into India) Order popularly known as the PFS Order which was revised in 1989 after the announcement of the New Policy on Seed Development by the Government of India in 1988, proposing major modifications for smooth quarantine functioning. This order has now been superseded by the Plant Quarantine (Regulation for Import into India) Order 2003 as there was an urgent need to fill the gaps in the existing PFS order regarding import of germplasm/genetically modified organisms (GMO's)/transgenic plant material/ biocontrol agents, etc. to fulfill India's legal obligations under the International Agreements.

The Directorate of Plant Protection Quarantine and Storage (DPPQS) of the Ministry of Agriculture and Farmers Welfare is the apex body for implementation of plant quarantine regulations. It has a national network of 35 plant quarantine stations at different sites, for example: airports, seaports and land frontiers. In all, two categories of materials are being imported under the PQ Order, 2003: (a) bulk consignments for consumption and sowing/ planting, and (b) samples of germplasm in small quantities for research purposes. The Plant Quarantine Stations under the DPPQS undertake quarantine processing and clearance of consignments of the first category (http:// www.plantquarantineindia.org).

Biosecurity-Safeguarding of Resources from Biological Threats

Biological threats include organisms that have the potential to harm people's health and life, food and agriculture, the environment and the economy. It encompasses the full spectrum of biological risk whether naturally occurring harmful organisms, or introduced by accidents and/or negligence through their deliberate use as biological weapon. "Biosecurity has wider implications in biological warfare and bio-terrorism. In our country, agricultural biosecurity covering crops, trees, and farm and aquatic animals is of even greater importance since it relates to the livelihood security of nearly 70 per cent of the population, and the food, health, and trade security of the nation" M S Swaminathan (2006).

Besides enhanced productivity, sustainability and profitability, interest in biosecurity is increasing as national regulatory and export certification systems are being challenged by large increase in the volume of food and agricultural products being traded internationally, by the expanding variety of imported products and by the growing number of countries from which these imports are originating. It is also creating more pathways to spread pests, diseases and other hazards that are moving faster and farther than ever before. Improved coordination is being sought among national bodies responsible for enforcing sanitary, phytosanitary and zoosanitary measures to better protect human, animal and plant life and health without creating unnecessary technical barriers to trade.

Impact of Introduced Harmful Organisms on Potato in India

Potato is the most popular non-cereal food crop of the world and produces substantially more edible energy, protein and dry matter per unit area and time than many other crops. These virtues make potato as a good candidate crop for providing food and nutritional security to the developing world. Keeping this in view, FAO has declared it as the "food for future". Potato was introduced in India sometime in early 17th century but by late 18th or early 19th century, the potato was an important established vegetable crop in the hills and plains of India. However, till that time, potato cultivation in the country remained restricted. Between 1924 and end of World War II, the State Agricultural Departments and other agencies introduced a large number of European potato varieties with a view to selecting those suitable for local conditions. With the introduction of potato seed, pathogens were also introduced to India and got established in the potato seed producing areas.

The Darjeeling hills of West Bengal were one of the important potato seed producing area in India prior to 1958. The seed produced in these hills were used to be sold to states like Bihar, Uttar Pradesh and Punjab. With the introduction of variety Furore from Denmark in 1953, the wart pathogen was also introduced which made Darjeeling hills unfit for quality seed production forcing Government of India to impose a legal ban on movement of potatoes from the state of West Bengal to other parts of the country through legislation. Thus, the country lost a potential seed producing area. Similarly, with the introduction of cyst nematodes (*Globodera pallida* and *G. rostochiensis*) from Scotland (UK) in the Niligiri hills, Government of India has to impose domestic quarantine for the movement of potatoes and the farmers are unable to export seed potatoes to nearby countries like Sri Lanka. Thus, the country lost another potential seed production area. Similarly, common scab pathogen (*Streptomyces scabies*) was introduced through bulk import of potato seed from Burma and has now established in every agro-ecological zones of the country.

Development of 'Seed Plot Technique' in early seventies made it possible to produce potato seed in sub-tropical plains as a result bulk import of potato seed was terminated. The pathogen profile remained more or less constant till 1990. During mid-nineties, potato was put under OGL as a result huge quantity of potato was imported into the country. But, realizing the threats posed by the bulk imports, the relaxation of its import was withdrawn within six months. However, by that time a huge quantity of potatoes had already been imported into country. This led to a change in the pest and disease scenario in the country. The hitherto unknown viruses (exotic) were introduced, which are now being intercepted during routine tests. This has put immense pressure on maintaining the potato seed health in the country.

Potential Threats to Potato Security

Currently, potato seed production programme in India is based on eight viruses only which are prevalent in the country. These are PVX, PVS, PVA, PVM, PVY, PLRV, potato apical leaf curl virus and GBNV. If bulk import of potato is allowed, there is every likely chance of introduction of quarantined pests and pathogens (**Table 1**), which might establish in the country and hamper potato production programme.

Table 1: List of potato pathogens which can make entry through planting material from abroad

1.	Fungi	Potato smut [*Thecaphora (Angiosorus) solani*], Gangraene (*Phoma exigua* var. *foeta*), Potato wart (*Synchytrium endobioticum*)
2.	Bacteria	Ring rot (*Clavibacter michiganensis* ssp. *sepedonicus*), Zebra chip (*Candidatus Liberibacter solanacearum*), Black leg & Soft rot (*Dickeya solani*)
3.	Viruses	*Andean potato latent, Andean potato mottle, Arracacha B virus, Potato deforming mosaic, Potato T (capillovirus), Potato yellow dwarf, Potato yellow vein, Potato calico strain of Tobacco ring spot virus* PVY strains (PVY^{Z}, $PVY^{N\text{-}Wi}$, PVY^{E}, $PVY^{NA\text{-}N}$, $PVY^{N:O}$ and $PVY^{NTN\text{-}NW}$)
4.	Phytoplasma	Potato purple-top wilt & stolbur *Phytoplasmas*
5.	Insects	Andean potato weevil (*Premnotrypes* spp.), Colorado potato beetle (*Leptinotarsa decemlineata*)
6.	Nematodes	Potato tuber nematode (*Ditylenchus destructor*), Stem and bulb nematode (*Ditylenchus dipsaci),* Potato cyst nematodes (*Globodera rostochinensis, G. pallida*)

If new viruses/pathogen enters into the country the entire seed production programme will become infructuous. It will take years to put it back on rails which country cannot afford. Therefore, it would be in the interest of the country that bulk import of potato from any country is not allowed and all appropriate steps are taken to avoid such a situation. Another lapse of similar nature may completely jeoparadize the indigenous potato seed production system in the country and we would end up importing potato seed from outside which our poor farmers cannot afford.

Drivers for Emergence of New Plant Diseases

The main drivers for emerging diseases are: (i) Movements of people and agricultural goods, (ii) Agricultural change: intensification, diversification and globalization, (iii) Evolution: more interaction, more recombination, more selection, and (iv) Weather: extreme events and climate change. A recent study has shown that the factors driving emergence of plant diseases are introductions (56%), weather (25%), farming techniques (9%), changes in vector population (7%), recombination (2%) and habitat disturbances (1%).

Future Thrust

India has been striving to become a biosecure nation but our facilities for sanitary, phytosanitary and zoosanitary measures are inadeaquate. India's consignments of farm exports are rejected in hundreds (often being on the top of the list of rejections) every year on grounds of mycotoxin, salmonella, pesticide residues, etc. The situation is likely to worsen in the coming years since health safety standards as presented by Codex Alimentarius are getting increasingly stringent and the goal posts in developed countries have been shifting fast. Food safety standards will become the most important non-tariff barrier. Therefore, we must not lose any further time in rendering India biosecure, both from within and outside. A quality food safety and biosecurity literacy campaign must be launched at all levels – from farmers to policy makers. The National Plant Protection Organization needs to be upgraded in terms of manpower, infrastructure and capabilities to raise it to international standards as the increase in imports and the stipulation of WTO has brought about additional challenges to be faced by the plant protection personnel. Strengthening should not only ensure prevention of exotic pests but would also check the interstate spread of indigenous pests and diseases by effective implementation of domestic quarantine regulations/ certification services against certain important pests and diseases which have been introduced/ detected in the country in the recent years and which are likely to spread fast. The new PQ Order is as an attempt to comply with the various provisions of the Agreement on Application of Sanitary and Phytosanitary (SPS) Measures of the WTO (of which India is a signatory member) and to promote trade and not to use plant quarantine measures as a technical barrier to trade.

Chapter 3

Host Resistance in Management of Potato Diseases

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Management of potato disease control involves six basis principles or strategies like **evasion** or prevention of the disease by selecting a time period of sowing where the environment is not conducive for disease proliferation or infection. The second is **exclusion** or prevention of the spread of inoculum. The third is the **eradication** or inactivation of the inoculum. Fourth is by application of **toxicant/ barrier** to infection. Fifth is the **therapy** which means curing plants that are already infected. The last and the most important is the **resistance** that involves deploying cultivars that are resistant or tolerant to infection. Plant host resistance is recommended as the best option for economic and sustainable control of the diseases.

Different biotic stresses *viz*., fungi (*Phytopthora infestans, Synchytrium endobioticum, Alternaria solani, Rhizoctonia solani*, *Verticillium dahlia*), viruses (*Potato virus Y*, *Potato leaf roll virus*, *Potato virus A*, *Potato virus M*, *Potato virus S*, *Potato virus V*, *Potato virus X* and *Tomato leaf curl New Delhi virus-potato*), bacteria (*Erwinia species, Streptomyces scabies* and *Ralstonia solanacearum*) and nematodes (*Globodera pallida* and *Globodera rostochiensis*) pose serious crop losses constraints, in different potato growing regions of the world. In India, among these biotic stresses, late blight, viruses and nematodes are the most distressing causing serious yield and quality losses.

Late blight caused by the oomycete, *Phytophthora infestans* is the most important disease of potato, estimated to be over 3.25 billion US $ in developing countries while in India, it inflicts losses up to 0.5 billion US $ (Bhat et al., 2008) and is a major problem in hilly potato growing regions. *P. infestans* belongs to heterothallic species having A1 and A2 mating types. Presence of both the mating types A1 and A2 are necessary for sexual reproduction and oospore may survive in soil for 3-4 yrs and can initiate in subsequent growing season. Resistance to late blight can be grouped broadly into vertical resistance which is race specific, monogenic and expressed in the form of hypersensitive response to all the races of *P. infestans* that lack the corresponding virulence to the resistance genes *i.e.* the *R*-genes specific resistance is governed by major *R*-genes while the other is horizontal resistance, that in contrast, is non-specific, quantitative, multigenic, durable called field resistance. Resistance breeding strategies includes conventional as well as non-conventional approaches like tissue culture techniques like somatic hybridization, to introduce valuable *R*-genes from sexually incompatible wild species into cultivated plants; Marker assisted selection (MAS) for breeding for resistance in potato through gene pyramiding *i.e.* incorporation of several different genes in single host background; Development of transgenics or cisgeneics and gene silencing methods etc. In India, several late blight resistant varieties were developed for different regions. These included Kufri Jyoti, Kufri Naveen, Kufri Muthu, Kufri Khasigaro, Kufri Jeevan, Kufri Neela and most of the present day varieties like Kufri Sutlej, Kufri Jawahar, Kufri Anand, Kufri Chipsona I, Kufri Chipsona III, Kufri Lalit for the plains and Kufri Megha, Kufri Himalini, Kufri Swarna, Kufri Neelima and Kufri Girdhari for the hills.

The most damaging viral diseases are caused by Potato Virus Y (PVY), Potato Leaf Roll Virus (PLRV), and Potato Virus X (PVX).). The viruses are transmitted by grafting and through aphids in non-persistent manner Resistance sources carrying dominant hypersensitive and extreme resistant genes have been exploited to breed novel potato varieties with resistance to PVY and PVX that is minimally inherited and carried forward in following generations. Dominant gene resistance offers more resilient resistance against viruses as compared to late blight where new resistant strains keep on emerging. Athough, resistance breaking strains are reported for major genes but appear gradually in non-persistent manner. Breeding potato varieties with multiple resistance genes can be achieved through various breeding approaches like MAS. Presently, there are four different *R* genes namely Ry_{adg}, Ry_{sto}, Ry_{hou} and Ry_{chc} known to confer extreme resistance (ER) to PVY while four *N* genes, *viz*., Ny_{chc}, Ny_{dms}, Nc_{tbr} and Ny_{adg} also confer hypersensative resistance (HR) to PVY. Molecular markers associated with these genes are used to select resistant genotype. The *R* genes Rx_{adg} (*Rx1*), Rx_{tbr}, Rx_{acl} (*Rx2*), $Rx_{HB}^{scr}/Rx_{CP}^{scr}$ confers extreme resistance to PVX. Resistance to PLRV function in the host potato plant at two levels, *i.e.* one operate against infection by viruliferous aphids and the other one limits virus multiplication and accretion. Transgenic potato cultivars tolerant to different viruses have been developed like Coat Protein(CP) mediated resistance, RNA-mediated resistance to PVY was demonstrated and is achieved by host mediated response rather than a direct effect of CP itself, and is now referred as virus induced gene silencing or post transcriptional gene silencing (PTGS)

Potato cyst nematodes (PCN) of the genus *Globodera* is one of the most economically important endoparasitic nematode and it is a quarantine organism in many countries including India. *Globoderapallida* (white cyst nematode) and *Globodera rostochiensis* (golden cyst nematode) are the two common species affecting potato crop and with loss up to 80% at high levels of nematode population due to repeated potato cultivation. Infestation of PCN species has been reported only in south Indian hills like Nilgiris and the Kodaihills.Tamil Nadu Government and ICAR in 1971 imposed domestic quarantine under 'Golden Nematode Scheme' to strict seed potato movement from infested fields of Ootacamund to other potato growing areas. The pest can survive in soil in the form of cysts which are dead females containing 300-400 eggs and larvae. The larvae enter the root system of actively growing plants. A number of PCN resistance genes have been ma Major Genes imparting specific resistance to *G. rostochiensis* are *H1, GroVI, Gro1* while *Gpa2, GpaV* and *GpaXI* genes against *G. pallida.* Besides, several other major and minor QTL offer partial resistance to either of these *Globodera* species (Milczarek *et al.,* 2011). Hyper-sensitive response in potatoes possessing resistance genes like Oxidative cell burst, degeneration of the feeding cell growth. low metabolic activity and arrest in female development. Molecular markers are available for selection genotypes resistant to PCN. So far, 19 genes including majorand minor QTLs have been placed on potato chromosome map, conferring resistance against PCN. Resistant genotypes can be identified and selected through molecular DNA markers linked to the resistant genes and therefore reducing work and costs of phenotypic tests. MAS make it feasible to conduct many rounds of selection in a year without depending on the natural occurrence of the pest. A number of transgenic strategies have been proposed to control nematodes but due to the complexity of the life cycle and infestation mechanism, control has been difficult. It is possible to construct transgenes with root specific promoters. Another area of promise is the use of plant produced antibodies or plantibodies which includes raising antibodies within plants to nematode salivary proteins under the genetic control of appropriate localized promoters in order to reduce the functioning of the nematode proteins. .'Maris Piper' in 1963, 'Saturna' in 1964 and 'Pentland Javelin'in 1968 are some of the popular resistant cultivars. Indian varities like Kufri Swarna and Kufri Neelima released in the year 1985 and 2012, possess combined resistance to late blight and cyst nematodes.

Bacterial wilt, caused by *Ralstonia solanacearum* is the second most important potato disease after late blight, locally and globally. When the pathogen encounters a susceptible host, it invades plant vascular tissues from wounded roots or natural openings (secondary roots). The pathogen enters the root and colonizes the root cortex, then invades the xylem vessels, and finally spreads rapidly to aerial parts of the plant through the vascular system and latent survival in potato tubers. This leads to browning of the xylem and partial to complete wilting with rotting of tubers. Furthermore, the pathogen has a wide host range and it persists for a long time in the soil. Host resistance is hard to find because of lack of co-evolution of the host and the bacterium, high variability in the bacterium and instability of the host resistance. Resistance to bacterial wilt is of polygenic and quantitative in nature involving genes with major and minor effects. the resistance has been shown to be very unstable due to its strong host-pathogen-environment interaction. Therefore, a pathogen race at one location may overcome the resistance effective at another location; and more than one race may occur in a given field. The strains of bacterium prevalent in India appear to be the most virulent making resistant sources ineffective. The identified resistance genetic sources (QTL) are strain specific and the available potato protein coding genes have not covered the bacterial wilt resistance genes. Because molecular information on *R. solanacearum* resistance is limited, a transcriptome analysis is indispensable to elucidate the characteristics of the defence responses. The recently developed RNA sequencing (RNA-seq) technique provides a conceptually novel approach to the study of transcriptomes that would allow the host and different phylotype transcriptomes to be analysed in parallel. The major benefit of such an approach is the potential to monitor gene expression in two organisms to a high level of accuracy and depth. RNA sequencing of susceptible host (wild *Solanum*sp) to mine the wilt responsible transcripts involved in degradation of defence genes. Thus, effective management of biotic stresses of potato crop is by combining conventional resistance breeding approaches and biotechnological tools.

Chapter 4

Principles of Pests and Disease Management in Potato

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Pest and Pest Identification

Potato production is affected by pests of various categories; most important among those are the diseases caused by fungi, bacteria, nematodes and viruses. Arthropods (insects and mites) and weeds are next in importance. Accurate identification is the first step in an effective pest management program. Identity and characteristic symptoms of damage are key to all kinds of information about the pest, including its life cycle, behaviour and nature of damage.

Pest Monitoring

For effective crop protection, the crop should be monitored regularly. Regular monitoring can answer several important questions:

- What kinds of pests are present?
- Are the numbers great enough to warrant control?
- When is the right time to begin control?
- Have the control efforts successfully reduced the number of pests?

Monitoring of arthropod pests is done by trapping or by scouting. Monitoring of weeds is usually done by visual inspection. Monitoring for microbial pests is done by looking for the injury or damage they cause. For weed and disease management, most often prophylactic pesticide application is done either based on a warning system or experience of the locality.

Monitoring is not necessary in situations where a pest is continually present and the threshold is zero. For example, there is zero tolerance for the presence of viral diseases in seed potato. Instead, vectors are kept under close watch.

Common methods of monitoring potato pests are given in Table 1.

Threshold Levels

Thresholds are the levels of pest populations at which you should take pest control action if you want to prevent the pests from causing unacceptable injury or harm. A threshold often is set at the level where the economic losses caused by pest damage, if the pest population continued to grow, would be greater than the cost of controlling the pests. These types of action thresholds sometimes are called "economic thresholds." In some pest control situations, the threshold level is zero: even a single pest in such a situation is unreasonably harmful. Economic threshold levels (ETL) of common potato pests are given in Table 1.

Table 1. Methods recommended for monitoring potato pests

S. No	Pest	Monitoring method	ETL
1.	Aphids	Leaf turn (100 leaves) Yellow water pan @ 15/ha	2/100 leaves -
2.	Whiteflies	Leaf turn (30 plants) Yellow sticky trap @ 10/ha	2-3/plant
3.	Mites	Leaf turn (30 plants)	5-10 mites/plant
4.	Leaf hoppers	Leaf turn (30 plants) Yellow sticky trap @ 10/ha	8-10/plant
5.	Thrips	Leaf turn (100 leaves) Blue/yellow sticky trap @ 10/ha	-
6.	Leaf miner	Yellow sticky trap @ 10/ha Mines per 100 leaves	-
7.	Potato tuber moth	Pheromone trap (10/ha) % tuber infestation Light trap (10/ha)	1 larva/2 plants (field) 1 hole/tuber (store)
8.	American pin worm	Pheromone trap-Catch Tuta (20/ha)	For Surveillance
9.	White grubs	Light trap (10/ha) Number of grubs per sq. foot	2 beetles/trap 2 grubs/sq ft.
10.	Cutworms	% Stand damage Light trap (10/ha) Pheromone trap (5-10/ha)	2 % stand damage
11.	Flea beetles	Leaf turn/100 leaves Flea beetle injury per 100 leaves	-
12.	Epilachna beetles	Number per plant (30 plants)	-
13.	Defoliators	Light trap (10/ha) Pheromone trap (5-10/ha) Number of caterpillars per 30 plants	2 larvae/ 10 plants

Formulations

The active ingredients (ai) in a pesticide are the chemicals that control the target pest. Most pesticide products also have other ingredients, called inert (inactive) ingredients. They are used to dilute the pesticide or to make it safer, more effective, easier to measure, mix, and apply, and more convenient to handle. Other chemicals in the product may include wetting agents, spreaders, stickers, or extenders. This mixture of active and inert ingredients is called a pesticide formulation. A single active ingredient often is sold in several formulations. Not only the active ingredient but also the formulation needs to evaluated for each situation. Therefore use only recommended formulations.

Applying the Correct Amount

One of the most important tasks for a pesticide applicator is making sure that the correct amount of pesticide is being applied to the target site. Studies indicate that only one out of four pesticide applications is applied within an acceptable range of the intended rate. Applying either too little or too much pesticide can cause problems. Under-dosing is expensive and you may not fully control the pest. Overdosing is expensive. Do not use any more than the amounts listed in the *Directions for Use* section of the pesticide labelling or of the recommendation. Overdosing may cause damage or injuries to plant, leave residues and pollute the environment. Study the *Directions for Use* section of the pesticide label to find out how much pesticide you should apply or follow the directions of the recommending agency.

1. Calculation based on pesticides

If recommended as kg a.i./ha:

Rate of herbicides is given mainly in terms of a.i./ha

$$\text{Quantity of material required} = \frac{\text{Rate of application x Area (ha)}}{\text{Active ingredient in \%}} \mathbf{X\ 100}$$

Example: Find out the quantity of Simazine 80WP to be sprayed in one hectare area if rate of application is 3 kg a.i. /ha

Quantity of simazin/ha =3/80 x 100 = 3.75 kg WP/ha

If recommended as per cent concentration:

$$\text{Amount of pesticide} = \frac{\text{Volume of spray solution (litre) x Per cent strength of pesticide solution to be sprayed}}{\text{Per cent strength of pesticide given (a.i./l or kg)}}$$

Example: Amount of malathian 25 EC when applied as 0.025 per cent solution

Assuming 500 litre of spray solution is needed to cover one hectare of standing crop;

Quantity of Malathion 25 EC needed = 500 x 0.025/25

= 0.5 litre or 500 ml/ ha

If recommended as ppm concentration:
Amount of pesticide needed (g or ml) = ppm x 0.001 x quantity of spray solution (L)

Remember the following conversions:

1 ppm = 1mg/l = 1000ug/L 100 ppm = 100 mg/l 1000 ppm = 1000 mg/l = 1 g/l 1 ppm = 0.001 ml/l 10 ppm = 0.01 ml/l 100 ppm = 0.1 ml/l 1000 ppm = 1 ml/l 1ppm = 1/1,000,000 = 0.000001 = 0.0001% 10ppm = 10/1,000,000 = 0.00001 = 0.001% 100ppm = 100/1,000,000 = 0.0001 = 0.01%	200ppn = 200/1,000,000 = 0.0002 = 0.02% 1000 ppm = 1000/1,000,000 = 0.001 = 0.1% 5000ppm = 5000/1,000,000 = 0.005 = 0.5% 10,000ppm = 10000/1,000,000 = 0.01 = 1.0% 1% =0.01 x 1,000,000 = 10,000 ppm 0.5% =0.0.005 x 1,000,000 = 5,000 ppm 0.1% =0.001 x 1,000,000 = 1,000 ppm 0.01% = 0.0001 x 1,000,000 = 100 ppm

Example: Amount of Streptocycline needed when applied @ 50 ppm for 1 ha.

Quantity of Streptocycline needed (g) = 50 x 0.001 x 500

= 25 g

Pesticide compatibility

Before mixing two or more pesticides, read all the product labels involved for special instructions.

To test compatibility, follow the give procedure:

1. Put 1 litre of water into a quart jar.
2. Add the proper amounts of each pesticide in the same order that will be followed when the actual spray mix is prepared. Pesticides usually are added in this order: 1) wettable powders, 2) flowables, 3) water solubles, 4) spreader-stickers, 5) emulsifiable concentrates.
3. Cap the jar and shake it vigorously to thoroughly mix the contents, and then let it set one-half hour.

The compounds can be mixed in the tank if:

1. There is a uniform mix or only a slight separation.
2. There are no sludges or clumps.
3. The oil disperses.

This procedure indicates physical compatibility. For chemical and physiological compatibility, treat only a small portion of the crop on a trial basis. Check if

1. The combined application results in phytotoxicity.
2. The two compounds may chemically or physically react, resulting in loss of effectiveness of one or both materials.
3. The combination may be more toxic to the applicator than either material alone.

If any of such reactions is noted, the compounds are not compatible.

Table 2 lists the compatibility of pesticides generally intended to be applied together. In Table 3 the compatibility reaction of common fertilizer combinations is listed.

Table 2. Compatibility among pesticides

S. No	**Pesticide Combination**	**Compatibility**
1.	Imidacloprid 17.8 SL + Mancozeb 75 WP	Compatible
2.	Imidacloprid 17.8 SL + (Cymoxanil + Mancozeb) 72 WP	Compatible
3.	Cypermethrin 25 EC + Mancozeb 75 WP	Compatible
4.	Cypermethrin 25 EC + (Cymoxanil + Mancozeb) 72 WP	Compatible
5.	Thiamethoxam 25 WG + Mancozeb 75 WP	Compatible
6.	Quinalphos 25 EC + Mancozeb 75 WP	Compatible
7.	Spiromesifen 240 SC + Mancozeb 75 WP	Compatible
8.	Wettable Sulphur + Mancozeb 75 WP	Compatible
9.	Indoxacarb 15.8 EC + Mancozeb 75 WP	Compatible
10.	Mineral oil + Imidacloprid 17.8 SL	Compatible
11.	Lime Sulphur + Mancozeb 75 WP	**Incompatible**
12.	Mineral oil + Wettable Sulphur	**Incompatible**
13.	Chlorpyriphos 20 EC + Mancozeb 75 WP	Compatible
14.	Deltamethrin 2.8 EC + Chlorothalonil	**Incompatible**
15.	Chlorpyriphos 20 EC + Wettable sulphur	**Incompatible**
16.	Chlorpyriphos 20 EC + Lime sulphur	**Incompatible**
17.	Glyphosate + 2,4-D	Compatible

Table 3. Compatibility among different fertilizers*

4	Fertilizer Combination	Compatibility	S. No.	Fertilizer Combination	Compatibility
1.	Urea + TSP	*To be mixed just before use*	18.	RP + MOP	**Compatible**
2.	Urea + MOP	**Compatible**	19.	RP + SSP	Not Compatible
3.	Urea + SSP	*To be mixed just before use*	20.	RP + DAP	Not Compatible
4.	Urea + DAP	*To be mixed just before use*	21.	TSP + MOP	**Compatible**
5.	Urea + RP	*To be mixed just before use*	22.	SSP + MOP	**Compatible**
6.	Urea + SOA	*To be mixed just before use*	23.	Lime +TSP	Not Compatible
7.	DAP + TSP	**Compatible**	24.	Lime + SSP	Not Compatible
8.	DAP + SSP	**Compatible**	25.	Lime + DAP	Not Compatible
9.	DAP + MOP	**Compatible**	26.	Lime + Urea	*To be mixed just before use*
10.	DAP + RP	Not Compatible	27.	Lime + SOA	Not Compatible
11.	DAP + SOA	*To be mixed just before use*	28.	Lime + MOP	Not Compatible
12.	RP + TSP	Not Compatible	29.	Lime + RP	*To be mixed just before use*
13.	MOP + Zn	**Compatible**	30.	Mg + Zn	**Compatible**
14.	Mg + B	**Compatible**	31.	Mg + Mn	**Compatible**
15.	Mg + MOP	Not Compatible	32.	Mg + DAP	**Compatible**
16.	Mn + B	**Compatible**	33.	Mn + Zn	**Compatible**
17.	Urea + Zn	**Compatible**			

*TSP-Triple superphosphate, MOP-Muriate of potash, SSPSingle superphosphate, DAP-Diammonium phosphate, RP-Rock phospahte, SOA- Sulphate of Ammonia, Zn-Zinc sulphate, Mg-Magnesium sulpahte, B-Boron, Mn-Manganese sulphate

Application of pesticides

Table 4: Volume rates of different crops (litre/hectare)

Category	Field crops	Trees and Bushes
High volume	>600	>1000
Medium volume	200-600	500-1000
Low volume	50-200	200-500
Very-low v	5-50	50-200
Ultra-low volume	<5	<50

Table 5: Recommended droplet range for pest control

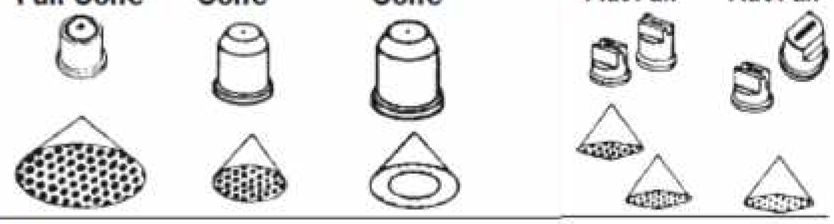
Application	Droplet Category[2]	Approximate VMD Range[3] (in microns)
Fungicide		
foliar protective or curative	Medium (M)	226-325
Insecticide		
foliar contact or stomach poison	Medium (M)	226-325
foliar systemic	Coarse (C)	326-400
soil-applied systemic	Coarse (C) Very Coarse (VC) Extremely Coarse (XC) Ultra Coarse (UC)	326-400 401-500 500-650 >650
Herbicide		
foliar/post-emergent contact	Medium (M)	226-325
foliar/post-emergent systemic	Coarse (C)	326-400
soil-applied/pre-emergent systemic	Coarse (C) Very Coarse (VC) Extremely Coarse (XC) Ultra Coarse (UC)	326-400 401-500 501-650 >650

[1] Always read the label. Pesticide product labels may specify what droplet size to use, which will direct nozzle selection and, in turn, affect spraying equipment configuration and calibration.

[2] ASABE (American Society of Agricultural & Biological Engineers) Standard 572.1.

[3] Reported VMD ranges vary widely, based upon the type of laser analyzer used. VMD = Volume Median Diameter: a value where 50% of the total VOLUME or mass of liquid sprayed is made up of droplets LARGER than and 50% SMALLER than this value.

Table 6: Nozzle Recommendations



	Full-Cone	Solid-Cone	Fine Hollow-Cone	Extended Range Flat-Fan	Standard Flat-Fan
Pre-Emerge Herbicides					
Soil Incorporation	Best			Best	Better
Band		Good			
Broadcast				Best	Better
Post-Emerge Herbicides					
Contact-Band		Good	Good		
Contact-Broadcast				Best	Better
Systemic-Band			Good		
Systemic-Broadcast		Good		Best	Better
Insecticide					
Band			Best		
Broadcast		Good		Best	Better

Transportation, Storage and Disposal

When you transport, store, or dispose of pesticides and their containers, you must take safety precautions. The safest way to transport pesticides is in the back of a truck. Never carry pesticides in the passenger section of your car, van, or truck. Never transport pesticides with food, clothing, or other things meant to be eaten by or come into contact with people or animals. Transport pesticides only in containers with intact, undamaged, and readable labels. Many pesticide handlers use existing buildings or areas within existing buildings for pesticide storage. However, if large amounts of pesticides will be stored, build a special storage building for pesticides. A suitable storage site: Protects people and animals from accidental exposure, Protects the environment from accidental contamination, Prevents damage to pesticides from temperature extremes and excess moisture, Protects the pesticides from theft, vandalism, and unauthorized use, and Reduces the likelihood of liability. Pesticide users are responsible for correctly dealing with empty pesticide containers, excess usable pesticides, and waste materials that contain pesticides or their residues. There is growing concern about the serious harm to humans and the environment that incorrect disposal of pesticide wastes can cause. The best solution to the problem of what to do with excess pesticides is to avoid having them: Buy only the amount needed for a year or a season. Calculate carefully how much diluted pesticide is needed for a job and mix only that amount. Use all the mixed pesticide in accordance with labeling instructions. If you have pesticide products in their original containers that you cannot use, you may be able to find another pesticide handler who can. Or you may be able to return them to a dealer, formulator, or manufacturer. Most container rinsates should not become excess pesticides because they can be added into the tank during mixing. You also may be able to add some rinsates from equipment cleaning, spill cleanup, and other activities to a tank mixture that contains the same pesticide, as long as doing so will not violate labeling instructions. Excess pesticides and rinsates that cannot be used must be disposed of as wastes. Other pesticide wastes include such things as contaminated spill cleanup material and personal protective equipment items that cannot be cleaned and reused. Sometimes pesticide wastes can be disposed of in a landfill operating with state, or local permit for hazardous wastes. Some regions have pesticide incinerators for disposing of pesticide wastes. Never burn, bury, or dump excess pesticides, and never dispose of them in a way that will contaminate public or private ground water or surface water or sewage treatment facilities. Some types of containers are designed to be refilled with pesticide repeatedly during their lifetime, which may be many years. To dispose of unrinsed containers, take them to an incinerator or landfill operating for hazardous waste disposal.

Insecticide Resistance management

The most effective strategy to combat insecticide resistance is to do everything possible to prevent it occurring in the first place. To this end, crop specialists recommend IRM programs as one part of a larger IPM approach covering three basic components: monitoring pest complexes in the field for changes in population density, focusing on economic injury levels and integrating multiple control strategies. Insecticides should be used only if insects are numerous enough to cause economic losses that exceed the cost of the insecticide plus application, or where there is a threat to public health. Exceptions are in-furrow, at-planting or seed treatments for early season pests that from experience it is known usually reach damaging levels annually.

Incorporate as many different control strategies as possible including the use of synthetic insecticides, biological insecticides, beneficial insects (predators/parasites), cultural practices, transgenic plants (where allowed), crop rotation, pest-resistant crop varieties and chemical attractants or deterrents.

A key element of effective resistance management is the use of alternations, rotations, or sequences of different insecticide mode of action (MoA) classes. Users should avoid selecting for resistance or cross-resistance by repeated use within the crop cycle, or year after year, of the same insecticide or related products in the same MoA class.

It is important to consider the impact of pesticides on beneficial insects, and use products at labeled rates and spray intervals to minimize undesired effects on parasitoids and predators.

Preserve susceptible genes. Some programs try to preserve susceptible individuals within the target population by providing a refuge or haven for susceptible insects, such as unsprayed areas within treated fields, adjacent refuge fields, or attractive habitats within a treated field that facilitate immigration. These susceptible individuals may out-compete and interbreed with resistant individuals, diluting the impact of any resistance that may have developed in the population.

The residue myth

- Use Recommended Pesticide
- At Recommended Dose
- At Recommended time
- At Recommended Location
- On Right Crop

There will be no "Pesticide Residue in Food" problem

Personal Protective Equipment

Personal protective equipment prevents pesticides from coming in contact with the body or clothing. These also protect the eyes and prevent the inhalation of toxic chemicals. Personal safety gear includes clothing that covers the arms, legs, nose, and head. Gloves and boots are used to protect the hand and feet, and hats, helmets, goggles, and face masks to protect the hair, eyes, and nose. Respirators are used to avoid breathing dust, mist or vapour.

Overalls made of cotton are the best but should not be worn without additional protective clothing. When there is a chance of contacting wet spray, large sleeves with cuff-buttons, and pants with buttons at the bottom offer good protection. Waterproof rubber or plastic aprons are effective. They should be long enough to protect the general clothing. Dust and mist settle easily on hair. Hats that are water resistant, wide brimmed with sweatbands are effective in protecting it. Many helmets provide attachments for face shields and goggles. Goggles are used to protect the eyes from splashes, spills, mist, and droplets. Goggles with plain lenses and full side shields are preferable. The lenses may become coated with pesticide droplets during spraying; hence cleaning tissues or an extra pair of goggles are a must. A face shield is a transparent acetate or acrylic sheet which covers the face and prevents it from splashes or dust. Face shields allow better air circulation and provide a greater range of vision than goggles.

Dermal exposure occurs the most in the hand region. The use of gloves reduces this risk. Gloves should be up to 2 to 3" long below the elbow i.e., they should extend to the mid forearm. Waterproof gloves, such as those made of rubber, latex or PVC are preferable. After use, they should be discarded away from ponds, wells, and animals or even incinerated. Shoes made of rubber or synthetic materials like PVC and nitrite can be used to prevent dermal exposure of feet. Protective footwear should be calf-high and worn with the legs of the protective pants on the outside to prevent spray from getting in. Leather or fabric shoes should never be worn as they absorb pesticides. Shoes should be checked for any leakage or damage before use. A respirator is a device that offers protection to the lungs and respiratory tract. Different kinds of respiratory equipment are used based on the type and toxicity of pesticides. They include nose filters/disposable masks, cartridge respirators, canister-type respirators/gas masks, positive pressure breathing apparatus, self-contained breathing apparatus, and powered air cartridge respirator.

Chapter 5

Fungal Foliar Diseases of Potato and their Management

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Introduction

Potato originated in the hills of Andes and Bolivia in South America. It was introduced into Europe by Spaniards in the second half of the 16th century, from there it spread throughout Europe and rest of the world in the mid seventeenth to mid eighteenth century. In India, it was introduced in by Portuguese in 17th century. The fungus like organisms co-evolved with potato in Central and South America and subsequently spread to other parts of the world mainly through infected seed tubers. The late blight disease caused by oomycete has a great importance in the history of plant pathology. Initially its causal organism was reported as *Botrytis infestans* in 1845 by C. Montagne, a retired French army doctor who had devoted much of his life to the study of fungi. About 30 years later, German scientist Anton de Bary renamed it as *Phytophthora infestans* (Mont.) de Bary. During 1844-45, entire potato crop across Europe, especially in Ireland, was killed prematurely leading to worst ever famine - the 'Irish Potato Famine'. One million people died of starvation and another million migrated to USA and other parts of the world.

Late blight was recorded in India for the first time between 1870 and 1880 in the Nilgiri hills. Under subtropical plains, it was first observed in 1898-1900 in Hoogly district of West Bengal. Subsequently, it was reported from other parts of the country. Afterwards, appearance of late blight disease is a regular feature with high disease severity in hill areas while in plains, disease severity is moderate to high depending upon climatic conditions. As far as Indian scenario is concerned, reduction in potato production due to late blight ranged between 5-90% depending upon climatic conditions, with an average of 15% across the country. Recently during 2013-14, 10-20% yield losses were observed due to late blight in major potato growing states of the India. Potato late blight had become more severe in recent years due to influx of a new population containing the A_2 mating type especially in USA. In India, most complex races, A_1 & A_2 mating with metalaxyl resistance and new population of *P. infestans* were observed. The late blight disease is re-emerging worldwide, therefore this disease is constantly observed by the late blight researchers. The disease is not only important for global potato production, but also poses severe risks on a local level, especially on small farms in developing countries. *Phytophthora infestans* is the most widely studied oomycete; about 1230 papers have been published in the last 10 years (2005-14) and is one of the top 10 oomycete pathogens studied using molecular techniques.

Symptoms

Late blight affects all plant parts especially leave, stem and tubers.

Leaves: Pale green water soaked spots (2-10 mm) appear mostly on the margin and tips. In moist weather, spots may appear anywhere on the leaves, enlarge rapidly and turn necrotic and black killing the entire leaf instantly. On the corresponding lower side, whitish cottony growth containing millions of sporangia forms around the dead area in a ring pattern.

Stem and petiole: Light brown lesions develop which elongates and encircles the stem and petioles breaking them and killing the plant /leaves instantly. Stem infection is more severe under high temperature and relative humidity conditions. Symptoms of stem blight are observed more in last ten years.

Tubers: Rusty brown discolouration of the flesh is the typical symptom of late blights. On outside tuber surface, hard depressions with purplish tinge on the sides are a common feature. Normally, late blight infected tubers are hard but associated secondary pathogens may set in soft rot symptoms.

Field Infection: Generally, late blight appears on lower most leaves of the plant which goes unnoticed from a distance. Slowly, the disease spreads to the middle and then upper leaves. Subsequently it spreads whole plants and near of the plants. The disease spreads faster and the entire crop gets killed as if burnt by fire. The heavily infected field gives fetid odor which can be felt from a distance.

Epidemiology and disease cycle

Sporangia are formed in wide range of temperature (3 to 26 °C), optimum being 18-22 °C. The sporangia geminate by two way process i.e. indirect and direct germination. It depends mainly on temperature. Indirect germination generally occurs at temperature range of 6 to 15 °C (optimum 12 °C) by means of zoospore production by sporangia. Direct germination takes place under warm temperature (a range of 4 to 30 °C optimum being 25 °C). High relative humidity (> 90%) is required for spore formation, germination and infection; whereas >80% is essential for lesions expansion. Extreme light is harmful for *P. infestans* and sometimes sporangia may be killed due to extreme light. Cloudy weather is favourable for late blight. The cool (12-15 °C) and high humidity (>90%) weather with heavy dews or rains alternating with warm (18-20 °C) moist period favour rapid development of disease. Infection and disease development is observed at a temperature range of 7.2-26.6 °C. The infected seed tubers carrying late blight infection serves as a primary source for disease initiation.

Management

The key to pathogenic oomycetes success resides in their capacity to adapt to overcome host resistance and occasionally jump to new hosts. Mainly two hosts i.e. potato and tomato are found in Indian condition. The late blight disease is considered weather dependent disease. Therefore, a forecasting model is better option to predict its appearance so that proper protection measure could be adopted at proper time. Van Everdingen (1926) evolved ‘Dutch rules’ for predicting the initial occurrence of late blight and for scheduling fungicide applications under Holland condition. After development of ‘Dutch rule’ Beaumont’s period, Irish rules, moving day concept, severity value accumulation, negative prognosis and mathematical based models were also developed worldwide. Large number of forecasting systems like BLITECAST, SIMCAST, ProPhy, PROGEB, PhytoPre, NegFry, Web-Blight, Plant Plus, PhytoPRE+2000, China Blight, Bio-PhytoPre etc have been developed for different regions of the world. In India, using rainfall data of 12 years periods, the dates of appearance of late blight in Darjeeling hills reported by Chaudhary and Pal (1959). Later, Bhattacharyya et al. (1982) predicted the actual appearance of late blight for Shimla, Shillong and Ootacamund utilizing daily weather data. Singh et al. (2000) developed computerized forecasting model ‘JHULSACAST’ for western UP for both the rainy and non-rainy conditions and it is being utilities for forecasting of first appearance of late blight in the regions and large scale of the farmers are benefited by timely adopting control measures as forecasting given by this model. JHULSACAST model, template was calibrated for development of forecasting model for Punjab, tarai region of Uttarakhand and plains of West Bengal. A decision Support system also developed for assisting in management of late blight by CPRI, which includes three modules i.e. i) decision rules for forecasting first appearance of late blight in plains during rainy and non-rainy years based on temperature, RH, and rainfall data, ii) decision rules for need based application of fungicides, and iii) regression models for yield loss assessment. All these modules have been combined and a web based decision support system developed for western Uttar Pradesh. Recently, Indo-Blightcast a web based Pan-India model for forecasting potato late blight which is an improvement over JHULSACAST has been developed. It predicts late blight appearance using daily mean temperature and RH data available with meteorological stations and does not require hourly weather data, not region/location specific and can be used across the country without any calibration. It is being used for forecasting of late appearance in different AICRPs centres.

Resistant cultivars

ICAR-CPRI has released varieties having moderate to high degree of resistance to late blight for cultivation both for plains and hills. Some of them are Kufri Girdhari, K. Shailja, K. Himalini and K. Himsona (for hills) K. Swarna and K. Neelima (specially for southern hills) and K. Pukhraj, K. Anand, K. Sutlej, K. Badshah, K. Arun, K. Jawahar, K. Garima, K. Mohan, Kufri Chipsona-1, K. Chipsona-2 and K. Chipsona-3 and K. frysona (for plains).

Cultural methods

- Use disease free seeds only. Avoid seed from the field which has been infected in previous year with late blight.
- High ridge making will reduce the tuber infection.
- Scouting of the field for identification of primary infection foci and their destruction by removal of infected plants after drenching them with recommended fungicides.
- When weather condition is very congenial for late blight, irrigation should be stopped wherever applicable and give the light irrigation if required.
- Destroy and removes the haulms from the field when disease severity reaches more than 80% to reduce tuber infection.

Chemical management

Chemical management is good option for late blight management. Farmers in Andes spend between 5 and 20% of total production costs on fungicides to control late blight, depending on their financial resources and diseases pressure. Different spry schedule were tested and found that Chlorothalonil (0.2%) before appearance followed by cymoxanil+mancozeb (0.3%) then metalaxyl+mancozeb (0.25%) and Mancozeb (0.2%) before appearance followed by cymoxanil+mancozeb (0.3%) then fenomidone+macozeb (0.2%) were effective for managing late blight of potato. Howe ever, Proper dose and proper time of spraying is very important. A spray schedule of minimum of four fungicides sprays is recommended, it can be increase or decrease depending upon disease pressure. As first spry of contact fungicides (mancozeb 75%WP/chlorothalonil 75%WP/propineb 70%WP) @ 0.2% should be spray as soon as weather conditions become congenial for late blight or any information received from forecasting models for appearance of late blight/ about a week of advance of canopy closure. As soon as the disease is noticed in the field, second spray with systemic or translaminar fungicide @ 0.3% [(cymoxanil % 8+ mancozeb 64% WP/ fenomidon 10% +mancozeb 50%WG/dimethmorph 50%WP (1g//L) + mancozeb 75%WP (2.0g/L)]. The remaining third and fourth sprays should be at 8-10 days interval (it may be increased or decreased depending upon disease pressure) used using systemic/translaminar for better results. However, contact fungicides could be used only at low disease pressure. Precautions should be taken that proper dose of fungicides with proper coverage of the foliage (top to bottom) with fungicides. Whenever, rains are heavy use sticker @ 0.1% with fungicides to reduce washing of the fungicides.

Early blight of potato

Early blight of potato caused by *Alternaria solani* (*Ell.&Mart*) *Jones & Grout.* The name of early blight was given by Jones, 1892 as this disease observed to develop earlier than Phytophthora blight in the USA. In India the disease was first reported by Butler (1903) on potato leaves at Farrukhabad in Uttar Pradesh. It cause up to 20% loss, sometime it may be more. The initial symptoms occurs on the lower leaves and latter develop on the upper leaves. The spots are mostly (1-2mm) circular to oval and brown to black lesions with concentric rings, which produce a 'target spot' effect. Sometime the spot may or may not have concentric rings. Infected leaves are affected by disease induced senescence, become necrotic but remaining attached to the plant. The spot may be found on stem at late stage of crop growth and tuber also. The tuber symptoms comprise brown, circular to irregular and depressed with underneath flesh turning dry brown and corky. Generally disease is more common on mature tissues or on tissues weekend by other diseases or environment and nutritional stress. Early blight is principally a disease of ageing plant tissues. *A. solani* is a polycyclic pathogen as many cycles of infection are possible during a season.

Leaf spots

Leaf spot diseases of potato caused by various fungi *viz., Alternaria alternata* (Fr.) Keissler, *Phoma exigua* Desm., *Phoma sorghina* Doerema,Doren and van Kest., *Cercospora solani-tuberosi* Thirumalachar.

Alternaria leaf spot

The alternaria leaf spot is caused by *Alternaria alternata.* The symptoms of this disease are large as well as small angular spot resembling to early blight. The severally affected leaves dry up and drop off prematurely. The symptoms are variable and non-specific. Some country, it named as brown spot and black pit disease.

Cercospora leaf spot

The cercospora leaf spot is caused by *Cecospora solani-tuberosi***.** This disease first observed at Patna in Bihar in the third week of December, 1951. It infects both foliage (leaves) and stems but latter suffers the most. On the lower leaves brown spot (2-5mm) and each spot has whitish center. Spots later coalesce to cover large areas. Stem infection shows brown spot, later turning black and looking like cankers. The another species of cercospora that is *Cercospaora concors* caused leaf blotch and some time it is also called as yellow leaf spot.

Phoma leaf spot

Phoma leaf spot is caused by two species i.e. *Phoma exigua and Phoma sorghina*. Leaf spot due to *P. exigua* are larger (1-2cm in diameter) with broad alternate light and dark concentric zones. Affected leaves tissues are not depressed into leaves tissues as in the case of early blight. Affected tubers have grey to greenish black depressed lesion on the surface up to 3.0 cm wide. *Phoma sorghina* caused pinhead size spot, which may be oval, circular or irregular, not exceeding 4.0 mm in diameter. This is more common in western UP. Infected tubers show dark grey large lesions (up to 1.7cm).

Disease cycle and epidemiology

Alternaria solani, A. alternata, *Phoma exigua and P. sorghina* can infect tubers hence capable of surviving during storage and form the primary source of inocululm. These pathogens can survive in soil and plant debris particularly in temperate climate. These disease favoured by moderate temperature (17-25°C) and high humidity (>75%). Early blight development in the field is very severe at day temperature of 25-30°C. Intermittent dry and wet weather is more conducive for early blight. *A. alternata* is a successful saprophyte and certainly survives in the soils and plant debris.

Management

1. The disease free seeds should be used for planting.
2. Cultivation of solanaceous crops being collateral hosts, nearby potato fields must be avoided.
3. Apply recommended dose of fertilizer especially nitrogen.
4. Spraying of mancozeb 75% WP or chlorothalonil 75%WP or Propineb 70%WP @ 0.2% for managing the early blight and leaf spot diseases.

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Chapter 6

Bacterial Diseases of Potato and their Management

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Introduction

Potato is affected by relatively a few bacterial diseases *viz*., bacterial wilt or brown rot, soft rot of stem and tubers, ring rot, common scab, pink eye and leaf spot. In India ring rot (*Clavibacter michiganensis* sub sp. *sepedonicus* (Spieck & Koth) Devis *et al.*) and pink eye (*Pseudomonas* species) do not occur. The leaf spot (*Xanthomonas vesicatoria* (ex Doidge) Vauterin *et al*.) is a disease of minor importance. Among the bacterial diseases, bacterial wilt/ brown rot is the most destructive disease followed by common scab and soft rot and are discussed in detail below.

1. Bacterial Wilt

Bacterial wilt or brown rot is caused by *Ralstonia solanacearum* (Smith) Yabuuchi *et al.* 1995. It is one of the most damaging pathogens on potato and has been estimated to affect potato crop in 3.75 million acres in approximately 80 countries with global damage estimates exceeding $950 million per year. Strains of this pathogen affect more than 450 plant species in over 54 botanical families throughout the world, including a wide range of crop plants, ornamentals and weeds. In India, Losses up to 75 per cent have been recorded under extreme conditions. With increase in global temperature, the disease is likely to spread to new areas and affect potato cultivation.

The disease causes damage at two stages; (i) killing the standing plants by causing wilt and (ii) causing rot of infected tubers in field, storage and transit. Another indirect loss results from the spread of the disease through latently infected tubers (infected tubers without exhibiting visible symptoms) if used as seed. Bacterial wilt poses a serious restriction to seed and processing potato production. Potato breeder seed production cannot by undertaken in those fields having even slightest bacterial wilt incidence. There is zero tolerance to this disease in most international seed certification systems.

Symptoms

The earliest symptom of the disease is the slight wilting in leaves of top branches during hot sunny days. The leaves show drooping due to loss of turgidity followed by total unrecoverable wilt **(Fig. 1a).** In well-established infections, cross-sections of stems may reveal brown discoloration of infected tissues **(Fig. 1b).** In advanced stages of wilt, cut end of base of the stem may show dull white ooze on squeezing. Bacterial wilt in field can be distinguished from other fungal wilts by placing the stem cut sections in clear water as shown in **Fig. 1c**. Within a few minutes, a whitish thread like streaming can be observed coming out from cut end in to water. This streaming represents the bacterial ooze exuding from the cut ends of colonized vascular bundles. The same test can also be carried out to see infection in tuber.

In tubers, two types of symptoms are produced; they are vascular rot and pitted lesion on surface. In vascular rot, the vascular tissues of transversely cut tuber show water soaked brown circles and in about 2-3 minutes, dirty white sticky drops appear in the circle **(Fig. 2b)**. In advanced stages of wilt, bacterial mass may ooze out from eyes (**Fig. 2c**). Such eyes may carry soil glued with the bacterial ooze. Second kind of symptom is the lesions on tuber. The lesions are produced due to infection through lenticels (skin pore). Initially, water soaked spot develop which enlarges in the form of pitted lesion **(Fig. 2a)**. The tubers may not rot in storage and also may not show vascular browning. These symptoms on tuber surface are more common in north eastern region of India**.**

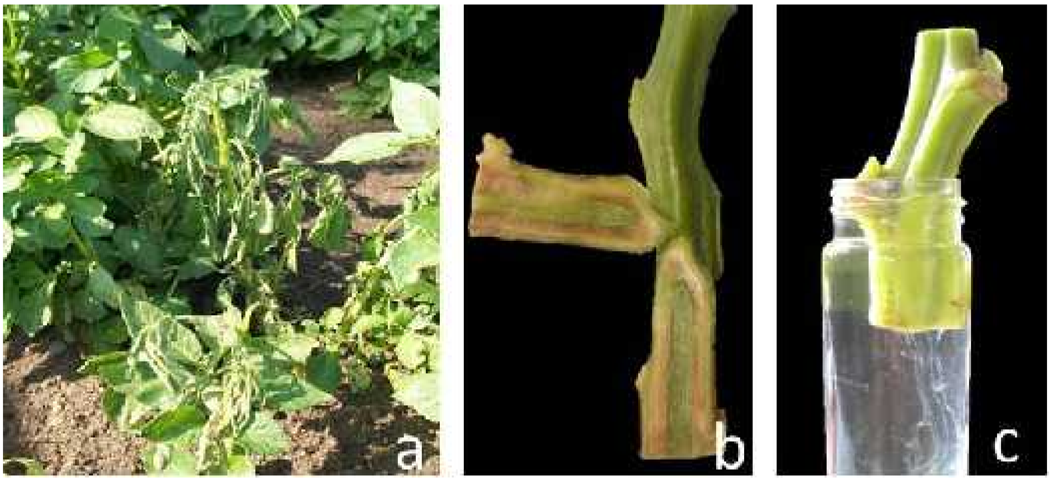

Fig. 1: Symptoms of bacterial wilt (a); brown discoloration of stem tissues (b); bacterial streaming in clear water from stem cut section of potato (c) infected with *R. solanacearum*

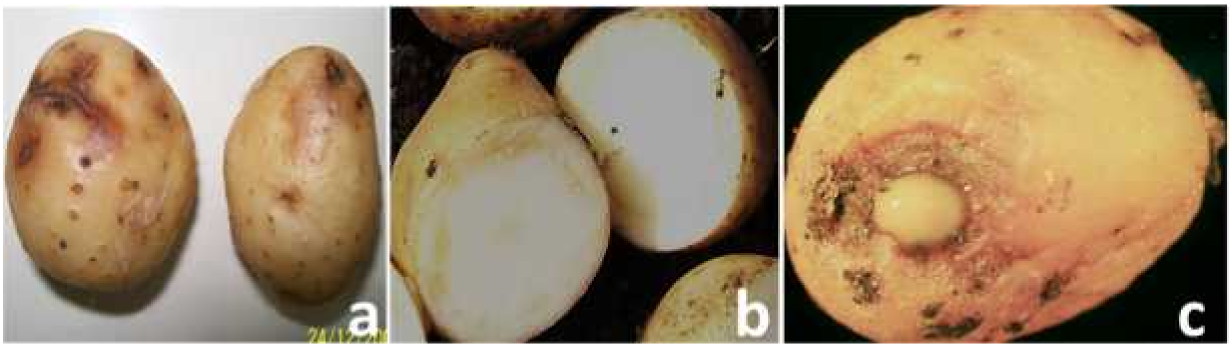

Fig 2. External symptoms on tubers (a); vascular browning of tubers (b); bacterial mass emerging through eye of tuber (c) due to *R. solanacearum*

Causal Organism

Ralstonia solanacearum (Smith 1896) Yabuuchi *et al.* 1995, is a Gram-negative, rod-shaped, strictly aerobic bacterium that is 0.5-0.7 x 1.5-2.0 Cm in size. For most strains, the optimal growth temperature is between 28 and 32°C; however some strains have a lower optimal growth temperature of 27°C. Strains of *R. solanacearum* have conventionally been classified into five races (related to the ability to wilt members of the family *Solanaceae* (r1), banana (r2), potato and tomato in temperate conditions (r3), ginger (r4) and mulberry (r5) and six biovars (metabolic profiles related to the ability to metabolize a panel of three sugar alcohols and three disaccharides). Based on this classification, potatoes are known to be affected by either r1 (bv 1, 3 and 4), frequent at warmer areas and lower elevations in the tropics, and r3 (bv 2), more common in higher elevations or latitudes. Recently, a new classification scheme has been described for strains of *R. solanacearum*, based on variation of DNA sequences. Four phylotypes were identified within the species that broadly reflect the ancestral relationships and geographical origin of the strains. Phylotype

I contains strains of Asiatic origin which belong to bv 3, 4, and 5. Phylotype II (American origin) contains r1bv1, r2bv1 (Moko disease causing strains), r3bv2 and bv2T strains. Phylotype III contains strains from Africa and Indian Ocean, which belong to bv1 and bv2T. Phylotype IV contains strains from Indonesia, Japan and a single strain from Australia. Each phylotype can further be subdivided into sequevars based on differences in the sequence of a portion of the *endoglucanase (egl)* gene. In India, the bacterial wilt of potato is known to be caused by strains of phylotype I, IIB and IV of *R. solanacearum*.

Disease Occurrence and Distribution

Bacterial wilt or brown rot has a worldwide distribution. It is a destructive disease of potato especially in tropical and subtropical parts of Asia, Africa, South and Central America and in some soils and waterways in Europe and Australia. In India, the disease is endemic in Karnataka, Western Maharashtra, Madhya Pradesh, eastern plains of Assam, Orissa and West Bengal, Chhota Nagpur plateau, north-western Kumaon hills, eastern hills of West Bengal, Meghalaya, Manipur, Tripura, Mizoram, Arunachal Pradesh and in Nilgiris, Annamalai and Palani hills of Tamil Nadu. Bacterial wilt is a serious problem in Malwa region and adjoining areas in Madhya Pradesh where potato is grown for processing industry. However, it has not been noticed in the north-western high hills (excluding Kumaon hills) and in the North-western and North-central plains which are major seed producing zones of the country and need to be protected from the introduction of the disease.

Disease Cycle

Infected tubers and plant debris in infested soil are two major sources of inoculum. The pathogen infects roots of healthy plants through wounds. Nematodes such as *Meloidogyne incognita* which affect potato roots and tubers increase wilt incidence. Inoculum potential of about 10^7 cfu/g soil favours infection which however is dependent on other predisposing factors. Race 1 has greater ability to survive in soil than race 3 because of the better competitiveness; wide host range and higher aggressiveness of race 1. Mean soil temperature below 15^oC and above 35^oC do not favour the disease development. Soil moisture influence the disease in at least four ways; (i) increasing survival of the bacterium in the soil, (ii) increasing infection (iii) increasing disease development after infection, and (iv) increasing exit of the bacterium from host and spread through the soil. *Ralstonia solanacearum* is capable of causing brown rot in a wide range of soil types and levels of acidity. In majority of the cases, the disease has been reported in acidic soils (pH 4.3 to 6.8) and only in a few cases in alkaline soils.

Several other factors that affect pathogen survival in soil and water, also affect disease development. The soil type and physiochemical properties have significant influence on survival of the pathogen. Soils having high clay and silt content with higher water holding capacity are favourable for long survival while high sand contents disfavor its survival. Also, soil moisture and temperature exert a combined effect on survival of the pathogen. The congenial conditions for slow decline of population and virulence for race 1 and 3 are temperature between $10\text{-}30^oC$, soil moisture between 20-60 WHC, heavy soils and aerobic conditions.

Survival

The pathogen survives through infected seed tubers and in plant debris in soil. Symptomless plants may harbour the bacterium and transmit it to progeny tubers as latent infection. This could lead to severe disease outbreaks when the tubers are grown at disease free sites. High soil moisture, temperature, oxygen stress and soil type affect the survival of the pathogen. The pathogen population declines gradually in soil devoid of host plants and their debris.

Spread

Transmission of *R. solanacearum* from one area to another occurs through infected seed, irrigation water and farm implements. Under favorable conditions, potato plants infected with *R. solanacearum* may not show any disease symptoms. In this case, latently infected tubers used for potato seed production may play a major role in spread of the bacterium from infected potato seed production sites to healthy potato-growing sites.

Management

The control of bacterial wilt has proved to be very difficult because of the seed and soil borne nature of the pathogen, and especially in the case of race 1 due to its broad host range. Chemical control is nearly impossible. Soil fumigants have shown either slight or no effects. Antibiotics such as streptomycin, ampicillin, tetracycline and penicillin also showed hardly any effect; in fact, streptomycin application increased the incidence of bacterial wilt in Egypt. Biological control has been investigated, but is still in its infancy. Potato cultivars developed in Colombia with a *Solanum phureja* and *S. demissum* background showed resistance to *R. solanacearum*, but the race and strain diversity of the pathogen made it difficult to utilize these in other countries. The absolute control of bacterial wilt, at present, is difficult to achieve, however, economic losses certainly can be brought down considerably using the following eco-friendly package of practices:

Healthy seed: Use of healthy planting material can take care of almost 80% of bacterial wilt problem. Fortunately, bacterial wilt free areas in western and central Indo-Gangetic plains can be the source of disease free seed in India. Do not cut tubers; if the tuber is infected, the cutting knife spreads the disease and also cut tubers contact disease from soil easily.

Field sanitation: Where the field is already infested, the best way to minimize the disease is to adopt the following agronomic practices:

Crop rotation: Follow 2-3 years' crop rotation with non-host crops like cereals, garlic, onion, cabbage and *sanai* (Indian Senna). Do not cultivate solanaceous crops like tomato, brinjal, capsicum, chilli, tobacco etc. in rotation with potato. Paddy, sugarcane and soybean, though are not hosts of *Ralstonia solanacearum*, still they carry the pathogen and contribute to the disease perpetuation.

Avoid tillage operations: Pathogen enters in plant through root or stolen injuries. Such injuries cannot be avoided during intercultural operations. Therefore, restrict tillage to the minimum and it is advisable to follow full earthing-up at planting.

Off-season management of the field: The pathogen perpetuates in the root system of many weeds and crops. Clean the field from weeds and root/foliage remnants and burn them. The pathogen in remnants can be exposed to high temperature above 40 ^{0}C in summer in plains and plateau and low temperature below 5 ^{0}C in hills by giving deep ploughing. This may cause extinction of pathogen from the field.

Chemical control: Application of stable bleaching powder @ 12 kg/ha at the time of potato planting in furrows along with fertiliser reduces pathogen population from field and gives effective control.

Based on intensive ecological and epidemiological studies at Central Potato Research Institute, Shimla, the following practices are recommended for checking the bacterial wilt in different agro-climatic zones of the country.

Zone I: It comprises of non-endemic areas like Gujarat, Maharashtra, north-western and north-central plains. This zone is characterised by hot and dry summer with scanty vegetation (April-June); temperature may go up to 40-43^{0}C. The bacterial wilt is no more a major problem. Therefore, deep ploughing in summer and use of disease free seed is adequate for the disease control.

Zone II: It includes north-western mid hills (up to 2200 masl), north-eastern hills and the Nilgiris. The zone is characterised by mild summer, profuse vegetation with a maximum temperature range of 26-30^{0}C. Winter temperature may go as low as 3-6^{0}C. Many weed hosts can provide perpetual niche for colonisation and survival of the bacteria. The use of disease free seed plus application of stable bleaching powder @ 12kg/ha mixed with fertiliser at planting, ploughing the field in September- October and exposing the soil to winter temperature are adequate for disease control. The application of bleaching powder can be substituted by 2 year crop rotation with crops like wheat, barley, finger millet, cabbage, cauliflower, knol-khol, carrot, onion, garlic etc. Early planting preferably in February and early harvesting are recommended to minimise the exposure of the crop to high temperature which favours the disease.

Zone III: It includes eastern plains and Deccan plateau. Here, potato is cultivated as short day crop during winter months (October-March). Day temperature sometimes reaches 38⌈C. Heavy precipitation occurs due to western disturbances. The area is relatively rich in vegetation. Eastern plains and Deccan plateau have many symptomless carriers of the pathogen. Therefore, management of the disease is most difficult. However, the disease can be kept under check with practices like use of disease free seed, application of bleaching powder, blind earthing-up and ploughing in March and leaving the soil exposed to summer temperatures during April- May and crop rotations along with clean cultivation.

Zone IV: It includes north western high hills (above 2200 masl excluding Kumaon hills). This zone has a temperate climate with severe winters; daily temperature ranges from –10 to 5⌈C during December–January. Snow is common during these months. Bacterial wilt is not endemic and the use of disease free seed alone is adequate.

2. Soft Rot or Black Leg

Bacterial soft rot can cause significant loss of potato tubers at harvest, transit and storage. Losses due to poor handling of the produce, poorly ventilated storage or transit may go up to 100 per cent. Soft rot bacteria usually infect potato tubers which have been damaged by mechanical injury or in the presence of other tuber borne pathogens. Bacterial soft rot develops much faster under warm and humid conditions. The disease also results in blackleg of foliage during the crop growing season.

Symptoms

Initially a small area of tuber tissue around lenticels or stolon attachment point becomes water soaked and soft **(Fig. 3a)**. Under low humidity, the initial soft rot lesions may become dry and sunken. Under high humidity, the lesions may enlarge and spread to larger area. Tubers in advanced stages of decay are usually invaded by other organisms and the decaying tissue becomes slimy with foul smell and brown liquid ooze. The tuber skin remains intact and sometimes the rotten tubers are swollen due to gas formation.

Fig. 3: Soft rot symptoms on tubers (a); black leg symptoms (b)

At harvest, many small rotten tubers with intact skin can be seen. The infected seed tubers rot before emergence resulting in poor stand of the crop. In cooler regions, another kind of symptoms called black leg phase develops from soft rot infected seed tubers. The affected haulms become black at collar region just above the ground **(Fig. 3b)**. Infected plants develop yellowing, start wilting and die early without producing any tubers.

Water soaked lesions develop on succulent stems, petioles, and leaves. On stem and petioles, the lesions first enlarge into stripes, turn black and then invade the affected parts causing soft rot and toppling of the stem and leaves.

Causal organism

Pectobacterium atrosepticum (syn. *Erwinia carotovora* sub sp. *atroseptica*), *Pectobacterium carotovorum* sub sp. *carotovorum* (Jones) (syn. *Erwinia carotovora* subsp. *carotovora*), *Dickeya* spp. (including *D. dianthicola*, *D. dadantii, D. zeae*) (syn. *Erwinia chrysanthemi*), *Bacillus polymyxa, B*. *subtilis, B*. *mesentericus, B*. *megaterium* de Bary, *Pseudomonas marginalis* (Brown) Stevens, *P*. *viridiflava* (Burkholder) Dowson, *Clostridium* spp., *Micrococcus* spp., and *Flavobacterium* have been found to cause soft rot.

Pectobacterium atrosepticum the primary enterobacteria causing soft rots are gram negative bacteria, rod shaped with peritrichus flagella which can grow both under aerobic and anaerobic conditions, produce pectolytic enzymes and degrade pectin in middle lamella of host cells, breakdown tissues and cause soft rot and the decay. The decaying tissue become slimy and foul smelling and brown liquid oozes out from the soft rot affected tubers. About 1500 strains of pectinolytic *Erwinia* have been isolated from infected plants and tubers. The pathogen produce certain volatile compounds such as ammonia, trimethylamine and several volatile sulfides and early detection of such volatile compounds in storage could be used as a method to detect the disease at initial stage.

Disease Occurrence and Distribution

Bacterial soft rot of potato is found wherever potatoes are grown. The disease affect the crop at all stages of growth but it is more serious on potato tubers under poor storage conditions especially in warm and wet climate. Black-leg (*Pectobacterium atrosepticum*) phase of the disease is not common in India. It occurs only rarely in the Shimla hills in HP, the Kumaon hills in Uttarakhand, Ootacamund in Nilgiris and also in Bihar plains. Stem and petiole rot due to *Pectobacterium carotovora* sub sp. *carotovora* has been observed in Shimla, Jalandhar, Ambala, Panipat, Meerut, Agra, Kanpur, Allahabad, and Burdwan.

Disease cycle

Soft rot bacteria may be carried latently in lenticels, wounds and on surface of tubers without any visible symptoms and spread to healthy tubers in stores, during seed cutting, handling and planting. Water film on surface of tuber which cause proliferation of lenticels and creates anaerobic conditions and injury on surface of tuber predispose potatoes to soft rot. From soft rot infected seed tubers bacteria may enter vascular tissues of developing stems and can develop black leg under favourable conditions. From black leg infected plants the pathogen can reach daughter tubers through stolons and initiate tuber decay at the site of tuber attachment. Decaying tubers in soil could serve as source of contamination for healthy tubers. The threshold level for disease development is about 103 cells of *E*. *carotovora* sub sp. *atroseptica* per tuber. Tubers harvested in wet soil, poor ventilation in transit and storage promotes the rot.

Survival

Soft rot bacteria may survive in soil, on tuber surface, lenticels, periderm, cortex, ground tissue and vascular tissue. Rotting and decay of infected tubers in fields or stores may cause extensive contamination of adjacent healthy tubers, which serves as the most important source of primary inoculums. Contaminated irrigation water, rain splashes, farm implements, soil micro-fauna, nematodes, earthworms, larvae and adults of some insects etc. also help in secondary spread of the disease. Excessive moisture creating anaerobic condition, high temperature, excess nitrogen, tuber injuries and poor ventilation during storage are the important factors helping in disease development.

Spread

In warm climates, where one potato crop follows another or where only short rotation cycles are applied, the bacteria can pass easily from one crop to the next, especially in poorly drained soil. The bacteria can be disseminated in the potato fields by irrigation water, insects, rain or bacterial aerosols. The pathogen may also spread through water during washing of the produce with contaminated water. Soft rot causing bacteria can also spread easily from diseased to healthy tubers during storage, handling and grading. Insects especially maggots of *Hylemyia* species may also transmit the bacteria from one tuber to another.

Management

Soft rot bacteria are carried deep inside the tuber, in lenticels and surface wounds making it difficult to eradicate. These quiescent bacteria proliferate in high moisture condition and require water film that cause anaerobic conditions leading to disease development. Surface injury predisposes the tubers to soft rot infection. Based on ecology and epidemiology of the disease following management practices have been worked out:

- In field, avoid excess irrigation, provide proper drainage and restrict nitrogen dose to minimum (150 kg/ha).
- Adjust planting time to avoid hot weather during plant emergence. Harvest the crop before soil temperature rises above 28⌈C.
- Harvest the crop only when the tuber skin is fully cured.
- Avoid injury to tubers and sort out bruised/injured tubers.
- Treat tubers (for seed purpose) before storage with 3% boric acid for 30 min. and dry under shade.
- Store the produce either in well-ventilated cool stores or cold stores.

3. Common Scab of Potato

Common scab of potato caused by *Streptomyces* species cause superficial lesions on surface of potato tubers and affect quality of the produce. The affected tubers fetch low price in market due to poor appearance and also because deeper peeling is required before consumption. Seed lots exceeding 5 per cent incidence is rejected by seed certification agencies (in India) causing huge loss to seed industry. This disease was first recorded in Patna during 1958. Since then, it has become endemic in various potato growing states. Its real impact is felt in states like Punjab, Uttar Pradesh and Lahaul valley of Himachal Pradesh where potato production is for seed industry.

Symptoms

Scab begins as small reddish or brownish spot on the surface of the potato tubers and its initial infection takes place during juvenile period of tuber. Infection takes place mainly through lenticels and surrounding periderm turns brown and rough. Lesion becomes corky due to elongation and division of invaded cells. Under Indian conditions multiple kinds of symptoms have been recorded and they are grouped as (1) a mere brownish roughening or abrasion of tuber skin (2) proliferated lenticels with hard corky deposition, might lead to star shaped lesion (3) raised rough and corky pustules (4) 3-4 mm deep pits surrounded by hard corky tissue (5) concentric series of wrinkled layers of cork around central black core **(Fig. 4).**

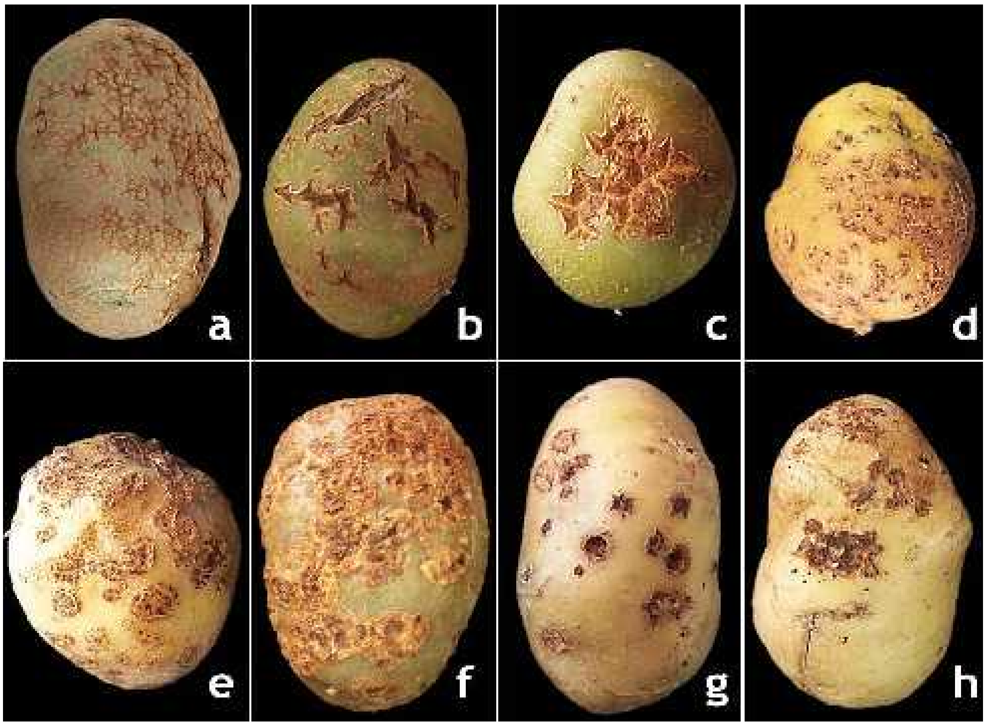

Fig. 4: Various types of scab symptoms caused by *Streptomyces* species on potato tubers

Causal organism

At least 13 different *Streptomyces* spp. have been found to cause common scab on potato worldwide. The prominent among them are *Streptomyces scabis* (Thaxter) Lambert and Loria, *S. acidiscabies* Bambert and Loria, *S. turgidscabis* Takeunchi, *S. collinus* Lindenbein; *S. griseus* (Krainsky) Waksman & Henria, *S. longisporoflavus*, *S. cinereus* , *S. violanceoruber*, *S. alborgriseolus*, *S. griseoflavus*, *S. catenulae* and others. *Streptomyces* are bacteria which resemble fungi due to formation of vegetative substrate mycelium that develop aerial filaments. However, the filaments are of smaller dimensions than the true fungi. These filaments produce spores through fragmentation. *Streptomyces* spp. may be pathogenic or non-pathogenic. The pathogenic species produce thaxtomins which are phytotoxins and cause hypertrophy and cell death. Considerable variation exists within the pathogen with respect to their pigment production in media, colour and shape of sporulating filaments and use of specific sugars. *S. scabies* form grey, spiral spore chains on several media and produce brown pigment whereas *S. acidiscabis* produce peach coloured wavy chains of spores and brown pigment in medium. The identification and taxonomy of *Streptomyces* spp. has been based on morphological and physiological characteristics combined with thaxtomin production and pathogenicity tests *in vitro* and *in vivo*. Ability to produce thaxtomin toxin is strongly correlated with the pathogen’s pathogenicity.

Disease Occurrence and Distribution

Common scab occurs in most potato producing areas in Africa, Asia, Europe, North and South America. In India, the disease is prevalent in almost all potato growing regions. It is spreading fast in some areas in Indo Gangetic plains due to cultivation of potato year after year in the same land.

Disease cycle

Potato is physiologically most susceptible to *Streptomyces* spp. in the period following tuber initiation. *Streptomyces*species infects the newly formed tubers through stomata and immature lenticels. Once the periderm has differentiated, tubers are no longer susceptible to the pathogen. The pathogen is both seed and soil borne. It can survive in soil for several years in plant debris and infested soil. Soil conditions greatly influence the pathogen. Favourable conditions include pH between 5.2 to 8.0 or more, temperature in the range of 20 to 30^{o}C) and low soil moisture. The pathogen is aerobic in nature and maintaining high soil moisture for 10 to 20 days after tuber initiation can help in reducing the common scab.

Survival

The organism is a tuber-borne and is well-adapted saprophyte that persists in soil on decaying organic matter and manure for several years.Infected tubers serve as inoculum foci in the field, giving rise to infected progeny tubers.

Spread

The pathogenic *Streptomyces* species are both soil and tuber-borne. Tuber-borne inoculum is likely to be involved in the distribution of new strains or species.

Disease management

The pathogen is difficult to eradicate because of long survival both on seed tubers and in soils. Therefore, following practices to minimize the inoculum and creating adverse condition for pathogen spread/disease development are recommended.

- Use only disease free seed tubers.
- Give tuber treatment with boric acid (3% for 30 min.) before or after cold storage (before sprouting); dry under shade before storage or planting.
- Irrigate the crop repeatedly to keep the moisture near to field capacity right from tuber initiation until the tubers measure 1 cm in dia.
- Maintain high moisture in ridges at least for a few weeks during the initial tuberization phase.

- Follow crop rotation with wheat, pea, oats, barley, lupin, soybean, sorghum, bajra, and adopt green manuring to keep the disease in check.
- Plough the potato fields in April and leave the soil exposed to high temperatures during summer (May to June) in the North Indian plains.

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Chapter 7

Virus Diseases of Potato and their Management

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Introduction

Viral infection cause enormous economic losses particularly in the areas of tropics and semi tropics which provide ideal conditions for the perpetuation of viruses and their vectors. So, any attempt to minimize the losses caused by these diseases must be, always, preceded by a correct and precise detection and diagnosis of the causal agent. Nevertheless, it is very difficult to diagnose the plant virus infections as the symptoms may vary depending upon the plant variety involved, the environmental conditions, strain of the virus. Sometimes different viruses can cause similar symptoms in the same plant species and sometimes the disease could result from the synergistic effect of infection caused by two or more different viruses. The most wide spread viruses causing mosaics in potatoes are usually PVY occurring worldwide. In combination with *Potato virus X*, it causes an even more destructive disease known as rugose mosaic. These viruses found wherever potatoes are grown.

Potato Mosaics

In general majority of the potato viruses like PVY, PVX, PVA, PVM, PVS, PAMV and PSTVd (viroid) causes mosaics mottling/crinkle, necrosis, etc., either individually or in different combinations. Whereas, *Potato leafroll virus* causes upward rolling and *Tomato leafcurl virus* causes curling of young leaves. These viruses generally infect potato and few other hosts from the family of *Solanaceae* like pepper *(capsicum spp.)*, tobacco *(Nicotiana spp.)*, tomato *(Lycopersicon esculentum)* and other families like *Chenopodiaceae, Leguminosae, Compositae and Amaranthaceae.*

Mosaics are the most common symptoms expressed by plant viruses infecting potato plants. Overlapping symptoms are invoked by different viruses individually and/or in different combinations, such as typical greening or yellows, mild or severe/rugose mosaics, faint mottle, chlorosis of plants and discolouration or distortion of foliage. Rugosity of leaves is accompanied by interveinal chlorosis and/or interveinal puckering. Besides, there can be necrosis of the veins (lower side), petioles and even inward curling of lamina which may lead to premature defoliation. Mosaics and mottle are prominent in cool and dull weathers.

Latent of faint Mosaics

Potato virus X (PVX): It's latent in many of the cultivars whereas the severe strains can cause mosaic symptoms and the appearance of mosaics is limited by the veins. Bright day light generally affects visual symptoms, which can be observed under low light or placing a white card below the leaf.

Potato virus S (PVS): Usually latent or very mild or barely perceptible mottle and faint vein banding. Some cultivars develop mild rugosity while few strains invoke bronzing of leaves and in few cultivars tiny necrotic spots can also be seen.

Mild Mosaics

Potato virus A (PVA): Slight and transient mosaics that are particularly visible in cloudy weather. Mosaic faint mottling, slight crinkling of leaves and inter-veinal and veinal chlorosis. These symptoms can be reinforced by placing a sheet of white paper under the leaf.

Potato virus A (PVA) **Potato virus M (PVM)**

Potato virus M (PVM): Spoon-shaped leaves corresponding to a soft curling of the leaves (while the potato leaf roll virus produces "cracking" of the roll). Called leaf rolling mosaic or para crinkle It occurs on developed plants, preferentially on the topmost leaves.

Potato spindle tuber viroid (PSTVd): The symptoms of PSTVd are very obscure and unusual. Generally the plants are slightly stunted, erect, often with curling leaves darker green than healthy. Eyes are numerous in number with distinct eye brows. Tubers are cylindrically longer than normal with tapered ends with cracks upon infection with severe strain of PSTVd.

Potato spindle tuber viroid (PSTVd)

Severe Mosaic and complex Diseases

Potato virus Y (PVY): Generally the symptoms vary with the strains of the virus or variety of potato i.e., plants will be stunted with mild or severe mosaic, veinal necrosis. Ordinary strain (PVY^{O}) and stipple-streak strain (PVY^{C}) causes necrosis, yellowing of leaflets and premature leaf drops. PVY^{NTN} strains cause mild mosaic and clearly visible raised necrotic ring spots on the tuber surface which later become sunken and skin cracking.

PAMV: Bright yellow spots in green lamina and mosaic symptoms with stunting. These symptoms of PAMV are depending on potato variety and strain of the virus as well.

Crinkle (PVX+PVA): Infection of PVA and PVA may lead to heavy blotching of distorted, erect leaves with wavy margins, severe stunting, mottling, necrotic spotting and streaking of leaflets.

Rugose (PVX+PVY): The primary cause of rugose mosaic is due to the infection by PVY but in combination with PVX may result in severe rugose symptoms, stunted growth and leaf drop or curling with veinal necrosis in lower leaves and severe mosaic in upper ones.

Rosette (PVX+PVS+PVM or PVX+PVA+PVY+PVM): Severe stunting of the infected plants with single or a few stems per hill, puckered, roughened leaflets with inward and yielding a few small tubers.

Disease cycle and transmission: Tubers are the main source of infection and all mosaic evoking viruses are tuber perpetuated. Highly contagious viruses and viroid are readily transmitted mechanically by leaf, root or tuber contact of diseased and healthy plants, though the viroid also readily spreads through pollen and true seed. Contagious viruses are also transmitted by the cutting knife, as well as cultivating and spraying equipment's. The other viruses are transmitted mainly by aphid species like *Myzus persicae* and *Aphis gossypii*.

Potato Leafroll

Potato leafroll is one of the most prevalent viral diseases of potato in India. All Indian potato varieties are susceptible to this virus. Infected plants produce only a few, small to medium tubers. Yield loss normally ranges from 20-50% in India but in extreme cases may be as high as 50-80 % (Mukherjee *et al*., 2003). However it is lower in autumn season (7-16 %) than in spring season (39-60%).

Potato leafroll virus (PLRV); (syn. = phloem necrosis virus). It is the type species of the genus *Polerovirus*, in the family *Luteoviridae* . PLRV has small, isometric virions (23-25 nm dia) which are primarily confined to the phloem of the infected plants. At genome level, Indian isolates are closer to European and Canadian isolates (95.8 to 98.6 %) than to an Australian isolate (92.9 % to 93.4 % similarity). In nature, potato is the principal host of PLRV yet several plant species, mostly from *Solanaceae*, are known as hosts *viz*., *Datura stramonium*, *Physalis floridana*, *Solanum villosum*. It can also infect some non-solanaceous plants like *Amaranthus caudatus*, *Gomphrena globosa etc*.

The primary symptoms are confined to top young leaves, which usually stand upright, roll and turn slightly pale in certain cultivars. Most varieties, however, develop reddish/pink colour in top leaves starting at the margins, sometimes accompanied with slight rolling of the leaflets. Secondary symptoms develop when the plants are grown from infected seed tubers. Such symptoms are rather prominent in older leaves, *i.e.* absent or less pronounced on younger top leaves. Infected plants have characteristic pale, dwarfed, and upright appearance with rolling of lower leaves that turn yellow, brittle and are leathery in texture. In some cultivars, a reddish or purple discolouration develops on the margins and underside of the leaves.


It also infects *Datura stramonium* leading to interveinal necrosis/chlorosis, *Physalis floridana* -chlorosis, rolling of the leaves and stunting and on *Solanum villosum* -chlorosis, leafroll and leathery texture of leaves.

Disease cycle and transmission: The virus is tuber borne, transmitted efficiently by aphid in a persistent manner (circulative type i.e. aphids normally need longer feeding periods on diseased and healthy plants). Primary infections are normally caused by the viruliferous aphids coming either from distant or nearby fields and/or diseased volunteer plants arising from the infected tubers. Potato plants infected with PLRV will produce infected tubers. If infected tubers are planted they will give rise to infected plants. The green peach aphid (*Myzus persicae*) is the most efficient and important vector of PLRV and also *Aphis gossypii*. *Macrosiphum euphorbiae* transmits potato strains less efficiently. *M. nicotianae* was found to be an efficient experimental vector. PLRV is not transmitted by mechanical inoculation, seed or pollen but it is transmitted experimentally by grafting.

Apical Leaf Curl Disease

Apical leaf curl disease has recently emerged as one of the most devastating viral disease of potato in India. It was first observed during 1999 in northern India and the association of a begomovirus with this disease was confirmed through electron microscopy in the year 2001. Further the virus was confirmed as a strain variant of *Tomato leaf curl New Delhi virus* (ToLCNDV) on the basis of nucleotide sequence of genomic components (2003). The incidence of apical leaf curl disease has been observed to be higher in early planted crop when temperature is high in October, than in November planted potato crop. Recently, 40-70 per cent infection was recorded in Indo-Gangetic plains of India. There are even reports of up to 100 per cent infection causing heavy yield losses. The disease incidence has positive correlation with whitefly population and whitefly infestation period.

It is caused by a strain of *Tomato leafcurl New Delhi virus* (ToLCNDV), a bipartite geminivirus consisting of either one or two ssDNA circles of ~2.8 kb and it is transmitted through whitefly. Infected potato leaves show chlorosis, crinckling, mosaic, curling of apical leaves, pinkish tinge on leaf margins, latter entire plant appears bushy and stunted due to reduced internodal distance.

Transmission and Disease cycle: Under field conditions, the virus is transmitted by whitefly (*Bemisia tabaci*) in a persistent manner. Once an adult has acquired the virus by feeding, it retains the virus for long period. The females are more efficient in transmitting the virus than the males. It is also transmitted through seed tubers from one generation to the next generation. These vectors acquire the virus and transmit from infected plant to healthy potato plants. Once the plant is infected, the infection will be systemic in a given plant and therefore the tubers will also be infected (serves as primary source of infection) with the virus. If this infected tuber is planted then it spreads the virus into the upcoming seedling/plant and again the secondary spread will be by whitefly as mentioned earlier. Therefore, whiteflies play a vital role in secondary spread of the virus. This entire cycle repeats till proper management practices are adopted.

Stem Necrosis Disease

Potato stem necrosis disease (PSND) has become a serious problem of the early crop in the central and western parts of India. Disease incidence up to 90 % was recorded in some parts of MP and Rajasthan. Initially, it was thought to be fungal disease due to necrotic symptoms but later after detailed investigations, revealed the presence of enveloped spheroidal virus-like particles measuring ca 10 to 110 nm in diameter;

particles being enclsoed in endoplasmic reticulum-like membrane. Characteristics of the virus like particles showed it to be *Groundnut bud necrosis virus* (GBNV).

It is caused by *Groundnut bud necrosis virus* (GBNV), which is spherical, enveloped particles, ranging from 70-110 nm in diameter and enveloped with glycoprotein. Under field conditions the virus is transmitted by viruliferous thrips in persistent manner. It acquires at nymphal stage and transmits in adult stage. The virus induces necrotic and chlorotic spots on leaves and stem, veinal-necrosis, leaf droop and hanging, blackening and cracking of stem. Distinct wavy concentric patterns with ligh and dark brown necrotic region cover the stem. In extreme cases of infection, cracking and blackening of stems also occur. It also infects *Amaranthus viridis, Pisum sativum*, tomato, sunflower, groundnut. The virus from these hosts induces chlorotic local lesions upon sap inoculation in cowpea var. C-152.

Transmission and Disease cycle: The virus is known to borne transmitted by thrips in a persistent manner. The vector thrips acquire the virus only as nymphs but retain and transmit it throughout their life. Four species, *Thrips hawaiensis, Megalurothrips distalis, Thrips palmi* and *Scirtothrips sp.* have been identified from early plated potato crop within a week of crop emergence. *T. Palmi* is the predominant species and probably most efficient vector. There is a strong positive correlation between the early planting and trips activity which declines with the post-ponment of date of planting to end of October or early November. The high temperature (30 to 35 ^{o}C) and dry weather during September/October are known to be favourable for thrips activity and consequently higher disease incidence and also greater severity.

Management

Diseases caused by viruses cannot be easily controlled by chemicals alone. Therefore, it has to be managed by adopting the following measure on co-operative basis and in an integrated approach:

1. Essentially plant the disease-free seed stocks from approved or reliable sources.
2. Place yellow trap (15X30cm^2) just above the canopy height @ 60 traps/ha at equidistance from each other.
3. Manage the weeds at regular interval and avoid/remove the reservoir plants like okra, brinjal and datura.
4. Roguing of infected plants and dehaulming the crop as soon as the vector populations exceeds critical limit of 20 aphids/ 100 compound leaves.
5. Viruses like PVX, S and viroid (PSTVd) are readily spread in stores and fields through contaminated hand, clothes of workers, farm machinery/tools etc. hence, disinfect all field equipment's by dipping in or washing them either with 3% trisodium phosphate or calcium hypochloride (1%) solution.

6. Seed treatment with imidacloprid (17.8% SL) @ 0.04% (4ml/10 lit) for 10 minutes before planting.
7. First spray with imidacloprid (17.8% SL) @ 0.03% (3ml/10 lit) at the time of emergence of crop.
8. Second spray with thiamethoxam (25WG) @0.05% after 15 days of crop emergence.

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Chapter 8

ELISA and other Sero-Diagnostic Techniques for Potato Pathogens

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Introduction

Early and reliable diagnosis methods allow the monitoring of the pathogen and enable farmers to administer suitable management strategies in a timely fashion and would greatly increase the effectiveness of the treatment. In general, the disease can be diagnosed by the presence of symptoms like blight, spots, wilting or by the presence of mycelia growth or other structures and bacterial ooze or can be diagnosed by mosaic patterns on leaves, stunting of the plant, leaf malformations, and tuber malformations in case of viral diseases. However, disease symptoms alone had the limitation as similar symptoms could be produced by certain nutrient deficiencies or other abiotic or biotic factors. Sometimes no perceptible symptoms may be visible in case of infection by PVA, PVX, PVM and PVS in certain varieties. This was overcome with use of indicator hosts. The technique of virus detection using indicator hosts, however, required more time, labour and space.

Therefore, techniques based on serology and histochemical tests were standardized for detection of viruses and phytoplasma diseases during 1960s through 1970s. The most commonly used serological tests were the precipitin and chloroplast agglutination. These tests were effectively used in detecting PVX, PVS and PVM. Since large volume of antisera was required for testing all the clones under breeder seed production, the institute started mass production of antisera by the year 1972. Chloroplast agglutination test was the standard method used for indexing potato clones till 1984. The technique suffered the following drawbacks namely requirement of large quantities of antisera, its applicability to only high titer viruses like PVX, PVS and PVM and a low sensitivity (detection had only about 60% reliability or confidence level). These limitations of chloroplast agglutination were overcome when CPRI introduced the use of ELISA (enzyme-linked immunosorbent assay) in 1984.

ICAR-CPRI started producing its own ELISA kits for potato viruses by 1990. Pure cultures of the important potato viruses are being maintained by CPRI for their multiplication, purification and antisera production. High titre and high degree of purification of the viruses is ascertained with electron microscope before use for immunization. This results in the production of virus-specific antisera suitable for the ELISA kits, which are prepared at CPRI. As a policy, antisera are cross adsorbed with healthy host plant tissue powder to remove traces of antibodies produced against host proteins. The ELISA reagents are then checked for antibody titre; precise dilutions of IgG, IgG-enzyme conjugate and plant saps for virus detection are determined. Presently, CPRI produces ELISA reagents for PVA, PVM, PVS, PVX, PLRV and PVY. ELISA is reasonably sensitive and highly amenable to high throughput automation. Hence, it is suitable for large scale screening of samples.

The use of serology based techniques for detection fungal and bacterial pathogens of potato is not so successful as in virus detection. Though the antisera raised from soluble mycelial protein of *Phytophthora* *infestans* are available, it cross reacts with another fungal pathogen, *Pythium* sp. The development of quick, reliable and cost effective late blight diagnostic techniques for use in testing large number of seed potatoes is a number one priority. Hence, we are working on developing *P. infestans* specific antiserum using the recombinant cellulose binding domain (CBD-1) protein. Another important disease of potato is bacterial wilt caused by a bacterium, *Ralstonia solanacearum.* Production of antisera using whole bacterial cells and its use in ELISA could successfully detect *R. solanacearum.* However, it failed in routine use due to its cross reaction with some non-pathogenic bacteria. Hence, ooze out test and subsequent isolation of pathogen is used in diagnosis of the disease and for large scale testing of tubers, PCR assay is being used at ICAR-CPRI.

Serology based techniques

Serology is the use of specific antibodies to detect their respective antigens (pathogens) in test specimen. Antibodies are composed of immunoglobulin (Ig) proteins produced in the body of an animal in response to the presence of antigens. Each antibody is specific to an antigen and will bind to it. Serological or immunological methods are generally specific, sensitive enough and have been used successfully for several years for the detection of pathogens. However, there are some limitations to the use of antibodies in pathogen diagnosis. Firstly, the nature of the cross reactions between heterologous antibody-antigen complexes are not well understood. Secondly, diagnosis is based on only part of the organism's structure such as the coat protein of a virus which represents only a small proportion of the information about the virus. Thirdly, serology is only useful when the antiserum has been prepared or when an antigen is available for producing an antiserum. Different diagnostic protocols based on antibody-antigen are routinely being used for detection of major potato pathogens and have been briefly discussed below.

1. Immunosorbent electron microscopy

The immuno sorbent electron microscopy (ISEM) for detection and identification of potato viruses by combining electron microscopy and serology are highly sensitive. ISEM for virus detection has been optimized for the most reliable detection of PVA, PVM, PVS, PVX and PVY. Though costly and having low throughput, ISEM has the advantage of being a direct method without any false positive results. ISEM is very useful where freedom from virus infection must be ascertained with a very high degree of confidence as in the case of pre-basic nucleus seed stocks, in post-entry quarantine testing of imported material and mericlones during cleaning of virus infected stocks. PLRV is a small, phloem-restricted virus occurring in very low concentration and poses problem in detection with conventional electron microscopic detection. ISEM will solve this problem and could be used for the reliable and sensitive detection of PLRV. PLRV was best detected when the virus and its antibodies interacted in liquid phase followed by trapping on the grid coated with protein A and homologous antibodies.

2. Precipitation, gel diffusion and agglutination tests

Precipitin tests (either in liquid medium or in agar/agarose) rely on the formation of visible precipitate when adequate quantities of virus and specific antibodies are in contact with each other. These tests are routinely used by some investigators, but agglutination and double diffusion tests are more commonly used. In double diffusion tests, the antibodies and antigen diffuse through a gel matrix and a visible precipitin line is formed where the two diffusing reactants meet in the gel. The Ouchterlony double diffusion method can be used to distinguish related, but distinct, strains of a virus or even different but serologically related viruses. In an agglutination test, the antibody is coated on the surface of an inert carrier particle (e.g., red blood cells), and a positive antigen–antibody reaction results in clumping/agglutination of the carrier particles which can be visualized by the naked eye or under a microscope. Agglutination tests are more sensitive than other precipitin tests and can be carried out with lower concentrations of reactants than are necessary for precipitation tests.

3. Enzyme Linked Immuno Sorbent Assay (ELISA)

The technique utilizes the ability of antibodies raised in animals to recognize proteins, usually the coat protein, of the virus of interest. In this method, the target epitopes (antigens) from the viruses, bacteria and fungi are made to specifically bind with antibodies conjugated to an enzyme. The detection can be visualized based on color changes resulting from the interaction between the substrate and the immobilized enzyme. Antibodies are fixed to the surface of a well within a microtitre plate, and a sap extract from the plant is added to the well. If the virus of interest is present in the plant, it will bind to the antibodies fixed on the surface. Any unbound extract is washed-off before a secondary antibody that recognizes the first antibody is added. The secondary antibody allows for indirect detection of the virus because it has a reporter molecule attached to it, usually an enzyme that acts on a substrate that changes colour, which is detected visually by a calibrated microtitre plate spectrophotometer. CPRI produces ELISA reagents for PVA, PVM, PVS, PVX, PLRV and PVY. ELISA is reasonably sensitive and highly amenable to high throughput automation. Hence, it is suitable for large scale screening of samples.

However, the sensitivity of ELISA for bacteria is relatively low (10^5–10^6 CFU/mL) making it useful only for the confirmation of plant diseases after visual symptoms appear but not for early detection before disease symptoms occur. The major constraint of the method is the requirement for polyclonal or monoclonal antibody sera specific for each virus of interest that does not cross-react with plant proteins. There are two different type of ELISA i.e. 1) Direct ELISA 2) Indirect ELISA. Both direct and indirect ELISA can be used for antigen (or antibody) detection, but the indirect ELISA is more common.

a. Direct ELISA: The direct ELISA uses the method of directly labelling the antibody itself. Micro-well plates are coated with a sample containing the target antigen, and the binding of labelled antibody is quantitated by a colorimetric, chemiluminescent, or fluorescent end-point (Fig. 1). Since the secondary antibody step is omitted, the direct ELISA is relatively quick, and avoids potential problems of cross-reactivity of the secondary antibody with components in the antigen sample. However, the direct ELISA requires the labelling of every antibody to be used, which can be a time-consuming and expensive proposition. In addition, certain antibodies may be unsuitable for direct labelling. Direct methods also lack the additional signal amplification that can be achieved with the use of a secondary antibody.

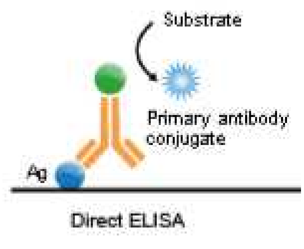

Fig. 1. Schematic representation of Direct ELISA

b. Indirect ELISA: The indirect ELISA utilizes an unlabelled primary antibody in conjunction with a labelled secondary antibody (Fig. 2). Since the labelled secondary antibody is directed against all antibodies of a given species (e.g. anti-mouse), it can be used with a wide variety of primary antibodies (e.g. all mouse monoclonal antibodies). The use of secondary antibody also provides an additional step for signal amplification, increasing the overall sensitivity of the assay.

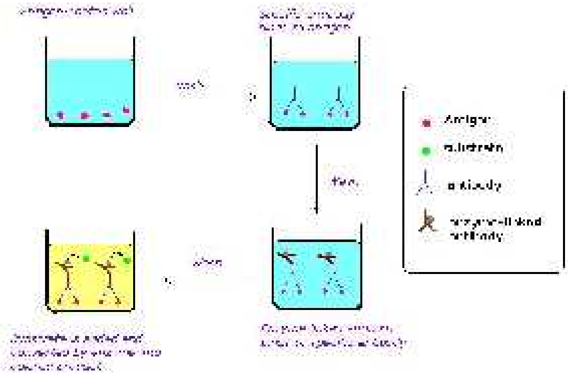

Fig. 2. Work flow of indirect ELISA

c. Sandwich ELISA: The sandwich ELISA is a sensitive and robust method in which the antigen of interest is quantified between two layers of antibodies: the capture and the detection antibody (Fig. 3).

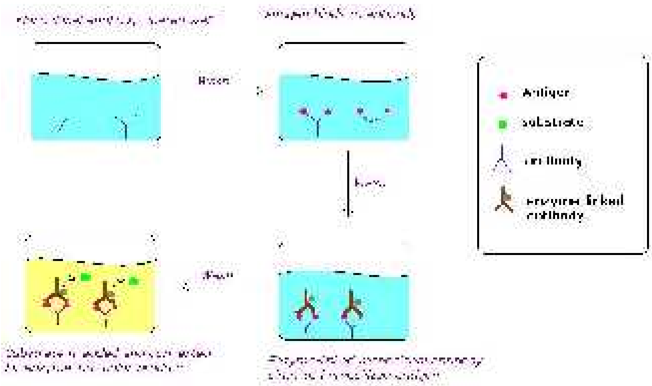

Fig. 3. Work flow of Sandwich ELISA

4. Dot blot assay

In immune blots or dot-blots assays antibodies or virus particles bound to nitrocellulose membrane filters are used. Dot blot ELISA tends to be rapid, easy to perform and conservative of reagents and often more sensitive than ELISA carried out in a microtiter plate. Immuno blot assays use the same reagents used in microtiter plate ELISAs, except that the substrate produces an insoluble product which precipitates onto the membrane. Positive reactions can be determined visually. Assays in which antibodies or antigens are bound to nitrocellulose or nylon membranes have been used to detect PVS, PVX, PVY and PLRV.

5. Immunofluorescence

Immunofluorescence (IF) is a fluorescence microscopy-based optical technique used for the analyses of microbiological samples. The technique can also be utilized to detect pathogen infections in plant tissues. For this technique, plant samples are fixed to microscope slides in thin tissue sections. Detection is achieved by conjugating a fluorescent dye to the specific antibody to visualize the distribution of target molecule throughout the sample. A significant problem with IF is photobleaching which results in false negative results. However, the decrease of sensitivity due to photobleaching can be controlled by reducing the intensity and duration of light exposure, increasing the concentration of fluorophores, and employing more robust fluorophores that are less sensitive to photo-bleaching.

6. Lateral flow immuno assay

Lateral flow immuno assay (LFIA) is based on the interaction between the target virus and immunoreagents (antibodies and their conjugates with colored colloidal particles) applied on the membrane carriers (lateral flow test strips). When the test strip is dipped into the sample being analyzed, the sample liquid flows through membranes and triggers immunochemical interactions resulting in visible coloration in test and reference lines (Fig. 4). CPRI has developed LFIA kits for the detection of five viruses *viz*., PVX, PVA, PVS, PVM and PVY either individually or in combination of two viruses viz., PVA & PVX, PVA & PVS, and PVY & PVM using a single strip. Several foreign companies produce test strips for detection of plant viruses: Spot Check LF (Adgen Ltd., UK), Pocket Diagnostic (Forsite Diagnostics Ltd., UK), and Immunostrips (Agdia, United States).

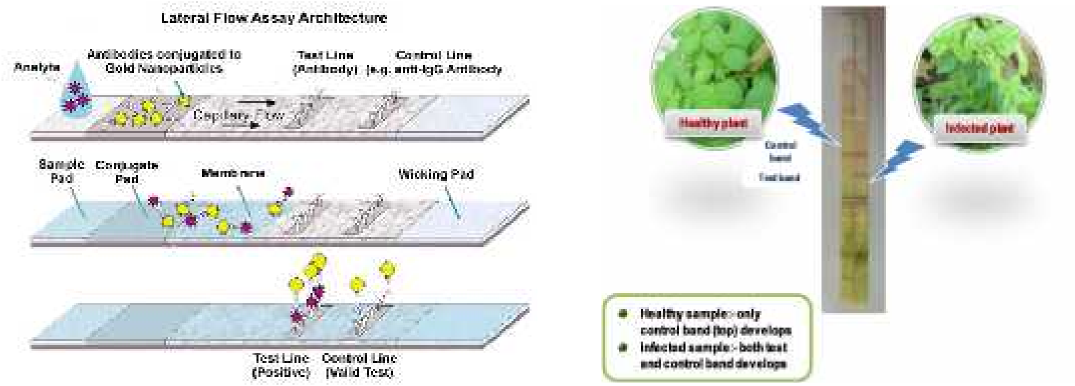

Fig. 4. Working principle of LFIA and interpretation results

Suggested readings

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Chapter 9

Fungal Soil and Tuber borne Diseases of Potato and their Management

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Introduction

Fungal soil and tuber diseases of potato such as black scurf, dry rots, wart, powdery scab, charcoal rot, silver scurf, sclerotium and sclerotinia rots, phoma dry rot, pink rot, black dots, dry and wet rots caused by early and late blight are prevalent in different parts of the country. These diseases affect quality and market value of the produce. Such diseases spread to new areas through the infected seed tubers and may cause economic huge losses. These fungal soil and tuber diseases need to be identified correctly and managed well so as to produce healthy seed and ware potatoes.

Black scurf

Black scurf of potato caused by *Rhizoctonia solani* is a well-known disease of potato with worldwide distribution. It causes damping off of seedlings, stem canker in growing plants and black scurf on potato tubers. The disease kill potato sprouts, delay crop emergence, reduce crop stand, affects tuber quality and marketability of the produce. The most common symptoms are on tubers as black irregular lumpy encrustations of fungal sclerotia which stick to the surface of tubers. Other symptoms on tubers could be cracking, malformation, pitting and stem end necrosis.

Seed-borne (i.e.tuber borne) inoculum is the main source of primary infection leading to stem canker symptoms on the underground plant parts.The pathogen is both soil and seed borne but the disease spreads to new growing areas through sclerotia-covered seed tubers . The disease gets established in fields wherever the untreated infected tubers are used as seed. Secondary inoculum of the *Rhizoctonia* disease is soilborne and accomplished by *R. solani* mycelia and sclerotia already inhabiting soil where the potato crop is planted.

Sclerotia of the pathogen germinate between 8 to 30 ^{o}C and invade emerging sprouts or potato stems. Optimum temperature for germination of sclerotia is 23 ^{o}C and for development of stem lesions is 18 ^{o}C. Sclerotial development on tubers is initiated depending on environmental conditions. Late harvested crop show more black scurf incidence since maximum development of sclerotia takes place in the period between dehaulming and harvest of the crop.

Soil borne infection emerges later in the season since the fungus needs some time to grow into proximity with its potato.

Use of healthy seed free from sclerotia of the pathogen helps in disease management. Soil solarization with transparent polyethylene mulching during hot summer months in Indian subtropical plains has been found to be very effective for control of the soil borne part of the disease. Crop rotation offers an effective protection against soil borne inoculum of *R. solani*. Planting of potato should be carried out in relatively dry and warm soil to achieve rapid crop emergence and an appropriate crop rotation programme should be followed to manage the disease. Shallow covering of seed tubers allows less opportunity for the fungus to attack the susceptible sprouts and thus less disease. Two to four year crop rotation with cereals and legumes leads to decline in the population levels of the *R. solani.* Cereals are good rotational crops since *R. solani* affecting cereals have different AG group of the pathogen and cannot affect potato

Various fungicides such as benomyl, thiabendazole, carboxin, pencycuron and azoxystrobin, fenpiclonil are effective for control of the disease. Seed treatment with 3% boric acid has been identified as a safe and effective chemical treatment for the control of black scurf. Seed treatment with 3 per cent boric acid as atomized application on infected tubers was found more economical than the dip treatment for control of seed inoculum. Spray treatment of boric acid was equally effective in washed or unwashed seed tubers.

Biocontrol agents such as *Trichoderma viride*, *T*. *harzianum*, *Bacillus subtilis*, non-pathogenic binucleate *Rhizoctonia*, *Trichoderma atroviride*, *Gliocladium virens*, *G*. *catenulatum* and others have been identified to be effective against *R*. *solani*. Biocontrol products developed to manage the disease have been found effective against black scurf disease. *Trichoderma* spp. are well documented for their ability to protect plants from *R. solani* infection by production of antibiotics, antifungal chemicals and hydrolytic enzymes. Some *Trichoderma* spp. have been reported to provide plant growth enhancement as well as crop protection. A bioformulation developed at Central Potato Research Institute from *T*. *viride* strain A-7 and evaluated in several field trials in India was found very effective when used as seed treatment before planting potatoes. Efficacy of *Trichoderma viride, Bacillus subtilis* and *Bacillus cereus* in consortium for control of *Rhizoctonia solani* was evaluated in field trials in India and the biocontrol agents used in combination were found to control the disease better than the biocontrol agents used alone.

An integrated use of *Trichoderma viride* and boric acid can also significantly improve the disease control. A combination of soil solarization carried out in north Indian Plains during summer months together with seed treatment with 3 per cent boric acid or *Trichoderma viride* was found very effective for control of black scurf in *Rhizoctonia* infested soils

Fusarium Dry rot

Fusarium dry rot, an important post-harvest disease of potato tubers, causes significant losses in storage and transit of both seed and table potatoes. The disease is distributed world-wide and occurs wherever potatoes are grown. The disease symptoms on potato tubers are generally visible in about a month after storage. The symptoms appear as small brown lesions on surface of the affected tubers. The lesions subsequently enlarge, appear dark, sunken, and wrinkled producing white, pink, or blue pustules. In later stages a cavity often develops in the centre of the concentric ring and whitish, pinkish or dark brown growth of fungal mycelium may become visible. Rotten tubers may shrivel and get mummified. Under high relative humidity the secondary organisms such as *Erwinia* spp. can invade the infected tubers and cause soft rot.

Fusaria are always present in soil, in air, on implements, containers and it is practically not possible to eradicate them. They cannot infect intact periderm and lenticels of tubers. Cuts and wounds created during harvest, grading, transport and storage predispose them to infection. The pathogen enters the tubers through wounds and proper wound healing could reduce the infection. Infected and rotting tubers are main source of spread of the inoculum of *Fusarium* spp. and results in soil infestation. *Fusarium* spores can survive in soil for several years and can infect the cut or damaged surfaces of seed potatoes whenever these come in contact with the spores infested soil. The pathogen may also get introduced to new locations through contaminated soil which adheres to the farm implements, through wind and irrigation water etc. The fungus remains viable in soil for 9 to 12 months. *Fusarium* spp. has good saprophytic ability to survive in soil.

The pathogen enters the tubers through wounds and proper wound healing could reduce the infection. Tubers cured for wound healing at 21^{o}C with adequate aeration develop wound periderm in 3 to 4 days but it takes more time at lower temperature. Development of disease is also affected by moisture and temperature. The fungus grows well between 15 to 28 ^{o}C. *F*. *oxysporum* has been reported to become non-pathogenic below 10 ^{o}C. However, disease development continues at low temperature in cold stores. Storage period and relative humidity have been found to be positively correlated with dry rot whereas maximum temperature was negatively correlated. Large sized tubers are more susceptible than small tubers. Susceptibility to tubers may also increase with tuber age during storage. No significant correlation exists between chemical composition of tubers and susceptibility to dry rots.

Avoiding bruises and damage to potato tubers by careful handling of the produce minimize the dry rots. This can be done by delaying harvesting for about two weeks after haulm destruction when skin of the tubers have matured. Harvesting on cold frosty morning predisposes potato to bruises. Bruises can also be avoided by taking suitable precaution with machinery, proper adjustment and padding etc. of the equipments. Washing of tubers to remove contaminated soil that adhere the tubers and drying these in shade can reduce the risk of infection. Harvested potatoes should be stored at around 13 to 18 °C and moderate humidity for two to three weeks for bruises to heal before putting the potato to cold stores. Planting of healthy seed, adopting sanitation measures to avoid soil contamination through farm implements, irrigation water and reducing soil inoculum through crop rotation and eliminating volunteer potatoes are some of the measures which can reduce the risk of dry rot.

Avoiding planting of cut tubers or treating the cut tubers with dithiacarbamates can reduce *Fusarium* seed piece decay. Tuber treatment with 1200 ppm thiabendazole or benomyl can reduce the disease incidence. However, resistance to thiabendazole in *Fusarium* has also been reported. Fungicides such as imazalil and mixtures containing TBZ have also found effective for control dry rot. Avoiding bruises and damage to potato tubers by careful handling of the produce minimize the dry rots. This can be done by delaying harvesting for about two weeks after haulm destruction when skin of the tubers have matured. Harvesting on cold frosty morning predisposes potato to bruises. Bruises can also be avoided by taking suitable precaution with machinery, proper adjustment and padding etc. of the equipments.

Wart

Potato wart has been reported from many countries. In India, it is prevalent in the Darjeeling hills. It is a quarantine disease. Rough warty mostly spherical outgrowths or protuberances appear on buds and eyes of tubers, stolons, or underground stems or at stem base. Wart may appear occasionally on above ground stem, leaf or flowers. Underground galls are white to light pink when young and become brown or light black with age. Above ground galls are green to brown or black. The wart tissues are soft and spongy. Tubers may get completely replaced by warts which desiccate or decay at harvest.

The pathogen spreads from one locality to another through infected seed tubers, infested soil adhering tubers, machinery and other carriers of contaminated soil. The pathogen survives passage through the digestive track of animals fed with the infected potatoes, and the contaminated manure, therefore, can disperse the inoculum. Earthworms have been found to serve as means of inoculum dispersal. The pathogen can also be dispersed by wind-blown soil or by flowing surface water. Wart is favoured by periodic flooding followed by drainage and aeration since free water is required for germination of sporangia and dispersal of zoospores of the pathogen. Temperature favourable for germination of resting sporangia to zoospores range between from 14 to 24 °C. Both summer sporangia and resting spores can germinate between 12 to 28 °C. Mean temperature below 18 °C and annual precipitation of about 70 cm favour disease development. Rotational crops such as bean and radish and intercropping of potato with maize have been found to reduce population of viable resting spores in soil. Application of fungicides and chemicals to soil is costly and not practical. Control of the disease is possible by cultivation of wart immune varieties. Many varieties resistant or immune to wart have been developed throughout the world. In resistant varieties the pathogen infects the plants but symptom development is suppressed while in immune varieties a hypersensitive reaction occurs upon infection with zoospores of the fungus which gets killed in the process. Development and introduction of wart immune varieties such as Kufri Jyoti, Kufri Bahar, Kufri Sherpa and Kufri Kanchan to wart infested region of Darjeeling Hills coupled with domestic quarantine had a great impact in containing wart in the region.

Powdery Scab

Powdery scab of potato is prevalent worldwide including India. It is mainly of importance in cool, wet climates and may cause extensive losses in seed and ware potato crops.

Powdery scab is caused by a fungus *Spongospora subterranean*. The disease appears on potato tubers as purplish brown sunken lesions which later turn to scab like lesions. However, unlike common scab the lesions of powdery scab are round, raised, filled with powdery mass of spores and surrounded by ruptured remains of epidermis. Under certain conditions wart like protuberances may develop. The infected tuber may shrivel or develop dry rot type symptom in storage.

The pathogen survives for many years in a quiescent form as uni-nucleate or binucleate thick walled resting spores. The spores can survive passage through the alimentary canal of farm animals thus the application of slurry or manure from stock fed on powdery scab infected tubers can provide an additional source of inoculum for the disease. The pathogen survives winter as sporangia in infected potato tubers. It can also survive in soil up to 6 years. The zoospores of the pathogen penetrate roots, stolons, tubers and produce multinucleate sporangial plasmodium in the host. In roots, the plasmodium produce sporangia which further produce secondary zoospores. The zoospores re-infect the host tissue and several such generations of zoospores may be produced in a single season under ideal environment. In tuber, the plasmodium produce resting spore which can over winter and persist in tuber and soil for a long period. Use of healthy seed from disease free area and avoiding planting of potatoes in fields having previous history of the disease can helps in management of powdery scab.

The disease can be managed by use of disease free seed, avoiding conditions leading to flooding of the fields through proper drainage and by following crop rotation with non-solanaceous hosts. Growing trap crops such as *Datura stramonium* immediately before planting potato could reduce powdery scab incidence.

Charcoal Rot

Charcoal rot is an important disease of many vegetable crops in tropical and subtropical countries including India. The disease affects growing potato plants and tubers both at harvest and storage. Affected plants exhibit stem blight or shallow rot similar to black leg. It causes the affected foliage to wilt and turn yellow. Early symptoms on tubers develop around eyes, lenticels and stolon end where a dark light grey, soft, water soaked lesion develop on the surface of the tuber. Subsequently, the lesions become filled with black mycelium and sclerotia of the pathogen. Secondary organisms may develop in such lesions especially under wet conditions causing significant losses. The lesions may shrink and develop symptoms similar to dry rots under low moisture conditions.

Charcoal rot is caused by *Macrophomina phaseolina* (Tassi) Goidanich. The perfect stage of the fungus is considered to be *Botryodiplodia solani tuberosi* Thiram. *M. phaseolina* is a weekly parasitic soil fungus and over winters in soil as sclerotia in plant debris, weeds and alternate host crops. Both soil and infected tubers serve as source of inoculum. Temperature around 30 ^{o}C is optimum for growth and infection of the fungus. Poor plant nutrition and wounds predispose the plants to charcoal rot. Temperature around 30 ^{o}C or above are very favourable for infection, the rot is slow at 20 to 25 ^{o}C and stops at 10 ^{o}C or below. Fungal growth stops in tubers placed in cold stores but it resumes the growth after cold storage. The fungus is found on underground parts of an extremely wide range of plants, both cultivated and wild. At least 284 hosts have been recorded including jute, sun hemp and maize.

The pathogen survives in soil as sclerotia present in plant debris, on weeds and alternate host crops. Both soil and infected tubers serve as source of inoculum. *M. phaseolina* persists on dead or dying plant tissues and survives the unfavourable periods by forming microsclerotia. The pathogen spreads through the infected seed tubers and through the infested soil carried along with the implement. Temperature around 30^{o}C is optimum for growth and infection of the fungus. Poor plant nutrition and wounds predispose the plants to charcoal rot. Temperature around 30 ^{o}C or above are very favourable for infection, the rot is slow at 20 to 25 ^{o}C and stops at 10 ^{o}C or below. Fungal growth stops in tubers placed in cold stores but it resumes the growth after cold storage.

Planting early maturing cultivars, frequent irrigations to keep down the soil temperature and harvesting before the soil temperature exceeds 28 ^{o}C can reduce the disease incidence in eastern plains of India

(Thirumalachar, 1955). Rotation with non-host crops and use of seed from disease free area, avoiding cuts and bruises at harvest can also be followed to reduce disease incidence. Bio-control using *Bacillus subtilis* through seed treatment has been reported to reduce incidence of charcoal rot.

Soil temperature preceding harvest is crucial for disease development. Planting early maturing cultivars, frequent irrigations to keep down the soil temperature and harvesting before the soil temperature exceeds 28 ^{o}C can reduce the disease incidence.

Some other Tuber diseases

Silver scurf caused by *Helminthosporium solani* is a tuber skin blemish disease which starts as small, round, silvery patches on the skin. In humid conditions, dark sooty conidiophores can develop around the edge of lesions. Large silvery patches develop as individual lesions expand and merge during storage. Tubers can become dehydrated leading to shrivelling. Infection can originate from seed tubers, infested soil and spores surviving in dry soil in stores. Symptoms are not normally present at harvest but the disease can develop rapidly in store under humid, warm (>3°C) conditions. Treatment of tubers with a fungicide prior to planting or at harvest (into store) may reduce infection and limit disease development but cannot control existing infections. Cold storage helps to control the disease. Routine annual store cleaning is advisable.

Pink rot caused by *Phytophthora erythroseptica* may develop in the tubers at lenticels and eyes soon after harvest when conditions have been wet and warm just before harvest. Tubers are rubbery, usually affected at the heel-end. Affected tissue turns pink on exposure to air within an hour. Tubers can have a distinctive sweet smell and ooze a colourless clear liquid if squeezed hard. Soil borne Infection is favoured by high soil moisture and high temperatures. Rots develop at, or soon after, harvest. Good crop rotation, proper drainage and discarding disease affected tubers before storage helps in the management of pink rot.

Sclerotium rot caused by *Sclerotium rolfsii* rot is pale-brown with fluffy white mycelia and black sclerotia developing in cavities. Sometimes tubers may have a heel-end rot. Depending on the stage of the decay, rot may turn into wet rot.

Sclerotinia rot caused by *Sclerotina sclerotiorum* produce almost white lesions with a distinct edge on the stems. The stem lesions frequently encircle the stem, leading to a wilting of the leaflets, which turn papery-white around the edges. The affected tubers develop a heel-end rot. Internally, the rot is pale-brown with fluffy white mycelia and black sclerotia developing in cavities. These diseases are encouraged by prolonged high humidity in well-developed foliar canopies with wet leaves (e.g. sprinkler irrigation on fertile soils). Such diseases are more likely when potato is followed after oilseed crops which are the alternative hosts. Avoiding high-risk fields, following cereal crops as rotation and using potato varieties with an open canopy helps in the disease management.

Dry rots caused by *Phoma exigua* and other spp. Initially the lesions are round, dark and slightly depressed, often like a thumb mark. As lesions develop, they become black and sunken with an irregular wavy edge. Black pycnidia may form on the surface. Rotted tissue is generally brown or black with a well-defined margin between healthy and diseased tissue. Cavities are usually lined with purple, yellow or white mycelia. The disease is mainly seed-borne but can spread in aerosols during rainfall. Tubers may be contaminated at harvest, but the dry rots develop only after harvest following grading and/or at low storage temperatures. The disease can be managed by early harvest followed by dry curing and fungicides applied to the seed soon after harvest.

Alternaria tuber rot- Tuber rots by *Alternaria solani* cause symptoms similar to dry rot. It shows lesions of irregular size and shape, brown to purplish-brown, slightly sunken with irregular borders. Alternaria tuber rot occurs in potatoes harvested during cool humid weather. The infection opens the way for secondary infections by species of *Fusarium* and other organisms. Normally, early blight is controlled chemically as a by-product of the application of late blight fungicides, particularly those incorporating mancozeb. Specific sprays may be necessary with susceptible varieties

Late blight tuber rots caused by *Phytophthora infestans* show up as a darker-brown, sometimes purplish area on the tuber surface. The internal rot is a reddish-brown granular rot which can remain close to the surface or progress to the centre of the tuber. Rot development is irregular without a distinct leading edge and can be threadlike. Affected tubers often have firm flesh with brown areas but secondary infection can lead to wet breakdown of the tubers. Spores from foliage infect tubers in soil. Tuber rots may be present at harvest and continue to develop during storage, often stimulated by damage at grading. Prevention of tuber blight in the harvested tubers can be achieved by controlling the disease in the field.

Black dot caused by *Colletotrichum coccodes* show tuber skin blemish disease occurring as silvery, irregularly shaped lesions present at harvest. Symptoms may become more severe in store, particularly under warm humid conditions but lesion expansion is very limited compared with silver scurf. Lesions are similar to but less well defined than silver scurf. The oval, pinhead black bodies (microsclerotia, bottom) are often visible on the skin and may be readily diagnosed using a hand lens. Infection of the growing plant may contribute to early dying disease in warm climates. The disease is soil-borne and favoured by wet soil conditions. The disease can be minimized through crop rotations with cereals.

Chapter 10

Morphological identification of Insect Vectors

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Introduction

The potential yield of potato is often limited by number of biotic and abiotic factors in hills, plains and plateau regions of potato in India. Among the biotic factors, vector borne potato viruses namely *Potato virus Y* (PVY), *Potato leaf roll virus* (PLRV), *Potato virus A* (PVA), *Potato virus S* (PVS), *Potato virus M* (PVM), *Tomato leaf curl New Delhi virus-potato* (ToLCNDV-potato) and stem necrosis virus are not only responsible for progressive degeneration of the seed but also limit the potential yield of potato. These viruses are known to cause huge economic losses up to 20-50% under severe infestation. In this context, the morphological identification and dynamics of insect vectors of potato viruses such as aphids (Green peach aphid, *Myzus persicae,* Cotton aphid, *Aphis gossypii* and potato aphid, *Macrosiphum euphorbiae*), whitefly (*Bemisia tabaci*) and thrips (*Thrips palmi*) are crucial for healthy potato seed production and also for increased productivity to meet the rising demand of the future generations. The vectors of potato viruses belong to sucking group of insects adhere mostly on abaxial surface of the leaf and draw the vital plant sap from phloem vessels for their survival and reproduction. The virus in phloem vessels is acquired by the vector in the process of feeding and transmits to the healthy plants. Aphids transmit PVY, PVA, PVM and PVS in a non-persistent manner while PLRV in persistent manner. The whiteflies and thrips transmit ToLCNDV and stem necrosis virus in a persistent and circulative propagative manner respectively. Therefore, morphological identification and monitoring the population of insect vectors is very crucial for healthy potato production in India. The vector population can be observed using magnifying lens/microscope and can be differentiated from each other using diagnostic characters as mentioned below.

Aphids

Aphids are soft bodied and green colour small insects and they infest the potato, out of which *M. persicae*, *Aphis gossypii* and *Macrosiphum euphorbiae* were predominant. Aphids are having complex life cycles. Aphids moult four times and optimum temperature for reproduction is around 21°C. Aphids are economically important polyphagous insect pests known to cause damage directly by sucking the plant sap and indirectly by transmitting the potato viruses (PLRV, PVY, PVA, PVM and PVS) affecting yield of potato crop.

Green peach aphid - *Myzus persicae* Sulzer (Aphididae: Hemiptera)

- Adult apterae small to medium-sized, whitish green, pale-yellow-green, grey-green, mid-green and uniformly coloured
- Alatae have a black central dorsal patch on the abdomen
- Apterae and alatae 1.2-2.1mm
- Siphunculi almost twice the length of cauda

Cotton aphid, *Aphis gossypii*

- Aphids are dark green, almost black, but the adults produced in crowded colonies at high temperature may be less than 1 mm long and very pale yellow to almost white.
- Siphunculi are dark/black in colour
- Cauda are pale or light in colour

Potato aphid, *Macrosiphum euphorbiae*

- Nymphs and adults are small sized, apple green or olive green and uniformly coloured aphids
- Antennae usually only dark apically, but sometimes almost entirely dark.
- Adult apterae medium-sized to rather large, spindle-shaped or pear-shaped, shiny, eyes are distinctly reddish
- Legs, siphunculi and cauda mainly same colour as body, but siphunculi often darker towards end in some cases.

Whiteflies - Bemisia tabaci (Gennadius) (Aleyrodidae: Hemiptera)

Whiteflies cause severe damage to number of agricultural and horticultural crops acting as vector for many viruses. It acts as vector for *Tomato leaf curl New Delhi virus* ToLCNDV-potato causing potato apical leaf curl disease in potato. The small nymphs and adult whiteflies were easily seen on the underside of the leaves and suck plant sap from phloem, they will quickly start fluttering at the slightest movement of the leaves. Whiteflies have six life stages viz, egg, four instars and the adult, but typically *Bemisia* spp. takes 20 days at 25±2^{o}C. The whiteflies can complete 11-15 generations in year depending upon the weather conditions and host plants. A black fungus that grows on the honeydew produced by the nymphs and adults will cover the plant.

- Whiteflies are small, long (1 mm) and covered with a white, waxy powder on both wings and white to slightly yellowish in colour.
- Two wings are distinct and separately attached to thorax are not overlapping.
- Variation of the sensorial receptors on the antenna and the number of ommatidia connecting the upper and lower compound eyes of adult whiteflies by using a scanning electron microscope (SEM)
- The length and width of the left, right and posterior wax fringes of whiteflies were recorded using a stereo camera.
- The pupae (late fourth nymphal stage with red eyes) of *whiteflies* were collected and observed under a binocular stereomicroscope at 10–90× magnification.

Thrips : *Scirthothrips dorsalis* (Thripidae: Thysanoptera)

Thrips are small and minute insects (1-2 mm long) distributed in most potato growing regions of Indian plains. Eggs are colourless to pale white in colour, bean-shaped and are deposited in leaf tissue by a slit cut by the female. Larvae resemble the adults except wings and size. These are tiny, slender, fragile insects, with adults having heavily fringed wings. The females have extremely slender wings with a fringe of long hairs around their margins. Life cycle is completed in about 20 days at 30^{o}C. All the nymphs were dark and they feed in groups along the midrib and veins of older leaves. Adults are dark and tend to feed and hide in young plant parts. Thrips are the vectors of *Tospovirus* which cause stem necrosis disease in potato.

Thysanoptera having two suborders: Terebrantia and Tubulifera these two sub orders can be distinguished by morphological, behavioural and other developmental characteristics.

Members of the Terebrantia all the females possess the saw-like ovipositor on the anteapical abdominal segment, lay eggs singly within plant tissue, and have two pupal stages.

Eg: *Frankliniella occidentalis*

Members of Tubulifera can be identified by their characteristic tube-shaped apical abdominal segment, egg-laying atop the surface of leaves, and have three pupal stages in case of females. Eg: *Haplothrips tenuipennis*

- A clear yellow body with no dark areas on the head, thorax or abdomen (slightly thickened blackish body setae)
- Number of antennal segments i.e. Antennae always seven-segmented
- Distribution and number of setae across the body and along the forewings

Leafhoppers: *Empoasca fabae* (Cicadellidae : Hemiptera)

Leafhoppers are polyphagous sucking pests distributed all over the world. Leafhopper lays transparent and pale yellow eggs in leaf veins/petioles. The nymphs and adults of the leafhoppers have piercing and sucking type of mouth parts and sucks the sap from lower side of the leaves causing direct damage to the plants and also inject a toxin into the plant, which causes yellowing, browning, curling and drying of leaves results in a burnt look appearance in a circular ring commonly known as "hoper burn" and the total life cycle of the leaf hopper is completed in about 30 days.

- The nymphs are green in colour and adults are pale green / greenish in colour
- Adults and nymphs are wedge-shaped with heads that are slightly broader than the rest of their bodies and fore wings are leathery and not thickened.
- Antennae are very short and end with a bristle or arista.
- Simple eyes or ocelli two in number and are present on the top or front of the head.
- Compound eyes are prominent or bigger in size in nymphs and adults
- Leaf hoppers have enlarged hind legs used for jumping. Hind femora with weak spines and hind tibiae with a row of movable spines, tarsi are made of three segments.
- Nymphs and Adult leafhoppers move diagonally or side wise just like crab motion.

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Chapter 11

Management of Insect Vectors in Potato

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Introduction

The potato production is often limited by a number of biotic and abiotic factors. Among biotic factors, insect-pests and diseases are of economic importance. Insects cause direct damage to leaves and tubers, and indirect damage by transmitting the viruses which reduce the yield and quality. The major sucking pests attacking potato are aphids, whiteflies, leaf hoppers and thrips. The possible management practices for these major pests are presented in this chapter.

Management

Aphids

Direct control of the plant viruses is not easy or feasible. Preventing or checking aphid transmission of viruses is a practical approach for which various cultural methods are effective. Cropping in aphid free or low aphid periods/areas, aphid forecasting, judicious chemical control and de-haulming are most effective and widely adopted.

1. Infestation of the main aphid vectors on potato crop can easily be avoided/kept low by adjusting the planting dates in the Indo-Gangetic plains, where about 90 per cent of seed crop is grown, i.e. upto 15th October in North-Western plains, upto 25th October in central plains and upto 5th November in the North-eastern plains. Besides, chemical control for aphids is also adopted.
2. Installation of yellow water traps/yellow sticky traps @60/ha for monitoring and mass trapping of aphids.
3. Removal of all weeds, hosts susceptible to viruses and for aphids especially those having yellow flowers, and volunteer (self-grown potato) plants from within and around the vicinity of seed potato plots.
4. The haulm cutting of seed crop should be done as soon as the aphid number crosses the critical level i.e. 20 aphids/100 leaves. In case of haulm cutting, care must be taken to prevent any regrowth of stumps before harvest.
5. Seed treatment with Imidacloprid(200SL) at 0.04% for 10 minutes. Before the aphids cross critical limit, one spray of Imidacloprid 17.8% S.L @ 0.03% is recommended and same may be repeated at an interval of 12-15 days depending on the stage of crop and level of infestation for seed crop.
6. Application of mineral oils @1-3% successfully protects potato plants from aphids and aphid transmitted potato viruses by interfering with the biology, physiology and feeding of aphids, and also makes the potato plants less attractive to aphids.
7. In Plains: Application of Phorate 10G @ 1.5kg a.i./ha in furrows at planting time keeps the aphid vectors under check up to 45-60 days provided there is enough soil moisture. This should be

followed by the need based foliar sprays of any suitable systemic insecticides such as Methyl Demeton 25EC or Dimethoate 30 EC @ 0.03%, Imidacloprid 17.8% S.L @ 0.03% and mineral oil @1-3%.

8. In Hills: The potato being a rainfed crop in hills, use of granular insecticides is not much effective due to either lack of moisture or heavy rains. Therefore, keep a watch on aphid appearance/buildup and apply foliar spray of above said insecticides at recommended intervals upto dehaulming based on aphid infestation level.

Whiteflies

1. Potato cv. KufriBahar is highly tolerant and can be planted in whitefly prone areas.
2. Maintain field sanitation by removing and destroying the weeds, alternate hosts and crop residues of vectors and viruses.
3. Place yellow sticky traps (15 x 30 cm^2) just above the canopy height @ 60 traps per hectare at equidistance from each other for mass trapping.
4. Trap crops such as cucumber (*Cucumissativus*) can be used to provide temporary protection. Cucumber is a favoured host plant for whiteflies but a non-host for virus, and whiteflies are known to lose their viruliferous capacity after feeding for few days on this plant.
5. Seed treatment with Imidacloprid at 0.04% for 10 minutes and its foliar application at 0.03% at emergence with repeated application after 15 days is standard recommendation in seed potato crop. Foliar sprays of Imidacloprid 17.8SL (0.03%) at 85% germination followed by Thiamethoxam 25WG (5gm/10 lit of water) after 10 days of the first spray.
6. Foliar spray with Imidacloprid 17.8SL @0.03% (3ml/10 lit of water) at the time of emergence of crop. Imidacloprid in combination with summer oil @2ml/ lit of water will give better control.
7. Second foliar spray with Thiamethoxam 25WG @0.05% (5 g/10 lit of water) after 15 days of crop emergence.
8. Spiromesifen 240SC can be sprayed @0.04% (4 ml/10 lit of water) to kill immature stages like eggs and nymphs after 15 days once the adult kill is achieved with imidacloprid and thiamethoxam.

Leafhoppers

1. A delay in planting to end of September for early crop and to mid-October for the main crop reduces the leaf hopper incidence.
2. Judicious use of nitrogenous fertilizers and balanced plant nutrition checks the hopper multiplication.
3. In seed crop, granular systemic insecticide, Phorate 10G@) 10kg/ ha can be applied at the time of planting or earthing up.
4. Application of Oxydemeton Methyl 25 EC @ 1 ml/ lit or Dimethoate 30EC @ 2 ml/lit. Spraying late in the day or in the evening gives better control than spraying early in the morning.

Thrips

1. Providing adequate irrigation is an effective control measure since dry weather helps them to thrive well.

2. Kufri Sutlej, KufriBadshah and KufriJawahar cultivars are comparatively resistant to thrips in comparison other varities.
3. Thrips can also be controlled with the systemic insecticide such as Imidacloprid 17.8SL @0.03% and Second foliar spray with Thiamethoxam 25WG @0.05% (5 g/10 lit of water)

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Chapter 12

Management of Soil and Storage Pests of Potato

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Introduction

In India, potato is grown in 2.07 m ha with an annual production of 45.95 m t with a average productivity 22.2 t/ha, out of which Uttar Pradesh has maximum area and production followed by West Bengal, Bihar and Gujarat. Potato is grown in almost all the states under diverse climatic conditions. Nearly 80% of potatoes are grown in Indo-Gangetic plains during short winter days from October to March while in the hills, it is grown during long summer days of April to October. Plateau regions and peninsular India, constitute about 6% area where potatoes are grown as rain fed crop during July to October or as irrigated crop during winter. In Nilgiri and Palni hills of Tamil Nadu, it is grown in about 4000 ha as irrigated and rain fed crop. It is also an important crop in the North Eastern region of the country. Low production (15 t/ha) in some of the regions is mainly due to lack of quality seeds, growing potato under rain fed conditions, non-adoption of recommended package of practices and lack of infrastructural facilities like cold storage. Apart from this, foliar diseases and soil and tuber borne diseases, viruses, soil pests, foliage feeders, sap feeders and storage pests also cause considerable damage at various stages of the crop and their severity and incidence varies from region to region. Amelioration of crop losses due to diseases and insect pests through scientific interventions is very critical and forms sound means of their management. In this article, major soil and storage insect pests inflicting potato crop and their management through Integrated Pest Management (IPM) has been dealt comprehensively. IPM interventions should be suitably modified and validated according to the region before its implementation.

Insect Pests of Potato

A great diversity of climate allows a variety of pests to flourish and inflict damage to potato crop both in the field and the stores. Insect pests damage the crop by feeding on potato tubers in soil, feeding or sucking sap from foliage and feeding on potato tubers in stores. Accordingly, these pests can be grouped as soil pests, foliage, feeders, sap feeders and storage pests.

Soil Pests

1. Cut worms (Lepidoptera: Noctuidae) Species complex:

i) *Agrotis segetum* Schiff (black cut worm) ii) *A. ipsilon* (Hfn) (greasy cut worm) iii) *A. flammatra* Schiff iv) *A. interacta* Wlk. v) *A. spinnifera* (Hb.)

Distribution: Cosmopolitan, present throughout world. In India cut worms are more serious in northern region than in south. **Host range:** Polyphagous

Nature of damage and symptoms:

- Caterpillars are damaging.
- Cut the seedling at ground level, drag the seedling into the soil. Sometime replanting is required.

- Cut worms usually do not eat plants beyond cutting through them, although some species climb stalks and feed on the upper parts of plants, which causes less damage.
- After tuberization, they feed on tubers by making deep and irregular galleries in them, thus reducing the market value of infested tubers.
- In badly infested fields, tuber damage may vary from 12-40 %.

Life cycle: Moths appear soon after dusk, mate and lay eggs on ventral surface of leaves or moist soil. Freshly ploughed fields are preferred for oviposition. Each female lays on an average 300-450 eggs in clusters of 30-50. Incubation period is 2-13 days depending upon the weather conditions. Tiny caterpillars feed gregariously on foliage for a few days and then segregate and enter into the soil. The caterpillars are nocturnal and feed at night. During the day these insects hide just beneath the soil close to the site of the previous night's damage. This pest is capable of damage sufficient to necessitate the replanting of potato. Total larval period is 10-30 days with five larval stages. Pupate in soil and the pupal period is 10-30 days. Total life cycle is completed in 30-68 days depending on the climatic conditions. Persistent dry weather with lesser or no rainfall, reduced humidity and 16 -23˚C temperatures favor the development of cutworm.

Management of cut worms:

- Flooding of fields.
- Cut worms either aestivate during summer months or hibernate during winters in the soil while completing their life cycles. Therefore, deep ploughing of potato fields during summer months in the plains exposes the immature stages to high temperature and predatory birds.
- Hand picking and destruction of early gregarious caterpillars.
- Light traps installed in/around potato fields attract the adults of cut worms, and helps in mass collection and destruction of the moths.
- Garlic as intercrop with potato was found to be effective in minimizing cut worm damage in potato crop at Shimla.
- Natural enemies like *Broscus punctatus* Dist, *Liogryllus bimaculatus* Linn, *Macrocentrus collaris* Spin, *Netelia ocellaris* Thomson, *Periscepsia carbonaria* Panzer and *Turanogonia chinensis* Wiedemann parasitizes *A. ipsilon* and *A. segetum* and therefore should be conserved under natural field conditions.
- Entomogenous fungus, *Metarrhizium anisopliae* Meld. is a best known fungal control of cut worm. Entomophilic nematode, *Steinernema* (*Neoaplectana*) sp. are also well known as dominant regulatory factors for cut worm populations from various parts of the country.
- Use well rotten farm yard manure (FYM).
- Soil application of Chlorpyriphos 20EC @ 2ml/lit of water at 2% plant damage.

2. White Grub (Coleoptera: Scarabaeidae) species complex 1. *Brahmina coriacea* 2. *Brahmina cirnicollis* 3. *Brahmina flavoserica* 4. *Melolontha indica* 5. *M. Furicauda* 6. *Holotrichia longipenis* 7. *H. Repitita* 8. *H. Rustica* 9. *H. Serrata* 10. *H. Conferata* 11. *H. Excise* 12. *H. Nototiocollis* 13. *Anomala dimidiate* 14. *A. Lineatopennis* 15. *A. polita* 16. *A. rugusa* 17. *A. rufiventis* 18. *A. communis* 19. *A. nathani* 20. *Xylotrupes Gideon* 21. *Phyllognathus Dionysius* 22. *Lepidiota stigma*

Distribution: Cosmopolitan in distribution **Host range:** Polyphagous, damage almost all the vegetable crops, pulses, oilseeds, cereals, millets, potato, tobacco, sorghum, groundnut, maize, soybean, chillies, ornamental plants, forest nurseries, etc.

Nature of damage and symptoms:

- The damage to potato is caused only by the grubs which feed on rootlets, roots and tubers. The first stage grub can survive on the organic matter present in the soil but roots are preferred as and when encountered.
- Older second instar and third instar grubs are more damaging, which make large, shallow and circular holes on tubers.
- Potato grown during summer as rainfed is prone to attack by these grubs.
- Due to concealed feeding white grubs generally remain unnoticed and at harvest a large number of tubers are found infested/damaged.
- Sometimes up to 80 % of the crop may be lost.
- Adult beetles feed on the foliage of many trees

Life cycle: Each female lays 4-40 eggs singly (in 2-7 installments) in soil in its life span. Incubation period is 7-12 days. There are three larval instars. The duration of respective instars is about 20, 30 and 75 day. Total larval duration is about 125 days. Pupal period ranges from 12-20 days. Adult longevity ranges between 15 - 145 days. Overwinter as grub in earthen cells. There is only one generation in a year. Optimum conditions for white grub growth and damage humid and wet climate with a temperature range of 20- 32ºC with a relative humidity of more than 70 per cent.

Management

- Two to three deep ploughings immediately after harvest or before potato planting, to expose the resting stages to birds or other natural enemies. Collect/trap adult beetles via light traps during May-June at night and kill them.
- The beetles can also be collected by shaking or jerking the host plants during night. The fallen beetles should be collected and destroyed by putting them either in kerosinized water or by burning.
- Application of well rotten FYM only. The use of nitrogenous fertilizers, especially ammonia and urea, at higher doses kill the first instar grubs
- Removal of weeds from crop vicinity. The host trees *(Rubinia*, *Polygonum*, Kaithe and temperate fruit crops) of adults (beetles) should be lopped or pruned.
- Seed potatoes should be planted little deep (8-10 cm) instead of normal depth (6 cm).
- Spraying the crop and ridges with this biopesticide *Bacillus thuringiensis* (*Bt* @ 10^9 spores/ml) gives a good control. Several strains of the bacterium, *Bacillus popilliae*, have been found that attack white grubs.
- Application of Entomogenous fungus, *Metarrhizium anisopliae* Meld, *Beauveria bassiana* and *B*. *brongniartii* Sacc. @ 5gm/lit of water.
- Conservation of the existing populations of natural enemies or by introducing and establishing the known bio-control agents obtained from new localities.

- Application of Phorate 10G (10-15 kg/ha) near plant base at the time of earthing up or drenching of ridges with Chlorpyriphos 20 EC @ 2.5L/lit when 2% plant damage is noticed or when adult beetles appears.
- Spray host trees with Chlorpyriphos 20 EC @ 2.5 ml/lit of water immediately after first monsoon shower.
- Potato crop should be harvested immediately after required maturity i.e. by September. Crop left beyond September suffers more.

Storage Pests

Potato tuber moth (PTM) - *Phthorimaea operculella* Zeller (Gelechiidae:Lepidoptera)

Potato Tuber Moth commonly called as PTM is most obnoxious pest of potato both in the field and country stores. PTM larvae damage foliage, stems, exposed tubers in the fields and in country stores and cause considerable losses.

Distribution: Cosmopolitan in distribution**. Host range:** Major pest of Potato but has also been reported from crops like egg plant, tomato, tobacco, etc.

Nature of damage and symptoms:

- Damage is caused by Larvae and mine the leaves, petioles and terminal shoots causing wilting.
- After tuberization, the larvae enter into the tubers and feed on them. Larvae tunnel into the pulp which ultimately becomes unfit for use as seed or for human consumption. The feeding tunnels are packed with black excretory pellets and the larvae are inside the tunnels.
- The infested tubers are further exposed to microbial infection which leads to rotting
- In areas where the pest is left unmanaged, the losses to potatoes kept in the country stores may be as high as 70 per cent.

Life cycle: The female moth lays eggs on the underside of leaves or on exposed tubers near the eye. Each female can lay 150-200 eggs. Incubation period is 3-7 days; Larval period is 15-20 days. Full grown caterpillars come out of the tubers/ foliage and pupate in silken cocoons either in dried leaves, soils, over the stored tubers or in cracks and crevices in the store. Pupal period lasts for 11-12 days. Total life cycle is completed in 20-30 days at optimum conditions of 22-28ºC temperature and 60-70% relative humidity. There are 8-overlapping generations in a year.

Management

- Planting seed tubers at a depth of 10 cm as against the traditional planting depth of 6 cm reduce its damage to a great extent.
- The fields should be ridged after 6 to 7 weeks of planting so that the tubers are burried at least 25cm below the soil surface.
- In areas where PTM population remains quite high and severe tuber damage is expected, ridging should be done twice so that the tubers are not exposed at any time for egg laying and infestation.
- Timely and adequate irrigations minimize soil cracking and thereby reduce the risk of tuber exposure to PTM attack or their laying eggs.
- This problem is quite common in areas where potato crop is taken in heavy soils. Harvested tubers must be removed from the field as early as possible and should not be kept overnight in the field.

- Leftover tubers, after harvest, should also be collected. All the plant debris including the weeds belonging to family solanaceae should also be collected and destroyed.
- The crops like tomato, tobacco, chillies and brinjal should not be grown in the vicinity of potato fields, particularly in PTM prone areas.
- Store healthy (PTM free) potatoes in cold stores with 2-3 cm thick layers of chopped dried leaves of either of *Lantana camara*, Soapnut, Neem, *Eucalyptus* spp.
- Installation of PTM sex pheromone traps @ 20 traps/ha for mass trapping of male moths.
- Spray the crop with Bt (10^9 cfu/ml) @ 3ml or GV @ 4 LE/lit of water.
- Spray of crop with quinalphos @ 0.375 kg or acephate @ 0.5 kg a.i./ha. for seed potatoes dusting with cypermethrin dust @500 gm/ton of potato in storage.
- CIPC (Isopropyl N-(3-chlorophenyl) carbamate) is a sprout suppressant commonly used on ware potatoes in country stores and is found effective against PTM damage in country stores when applied @30ppm.

Chapter 13

Nematodes and their Management

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Introduction

Plant parasitic nematodes are very small ranging from less than half millimeter to one millimeter in length hence, they are not easily seen by naked eyes and require stereo zoom microscope for their observations. Generally, nematode infestations in plants are not easily recognized since the external foliage symptoms are often mistaken to nutrient deficiency symptoms. These nematodes are also enhance the severity of other diseases caused by fungi, bacteria, several other nematodes act as carriers of viral diseases and form disease complexes (Swarup and Seshadri, 1974). The earliest record of parasitic nematode infestation in potato crop was of the cyst nematode recorded in the year 1881 by Julius Kuhn from Germany. This cyst nematode was established as one of the major plant protection globally accounting for an average tuber yield loss of about nine per cent, which is about 43 million tons (Krishna prasad, 2006). In India, the root knot nematode infection in potato tubers was first noticed by Dr. Thirumalachar in 1951. Later, the report of cyst nematode occurrence in potato crop from the Nilgiri hills in South India by Dr. Jones in 1961activated the nematological research not only in potato but also in other crops. About 90 species of nematodes belonging to 38 genera have been reported to be associated with potatoes in India alone. But among these, the potato cyst nematodes (PCN) and root-knot nematodes have been reported as the major pests of potato.

1. Potato Cyst Nematodes

Potato cyst nematodes *viz., Globodera rostochiensis* (Woll) and *G. pallida* (Stone), also popularly called the Golden nematodes, are one of the dangerous pests hindering the sustainable production of potato in many countries including India (Seshadri and Sivkumar, 1962). Their small size, intimate association with their host and adaptation for long term survival in the soil in the absence of a suitable host present them challenging to the farmers, scientists and policy makers. Potato cyst nematodes are one of the important biotic constraints in the sustainable production of potato in many countries worldwide including India. They are subjected to stringent quarantine and/or regulatory procedures, wherever they occur.

Origin and distribution

Potato cyst nematodes originated in the Andean mountains of South America along with its principal host, potato. They were then introduced into Europe in the 1850's and later spread throughout the world through the introduction of improved varieties. Presently, Potato cyst nematodes have been reported from 65 countries with *Globodera rostochiensis* in all countries and *G. pallida* in 47 countries.

In India, Dr. F. G. W. Jones first detected the nematode in 1961 from a field in Vijayanagaram farm in Ootacamund, The Nilgiris district, Tamil Nadu at an elevation of 2125 m above MSL. Later on, their occurrence was also reported from Kodaikanal hills. Realizing the potential danger by this nematode to potato cultivation, 'Golden Nematode Scheme' jointly financed by ICAR and the Government of Tamil Nadu was launched in Ootacamund in October, 1963 and the Destructive Insect Pest Act, 1919 was suitably amended by the Tamil Nadu Government in 1971 to impose domestic quarantine and ensure strict checking of seed potato for marketing from infested field of Ootacamund. Hence in India, Potato cyst nematodes are mainly restricted to the Nilgiris and Kodaikanal hills of Tamil Nadu. However the presence of PCN in Karnataka and Kerala, though in very low intensities, necessitates the strengthening of domestic quarantine to prevent its further spread to new areas.

Species and pathotypes

There are two species of PCN *viz., Globodera rostochiensis* (Wollenweber, 1923) and *G. pallida* (Stone, 1973). The differential host reactions of PCN populations from Nilgiris and Kodaikanal hills revealed that the pathotypes Ro1 of *G. rostochiensis* and Pa2 of *G. pallida* are the most prevalent forms. The other prevalent pathotypes are Ro2 and Ro5 of the former and Pa1 and Pa3 of the latter.

Host range

Potato cyst nematodes are confined to the family Solanaceae with potato, tomato and brinjal as the most preferred hosts.

Means of dispersal

The major routes of dissemination of PCN is through the contaminated seed potatoes, movement of farm workers, livestocks and farm implements from infested land, irrigation water, high winds, soil in gunny bags used for transportation, etc. Ensuring strict hygiene practices will help minimize PCN spread.

Yield loss

Worldwide PCN alone causes estimated losses up to 30% in potato crop yield. The tuber yield loss estimates vary from 5 to 80 per cent depending on the initial inoculum level. The economic threshold level for crop loss due to PCN is usually around 20 eggs per g of soil, which may vary with the environmental interactions and host tolerance.

Symptoms

At low PCN population densities, most plants can tolerate nematode invasion and respond by developing more lateral roots as wound response, without affecting their growth and yield. However, as the degree of invasion increases, the plant is unable to compensate and ultimately exhibits a range of symptoms. The typical above ground symptoms of PCN can be divided into two phases. In the first half of the growing season, PCN cause reduced photosynthetic rate, production of fewer stems and smaller, thicker leaves and overall stunting of the haulms. In the second half of growing season, leaves senesce earlier, water and nutrient uptake are reduced causing incipient wilting during hotter days and the number of the tubers and dry matter production are reduced. The above ground symptom first appears in the field as a small patch of stunted plants with pale yellow coloured leaves (**Plate 1**). These patches increase in size gradually year after year and cover the entire field if potato is continuously grown without any protective measures. Close examination of the roots of infected plants reveal the presence of small pinhead sized, white or yellow female nematodes sticking to the roots (**Plate 2**).

Biology

The hatching of cysts is stimulated by the chemical substances called hatching factors present in the potato root diffusates (PRD). There are at least 25 hatching factors (Byrne *et al.*,1996) responsible for hatching of both the species of potato cyst nematode. Maximum activity of PRD is reached three weeks after plant emergence and most actively from the root tips. Devine *et al.* (1966) identified two hatching factors for *G. rostochiensis* as the potato glycoalkaloids, solanine and α-chaconine. Blaaw *et al.* (2001) identified the compound Solanoeclepin A, which occurs naturally in potatoes, as one of the agents involved in hatching of cysts and determined its structure. Hatching depends on host root diffusate, physical conditions before and during juvenile emergence and hereditary preconditions of the cyst.

The second stage juvenile (J2) coming out of the cysts moves actively in soil and invade the roots by rupturing with its stylet. It enters through the epidermal cell walls and eventually settles with its head towards the stele and feeds on cells in pericycle, cortex or endodermis by forming a feeding tube. This induces enlargement of root cells and breakdown of their walls to form a large 'syncytium' or 'transfer cell' with dense granular cytoplasm that provides nourishment for nematode development. The nematode molts and remains in the syncytium until its development is complete.

The sex of the nematode is determined during J3 stage. The females become sedentary, swollen and remain attached to the roots and posterior part of the body comes out by rupturing the root cells. Males retain their thread shape and come out of the roots to locate and mate the females. The immature females of *G. rostochiensis* are golden yellow in colour while *G. pallida* are white or cream in colour. After the female dies, the body wall thickens to form a hard brown cyst that is resistant to adverse weather conditions. Each cyst contains 200-500 eggs and are easily dislodged in soil at harvest. The cysts can survive in soil for 20-30 years even in the absence of a suitable host crop. The life cycle is completed in 35-40 days and generally, one generation is completed in one year. However, there are evidences of second generation of *G. rostochiensis* being completed because of its shorter dormancy (45 to 60 days) and long crop duration (120 days) and *G. pallida* has a dormancy of 60 to 75 days. Once J2 have developed inside cysts, they enter an extreme form of dormancy, known as 'diapause' and they cannot be stimulated to hatch until the diapause has ended. Only 60 to 80 per cent of juveniles can be stimulated to hatch in the presence of root diffusates and it never reaches 100 per cent. This is a part of the survival strategy of PCN and some juveniles will remain dormant for several years before hatching.

Management

Once established, PCN are very difficult to be eradicated from infested fields. Despite massive chemical control measures taken up to eradicate PCN soon after its appearance in the Nilgiris, the nematode remains a serious endemic pest of potato in this region due to intensive cultivation of potato and favourable climatic conditions. PCN have to be managed by a combination of preventive and management methods as follows.

(a) Preventive methods:

Preventive measures include

- Ensuring strict international quarantine regulations to prevent introduction of new pathotypes into areas which are now free of these pathotypes
- Implementing strict domestic quarantine procedures to prevent further spread of this pest to new areas that are free from this pest.
- Adopting good sanitation at field level to prevent the spread of nematodes from infested areas through the farm implements, irrigation water, gunny bags, etc.

(b) Integrated management

As no single method of control is fully effective in giving desirable level of nematode suppression, an integrated nematode management package incorporating judicious blend of various management options such as chemical, biological and cultural methods is being advocated in the Nilgiris to bring down the PCN population to levels that permit profitable cultivation of potato.

Chemical control: Chemical control of PCN using nematicides is an effective and reliable method of bringing down the nematode population quickly. Currently, application of Carbofuran 3G at 2 kg a.i./ha at the time of planting is being recommended as a part of package of practices for potato in the Nilgiris to bring down the PCN population. However, it is not that much effective to control the PCN population. Therefore, new soil fumigant, Basamid 90 G was evaluated in different doses in field conditions. Before applying Basamid 90 G, made the soil surface compact, irrigated with ten to twenty liters of water per sq. metre. Afterwards applied soil fumigant, Basamid 90 G. Covered the treated area with a tarp for 10-12 days and sealed the edges with soil. This method allows the effective gases to act more efficiently on cyst of PCN. After this removed the tarp, soil samples collected and counted cyst in all the treatments. In Basamid 90 G@ 50 g/m^2 recorded less nematode multiplication (Rf = 0.87) followed by Basamid 90 G @ 40 g/m^2 (Rf = 1.05) as compared to Carbofuran 3G @ 65 kg/ha (Rf = 1.17) and untreated control (Rf = 1.34).

Resistant varieties: Growing resistant varieties is an effective, economical and eco-friendly method for the management of PCN as it requires no additional expenditure, labour and technical skills. Concerted breeding efforts at ICAR- Central Potato Research Station, Muthorai released 'Kufri Swarna and Kufri Neelema' high yielding varieties with combined resistance to local pathotypes of PCN and late blight disease in the Nilgiris. one advance hybrids OS/01-497 with combined resistance to PCN and late blight has been recommended for its release in the 34^{th} Group Meeting of Potato Workers of All India Co-ordinated Research Project (Potato) at ICAR-CPRI, Shimla, 2016.

Crop rotation: Since the host range of PCN is restricted to few plants in Solanaceae, crop rotation with non-solanaceous crops is widely recommended for management of PCN. A three to four year rotation with crops like radish, cabbage, cauliflower, turnip, garlic, carrot, green manure crop like lupin etc. brings down the cyst population by more than 50 per cent. Growing potato in summer and rotational crop in autumn and spring was found to be successful in managing PCN in the Nilgiris.

Intercropping: Intercropping with French Beans (75:50) was profitable as it recorded higher potato equivalent yield and was effective in bringing down the cyst population.

Integrated management practices: For eradication of PCN integration of trap crop (45 days), soil solarization (4 weeks), furadon (3G @ 2kg a.i./ha) application followed by organic amendment and bio-control agent recorded the maximum yield and minimum reproduction factor in the resistant variety Kufri Neelima. Soil solarisation (4 weeks) combined with neem cake (5t/ha) and *Trichoderma viride* (5kg/ha) recorded less nematode population.

Biological control and organic amendments: Recent studies revealed that application of biological control agents *viz., Pseudomonas fluorescens* and *Paecilomyces lilacinus* and organic amendments like neem cake blended with *Trichoderma viride* show promise in suppressing PCN population. Efforts are being made to incorporate these eco-friendly components into the integrated PCN management package.

2. Root Knot Nematodes

The root knot nematodes (*Meloidogyne* spp.) are amongst the most economically important nematode pests of potato. They are prevalent all over the world and can cause significant crop loss in both warm and cool climatic conditions, depending on their species. They have a wide host range and many important cereals, pulses, vegetables, fruits and ornamental crops are good hosts including potato. In India, the root knot nematode infection in potato tubers was first noticed by Dr. Thirumalachar in 1951. Later on, it was reported from almost all potato growing regions of our country.

Species

Although many species of *Meloidogyne* are known to infect potato, only four species are reported from India *viz., M. incognita* (Kofoid and White, 1919); *M. javanica* (Treub, 1889); *M. hapla* Chitwood, 1949 and *M. arenaria* (Neal, 1889).

Distribution

Root knot nematodes are recorded from all potato growing countries of the world. In India, the dominant root knot species affecting potato both in hills and plains has been *M. incognita* while *M. javanica* infestation is in mid hills and plains of northern India. *M. hapla* is confined to hilly tracts of Uttar Pradesh, Himachal Pradesh, Jammu and Kashmir and Tamil Nadu. *M. arenaria* is reported form the plains of Uttar Pradesh.

Host range

Root knot nematodes have a very wide host range and have been found to infect more than 2000 plants worldwide that includes major field and horticultural crops. This makes them very difficult to control because they can always survive and reproduce on other host crops including weeds.

Yield loss

Upon severe infection, the root knot nematodes drastically affected the potato yield which recorded even lesser than the quantity planted in Himachal Pradesh and Karnataka, during 1960s. An initial inoculum of 200 juveniles per 100 ml soil resulted in an overall yield reduction of 40 per cent with 100 per cent tuber infestation.

Besides the direct yield loss, root knot nematodes also cause indirect damage in potato in the form of blemishes and deformations in tubers which make it unmarketable. Thus the nematodes cause both quantitative and qualitative loss in potato.

Interaction with other micro-organisms

Root knot nematode infection is found to predispose potato plants for early blight fungus *Alternaria solani* and brown rot bacterium *Pseudomonas solanacearum.* It is suspected that the nematode favours the spread of brown rot disease in Himachal Pradesh, Uttar Pradesh and Karnataka.

Life cycle

The vermiform second stage juveniles hatch out from the egg masses, penetrate the young potato roots and starts feeding. This leads to the formation of specialized, enlarged cells called 'giant cells' which provide nourishment to the nematodes throughout its development. Hence knots or galls appear in the roots because of the specific host parasite interaction. The second stage juveniles (J_2) undergo molting and pass through J_3 and J_4 stages and finally become adult females or males. The adult females are sedentary and pear shaped while males are migratory and vermiform or thread shaped. Males move out of the root to locate and mate the females. The females lay about 300 to 400 eggs in gelatinous matrix, usually adhering to the root galls. These eggs readily hatch and infect fresh roots. At the time of tuber formation, the juveniles usually enter the tubers since the root system would have started decaying.

Life cycle is completed in 25-30 days during summer and 65-100 days in winter. The eggs and juveniles survived for more than 100 days in summer months in Shimla hills. In the hilly regions, two generations are completed by the time of tuberization and hence tuber infestation is invariably observed even under low initial inoculum levels, whereas, in plains, tuber infestation could be low because of the shorter crop duration and preference of the fresh roots by the newly hatched juveniles.

Symptoms

The above ground symptoms due to root knot nematode infection include stunting and yellowing of plants with chlorotic leaves due to the hindrance in water and nutrient uptake in roots by nematode infection. In roots, the characteristic swellings called 'galls' are formed (**Plate 3**). The galls on the root are small and often unnoticed but the warty 'pimple-like' blemishes on the tubers due to nematode infection reduce the commercial value and keeping quality of potato (**Plate 4**). Brown spots are evident in the flesh of the cut tubers due to the presence of nematodes (**Plate 5**).

Management

Because of the wide host range and semi-endoparasitic adaptation of the root knot nematodes, complete eradication is not possible from an infected area, if once established. The problem may be managed by adopting the following strategies under our conditions.

Cultural practices

- Avoiding seed tubers from infected areas and planting of nematode-free tubers.
- Deep ploughing and sun drying during summer months exposes the infective juvenile stages of the nematode to direct sun, thereby killing them.
- Adopting good sanitation and keeping the field free of weeds which otherwise would serve as alternate hosts for nematodes.
- Crop rotation with non-host crops like maize or wheat helps in minimizing the nematode damage.
- Early planting of spring crop in first week of January and late planting of autumn crop in second and third week of October reduce nematode infection in potato due to the lower temperature prevailing during crop period.
- Growing trap crops such as marigold, *Tagetes patula* in alternate rows with potato reduce nematode population in soil.

Chemical control

- Application of carbofuran at 1-2 kg a.i./ha reduce nematode infestation and increase yield. The efficiency of these pesticides increase when applied in two split doses once at planting and then at the time of earthing up. This helps keep juveniles of RKN at less than the threshold level of 10 to 20 larvae /100 g of soil sample.

Breeding for resistance

- The post-inoculation development and reproduction of root knot nematode was hindered in Kufri Dewa. The availability of resistant materials needs to be exploited further to breed nematode resistant variety as this is the only economic means to manage nematode under field conditions.

Integrated approach

- Since a single method of control is uneconomical and not adequate for better nematode management, a judicious blend of the above methods is always advisable for achieving higher crop production.

Suggested Reading

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Plate 1: PCN infected potato field

Plate 2: PCN on potato root-ball

Plate 3: Root knot nematode infected potato roots

Plate 4: Root knot nematode infected potato tubers showing warty pimples

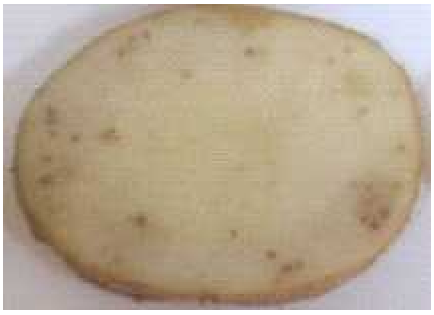

Plate 5: Brown spots indicating the presence of root knot nematodes inside the tuber

Chapter 14

Pesticide Resistance Management

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Introduction

Pesticide resistance is a consequential concept to understand when endeavouring to manage a pest. Without taking actions to delay or minimize pest resistance now, the pesticide management tactics we currently use may someday no longer work. A population of pests in a crop production field can be composed of different biotypes of the pest organism. A biotype of an organism is identically species, but has genetic variances. A pest organism can also have different genetics within the same species. For an example, green foxtail (weed) has a variant called purple robust foxtail. This natural genetic difference within a pest species can sanction some members of the species to survive a pesticide application. Pesticides damage or avert categorical processes in an organism that are required for life and a genetic difference may protect the organism from damage due to the pesticide. The surviving members of that population are resistant to the pesticide. Thus, pesticide resistance is the natural faculty of a biotype of an organism to survive exposure to a pesticide that would customarily kill an individual of that species. This occurs with insects, fungi, weed, and other pests.

"***Pesticide resistance is a shift in the genetics of a pest population that allows individuals within a previously susceptible population to survive".*** Resistant pest populations have inherited traits that reduce their susceptibility to individual pesticides or groups of pesticides. Resistance develops in all agricultural pest groups–insects, mites, fungi, bacteria, nematodes, and weeds. Pesticide-resistant individuals are initially quite rare in pest populations. However, when a new pesticide is first used, a very low number of individual pests never previously exposed to the novel chemistry can be expected to be resistant. The frequency of resistant genes to novel chemistries varies tremendously, but history makes it clear that resistant individuals should be expected to be present in all pest groups. By the nature of the process, resistance most often develops to pesticides that are initially very effective and frequently used.

Pesticide resistance at a population level, as opposed to just a few individual pests within a species, can occur after repeated exposure to a single type of pesticide. This is because only the resistant organisms are left to reproduce with other resistant organisms. The new resistant biotype (with the natural ability to survive a pesticide exposure) then becomes the dominant biotype of the pest population. This is why planting a refuge of susceptible corn along with Bt corn is important: so that some biotypes of the susceptible pest survive and mate with the resistant organisms, delaying the ability of the pest to develop a resistant population. When a resistant population occurs, the pesticide is no longer useful for managing that specific pest and other management options must be sought out. However, if pest resistance is managed effectively, a pesticide can remain useful for growers to continue using into the future.

Why is pesticide resistance a major concern?

The number of pesticide-resistant insect pest species worldwide has incremented, with many such insects being resistant to even the incipient chemicals. The variety and rigor of pest infestations increase, thus incrementing the threat to agriculture in the areas concerned. There is incrementing concern throughout the world over the quandaries of pesticide resistance in pests which affect stored grain and different food commodity. Resistant strains of these pests have been shown to be moving actively in world trade and there is an earnest threat to the efficacious utilization of chemicals in maintaining stored foodstuffs in a sound and insect-free condition. Insecticide resistance is now so widespread in certain species that it has become essential that resistant strains are utilized in the evaluation of candidate alternative materials. Currently, more than 200 species are kenned to be resistant to insecticides. The number of pesticide-resistant insects and mites has doubled in 12 years. The extent to which resistance can be met by incremented dosages is rigorously constrained by the level of residues internationally acceptable in stored foodstuffs. Countermeasures to resistance will thus necessitate the utilization of alternative insecticides and possibly fumigants; but because of stringent requisites with reverence to chemical residues, there are comparatively few materials that can be utilized for the control of grain pests. These few materials, however, after perpetual use have led in many instances to the development of resistance.

Stored grain insects are unique in that most of the major species are cosmopolitan and readily move about in domestic and international trade. Hence, resistant strains are also moving throughout the world, reaching countries where resistance had not been suspected. Fumigation has long been regarded as a basic method of controlling stored product insects and one which would be of material assistance in delaying the development of resistance to the unrelated residual pesticides. The method itself, by virtue of the low variability in response of individual insects to the commonly-used materials such as methyl bromide, is also usually considered to be less prone to resistance development than the normal methods with residual pesticides. It is disturbing then to note the increasing prevalence of resistance to fumigants and the resultant weakening of one of the most powerful tools available in stored product pest control for delaying or preventing development of resistance. The emergence of resistance to fumigants under practical conditions is a matter for particular concern. With major world dependence on fumigation both as a routine disinfestation treatment and as a means of combating insecticide-resistant strains, the occurrences reported, although as yet limited in number and often at marginal resistance levels, are of considerable significance and pose a real threat to a continued ability to store grain safely.

Only about 1% of the applied pesticide actually reaches the target pest. The other 99% enters the ecosystem. The ecological impact of pesticides has been well documented and the list includes the near extinction of the peregrine falcon, osprey, and bald eagle, as well as many other creatures. A less well-known but far-reaching effect of pesticides is on bee populations. As early as 1944, there was evidence that pesticides were seriously affecting honeybee and wild bee populations. Since the World Health Organization began to use DDT against Anopheles mosquitoes, the carriers of malaria, the lives of millions of people in malaria-infested parts of the world have been saved by eliminating mosquitoes, and similar successes were reported for other pests. The future seemed bright for both the farmers and the pesticide industry until the first warning came in 1947, when houseflies began to develop resistance to DDT. Insects with genes giving them resistance to DDT survived the massive sprayings in fields, gardens and homes, and these insects reproduced offspring that were also resistant. As more species of insects evolved into DDT-resistant populations, other chemicals were tried, such as organophosphates and carbamates, but many insects developed resistance to these as well.

Pesticides are not applied to pests: they are applied to ecosystems that happen to include the pests. Humans are also part of the ecosystem. Indiscriminate spraying does more to eliminate the natural enemies of pests than the pests themselves. A continuing spiral of increasing doses of greater varieties of insecticides foster the development of more and more robust pests requiring more insecticides.

How does pesticide resistance occur?

The risk of resistance development is quite variable among and within pesticide groups and pest species but is particularly high for many of today's selective pesticides with specific modes of action. In general, pesticides with a single target site that are applied numerous times to a large population of pests with a high population turnover will be more at risk of resistance development than pesticides that attack several target sites and are used less frequently on a pest that has a low population turnover. In the first situation the selection pressure would be very high; in the latter it would be much lower. That being said, resistance does not always develop as predicted. For current pesticides a considerable amount of information related to resistance on a variety of crops and pests is often available. This information can be used to estimate the risk of resistance development for new uses and uses in new geographic locations. For new pesticides, however, especially if they represent new chemical groups, assessing the risk of resistance development is more difficult. Experience with similar chemistry and target pests, as well as the mode of action of the compound, will provide some insight. However, there is still a lot to be learned. At present it is really only possible to estimate whether the risk of resistance development is low, medium, or high. The factors that affect resistance development can be grouped into three categories: the pest's genetic make-up, the pest's biology, and "operational factors" including cropping practices and the pesticide characteristics and application (see Table 1).

Table 1. Biological, genetic, and operational factors in resistance development.

Factor	Potential for resistance development	
	Lower	**Higher**
Biological factors		
Population size	Small	Large
Reproductive potential	Low	High
Generation turnover	One or less generation per year	Many generations per year
Type of reproduction	Sexual	Asexual
Dispersal	Little	Much
Seed bank	Large	Small or none
Pesticide metabolism	Difficult	Easy
Number of target sites of the pesticide	Multiple sites	Single, specific
Pest host range	Narrow	Wide
Genetic factors		
Occurrence of resistance genes	Absent	Present
Number of resistance mechanism	One	Several
Gene frequency	Low	High
Dominance of resistance genes	Recessive	Dominant
Fitness of "R" individuals	Poor	Good
Protection provided by the R gene	Poor	Good
Cross resistance	Negative or none	Positive
Past selection	None	Significant
Modifying genes	Absent	Present
Operational factors		
Activity spectrum of the pesticide	Narrow spectrum	Broad spectrum

While it is not possible to precisely predict the development of resistance to a particular compound, it is possible to assess the risk generally by evaluating these factors for each pesticide-pest-crop situation. That is why it is critical to gather as much information as possible on the biology of the pest, the characteristics of the compound, the use of the compound, and the specific situation in which the compound will be used. Similarities will exist between compounds, pests, and uses but each situation will be different. Taking all these factors into consideration when designing a resistance management programme will go a long way toward ensuring its success.

Insecticide resistance

Following the introduction of synthetic organic insecticides in the 1940's, such as DDT, it was not long before the first cases of resistance were detected and by 1947, resistance to DDT was confirmed in houseflies. Thereafter, with every new insecticide introduction, cyclodienes, organophosphates, carbamates, formamidines, pyrethroids, *Bacillus thuringiensis*, spinosyns and neonicotinoids, cases of resistance appeared some 2 to 20 years after their introduction in a number of key pest species. This phenomenon has been described as the *'pesticide treadmill'*, and the sequence is familiar. As a result of continued applications over time the pest evolves resistance to the insecticide and the resistant strain becomes increasingly difficult to control at the labeled rate and frequency. This in turn has often led to more frequent applications of the insecticide. The intensity of the resistance and the frequency of insecticide-resistant individuals in the population both increase still further and problems of control continue to worsen as yet more product is applied. Eventually users switch to another pesticide if one is available. The genetics of the heritable resistance traits and the intensive repeated application of pesticides together are responsible for the rapid build-up of resistance in most insects and mites. Since *M.persicae* has been reported to develop resistance to all major classes of insecticides and with the increased use of these, the number of cases of resistance has increased considerably therefore, pesticides as means of controlling it or other potato aphids should be used judiciously. Malathion, the most commonly used insecticide belonging to organophosphates, was found to be the least toxic insecticide to *M. persicae.* Low toxicity of malathion to the aphid has also been reported by Khalequzzaman and Jesmun (2008) who tested five insecticides viz. malathion, carbosulfan, cypermethrin, imidacloprid and azadirachtin against the aphid and found that malathion was the least toxic.

Development of resistance

Natural selection by an insecticide allows some initially very rare, naturally occurring, pre-adapted insects with resistance genes to survive and pass the resistance trait on to their offspring. Through continued application of insecticides with the same mode of action, selection for the resistant individuals continues so the proportion of resistant insects in the population increases, while susceptible individuals are eliminated by the insecticide. Under permanent selection pressure, resistant insects outnumber susceptible ones and the insecticide is no longer effective. The speed with which resistance develops depends on several factors, including how fast the insects reproduce, the migration and host range of the pest, the availability of nearby susceptible populations, the persistence and specificity of the crop protection product, and the rate, timing and number of applications made. Resistance increases fastest in situations such as greenhouses, where insects or mites reproduce quickly, there is little or no immigration of susceptible individuals and the user may spray frequently.

Insecticide Resistance Action Committee

Insecticide Resistance Action Committee (IRAC) was formed in 1984 and works as a specialist technical group of the industry association CropLife providing a coordinated industry response to prevent or delay the development of resistance in insect and mite pests. There are IRAC country group committees in many parts of the world researching and responding to local resistance issues as well as IRAC International which operates at a global level.

The IRAC Mission is as follows:

- Facilitate communication and education on insecticide and traits resistance.

Promote the development and facilitate the implementation of insecticide resistance management strategies to maintain efficacy and support sustainable agriculture and improved public health

Fungicide resistance

Fungicides have become an integral part of efficient food production. The loss of a fungicide to agriculture through resistance is a problem that affects us all. It may lead to unexpected and costly crop losses to farmers causing local shortages and increased food prices. Manufacturers lose revenue vital for funding the enormous development costs of new products. Without reinvestment there would be no new compounds. This would cause serious disease management problems that would endanger the world food supply. The problem of resistance has increased since the advent of highly effective compounds with specific sites of action. Although representing marked improvements in performance, including systemic and therapeutic properties, experience has shown that these compounds may be prone to resistance. As reliance on these fungicides grows, action is required to safeguard their effectiveness. Industry recognises its responsibility in safeguarding new chemistries that are brought to market. Few cases of resistance development in field situations have been reported in some pathogens from different parts of the country, such as resistance to metalaxyl in *Plasmopara viticola* (grapevine), *Phytophthora infestans* (potato), *P. parasitica* (citrus) and *Pseudoperonospora cubensis* (cucumber), carbendazim in *Gloeosporium ampelophagum* (grapevine) and *Venturia inaequalis* (apple), edifenphos in *Dreschlera oryzae* and *Pyricularia oryzae* (rice), triadimefon in *Uncinula necator* (grapevine). Reduced levels of disease control have also been observed in some cases. Simple and rapid laboratory methods have been devised for monitoring and early detection of resistant strains. Fungicide use strategies have been worked out to counteract the development of resistance. Novel action fungicides can play an important role in managing resistance. Status of fungicide resistance in India will be discussed with emphasis on monitoring and management options.

FRAC and its Working Groups originated as a result of a course on fungicide resistance in 1980, and developed at an industry seminar in Brussels in 1981. Through FRAC and the Working Groups it coordinates, companies are striving to establish more effective communications to alert all people involved in the research, production, marketing, registration and use of fungicides to the problems of resistance. With an enlightened attitude, effective strategies can be conceived and adopted. Cooperative action is essential if we are to preserve the option of chemical disease control for our crops. Working Groups for benzimidazoles, dicarboximides, demethylation inhibitors (DMI's) and phenylamides were organised and companies were soon cooperating in monitoring studies and other technical projects. Fungicide use guidelines designed to reduce the risk of resistance developing or to manage it if it was present, were produced and have been refined as knowledge grew. The DMI Working Group was expanded to cover all Sterol Biosynthesis Inhibitors, and renamed the SBI Fungicides Working Group. The introduction of the anilinopyrimidines in 1995 and STAR fungicides (Strobilurin Type Action and Resistance) in 1997 and more recently the introduction of new carboxylic acid amides (CAA fungicides) led to the formation of working groups for these new areas. The purpose of FRAC is to provide fungicide resistance management guidelines to prolong the effectiveness of "at risk" fungicides and to limit crop losses should resistance occur.

The main aims of FRAC are to:

1. Identify existing and potential resistance problems.
2. Collate information and distribute it to those involved with fungicide research, distribution, registration and use.
3. Provide guidelines and advice on the use of fungicides to reduce the risk of resistance developing, and to manage it should it occur
4. Recommend procedures for use in fungicide resistance studies.
5. Stimulate open liason and collaboration with universities, government agencies, advisors, extension workers, distributors and farmers.

Resistance mechanisms

Agricultural pests utilize a variety of mechanisms to survive exposure to toxicants. Resistance can develop more easily when two or more of these mechanisms are utilized concurrently. The resistance mechanisms fall into the following general categories

Metabolic detoxification (enzymatic): Resistance through metabolic detoxification is most often found in insects and is less prevalent in weeds and pathogens. It is predicated on enzyme systems that insects have developed to detoxify naturally occurring toxins found in their host plants and in the blood ingested by blood alimenting insects. These systems include esterases, cytochrome P450 mono-oxygenases, and glutathione S-transferases. Resistant insects may have elevated levels of a particular enzyme or altered forms of the enzyme that metabolize the pesticide at a much more expeditious rate than the non-altered form. In either case the resistant insect can detoxify the pesticide before the pesticide kills it. Metabolic resistance can range from compound specific resistance to very general resistance to a broad range of compounds. Similarly, the level of resistance provided to the insect can range from very low to very high, and can vary from compound to compound. This mechanism often cleaves the pesticide molecule or integrates molecules to the pesticide, e.g. glutathione transferase, which detoxifies the compound. Enhanced metabolism is additionally a common resistance mechanism in weeds. For example, enhanced rates of metabolism of acetyl-CoA carboxylase (ACCase), acetolactate synthase (ALS), and photosystem 2 (PS2) herbicides have been reported.

Reduced sensitivity at the target site: With this mechanism the binding site of the pesticide is changed so that it cannot efficaciously bind to the target site, thus eliminating or significantly reducing the pesticide's efficacy. This is the most common mechanism in fungi and weeds, and is additionally very prevalent in insects. There are four general categories of target site resistance in insects:

- *kdr* (knock-down resistance) interferes with the sodium channel in nerve cells. This is a common mechanism used for resistance to DDT and pyrethroids, e.g. in *Anopheles gambiae*, *Blattella germanica.* There are several mutations that produce *kdr* and super *kdr*.
- *MACE* (modified acetylcholinesterase) modifies the structure of acetylcholinesterase so that it is no longer affected by the insecticide. This is, for example, the mechanism for pirimicarb resistance in *Phorodon humuli* and is responsible for resistance in *Tetranychus urticae.*
- *Rdl* (resistance to dieldrin) is a point mutation that reduces dieldrin binding at the GABA receptor. It is responsible for dieldrin resistance in *Anopheles quadrimaculatus* mosquitoes and in *Lucilia cuprina*, the sheep blowfly.
- *Bt* resistance occurs through loss of cadherin, which has important roles in cell adhesion, ensuring that

cells within tissues are bound together. This mechanism is found, for instance, in *Bt*-resistant diamondback moth (*Plutella xylostella)*

There are many examples of target site resistance in weeds. The most important of these include:

- *ALS* (Acetolactate synthase) inhibitors, which cause a change in target site enzyme ALS
- *ACCase* (Acetyl-CoA carboxylase) inhibitors
- *PS2* (Photosystem 2) inhibitors

Reduced penetration: This mechanism slows the perforation of the pesticide through the cuticle of resistant insects. Alone, this mechanism provides only low levels of resistance. However, by slowing the perforation of the toxicant through the cuticle it can greatly enhance the impact of other resistance mechanisms. For example, an insect without any perforation resistance might be 25-fold resistant, whereas if perforation of the pesticide were reduced two-fold then the overall resistance could be nearly 50-folds.

Sequestration: In plants, the pesticide is removed from sensitive parts of the organism to a tolerant site, such as a vacuole, where it is effectively harmless to the target organism. This type of resistance has been demonstrated for the herbicides glyphosate, paraquat and 2,4-D. In insects (aphids, *Culex* mosquitoes, etc.) metabolic enzymes are significantly amplified (up to 15% of the total body protein) and bind to the insecticide but the insecticide is not metabolised, i.e. the insecticide is sequestered.

Behavioural resistance: Behavioural resistance is limited to insects, mites and rodents. It refers to any modification in the organism's behaviour that helps to avoid the lethal effects of pesticides. This mechanism of resistance has been reported for several classes of insecticides, including organochlorines, organophosphates, carbamates and pyrethroids. Insects may simply stop feeding if they come across certain insecticides, or leave the area where spraying occurred (for instance, they may move to the underside of a sprayed leaf, move deeper into the crop canopy, or fly away from the target area). Behavioural resistance does not have the same importance as the physiological resistance mechanisms mentioned above but can be considered to be a contributing factor, leading to the avoidance of lethal doses of a pesticide.

Over-expression of the target protein: If the target protein, on which the herbicide acts, can be produced in large quantities by the plant, then the effect of the herbicide becomes insignificant.

Management

Developing a resistance management plan (RMP)

A RMP describes the tactics or measures that should be taken to prevent and/or manage pesticide resistance for a specific pest. The objective is to reduce the selection of resistance genes in a pest population. The tactics should be designed to maintain a high frequency of susceptible genes and a low frequency of resistance genes in the pest population by reducing selection pressure, while providing the required level of pest control.

General principles

Pesticide resistance management as part of IPM: It is highly recommended for a resistance management plan to be developed within the framework of an overall integrated pest management approach for a given pest and cropping system. This should ensure that rational pest control strategies based on IPM principles - including the use of pesticides only when necessary and the use of alternative pest management techniques whenever possible - are designed to manage resistance.

Implement resistance prevention and management programmes when new pesticides are introduced: When the first noticeable symptoms of resistance appear, the frequency of the resistance gene(s) will have already increased substantially. This will make it more difficult to maintain the overall susceptibility of the pest population. Unless there is a very heavy fitness cost, the resistance gene(s) may gradually accumulate in the pest population.

Focus on the pest: In designing a RMP, it is important to learn as much as possible about the biology of the pest and its hosts. This information is essential for understanding the loss of susceptibility and development of resistance in the target pest. The RMP should address the entire area where the pest is found, not just the crop of concern. Ideally, it should be implemented across an entire cropping region, focusing on the pest rather than on any particular crop, with widespread adoption by all growers in the area.

Consider adjacent host crops: To manage resistance in insects, in particular, RMPs should consider pesticide treatment of alternate host crops located in the vicinity of the main host crop. Many of the same insect pests are likely to be present on other crops that are growing in close proximity or in sequence, or wild hosts. If the same, or related, pesticides are used in all the crops, the population is under much heavier selection pressure than might be calculated.

For example, *Bemisia sp.* occurs on both cotton and vegetables and easily moves from one crop to another. If there were five applications on cotton and five on a vegetable crop, the *Bemisia sp*. population would receive ten applications or selections annually. If each crop were evaluated separately, it would appear that the population was only receiving only five selections per year. It is important to take this into account in designing a RMP.

Consider alternative (non-chemical) pest management measures: In keeping with IPM principles and strategies, a RMP should comprise as many alternative, non-chemical pest control tools and methods as possible, as long as they contribute effectively to managing the pest. These can include biopesticides, biological control agents such as predators and parasitoids, resistant crop varieties, the timing of planting so as to reduce the risk of infestation, use of crop rotation and other cultural practices that interfere with pest reproductive cycles, attention to hygienic practices such as equipment cleaning to stop the spread of seeds and spores, etc.

Use more than one class of pesticide: A RMP should incorporate as many different classes of pesticide as possible to avoid the development of cross-resistance, when resistance to one pesticide confers resistance to another, even where the pest has not been exposed to the latter product. The more non-cross resistant compounds are used the lower resistance selection pressure will be on any one compound or class of compounds. Such different classes can be applied in sequence (alternating applications) or as co-formulated mixtures or tank mixes containing compounds with different modes of action and different modes of resistance.

Consider all treatments made during the year: RMPs should consider all pesticide treatments made to a crop during the year, including treatments with different compounds and of different pest life stages. Some selection for resistance occurs each time a pesticide is applied. Generally, the more treatments made, and the more insect life stages and plant pathogen generations treated, the faster susceptibility will be lost and resistance will increase, unless measures are taken to mitigate the selection of resistance genes. For example, if a soil insect is treated with a soil insecticide, the larvae will have selection pressure for resistance. Some heterozygote larvae may survive, because it is difficult to obtain a uniform concentration of the pesticide in the soil. If the adults that develop from the treated larvae are treated again with the same or a related insecticide, then a second selection of that generation will occur. Thus, in this situation two stages of the pest will have been selected. Some of the heterozygote individuals surviving the soil treatment may be killed when the adults are treated, but over time there will be a build-up of resistant individuals in the population. To avoid this, unrelated compounds should if possible be used to treat the larvae and the adults.

Apply only recommended pesticide application rates: The correct application rate should always be used. Reducing pesticide application rates to reduce costs may appear to provide the pest control desired, but this is only temporary. Continuous use of below label rates will result in the increased selection of heterozygote and homozygote resistant individuals thus increasing the development of a resistant population. The properly applied label rate should eliminate the heterozygote resistant individuals from the pest population and significantly slow the development of a resistant population.

Involve stakeholders: To have a chance of success any resistance management strategy should be agreed on by all stakeholders, including growers, the pesticide registrar, pesticide companies/distributors, the ministry of agriculture and extension services. In particular the strategy must be understandable and acceptable to farmers. For RMPs that cover large areas, such as those designed for fungicides, local and regional cooperation are essential elements for the successful development and implementation of a RMP.

All types of pesticides – resistance management tactics

Mixtures of pesticides with different modes of action or mechanisms of resistance: Mixtures of pesticides with different modes of action can be effective in managing resistance development. Various types of pesticide mixtures are used in agriculture and pest control - for example, two pesticides with different pest spectra, the combination of a pesticide and a synergist, the combination of an insecticide and a fungicide, the addition of micronutrients to an insecticide, etc. Pre-formulated mixture products and some tank mixes have proven to be relatively successful in controlling insect pests and in delaying resistance development. Successful mixtures or pre-formulated mixture products have been designed for specific situations and only after careful consideration of the cropping system, the effects on beneficial arthropods, and the pest complex. If the target pest population has substantial resistance to any of the components in a pesticide mixture, application of the mixture could exacerbate the situation by selecting for multiple resistance in the pest population. Pesticide mixtures should be used with care and are not recommended unless the mixture has been carefully researched and meets the following requirements:

- the components of the mixture are not cross-resistant, individuals with resistance to one or the other component are rare, and individuals resistant to both components are extremely rare;
- the mixture is prepared such that both pesticides are applied at their label rate. If the rates applied are only marginally effective, resistance will be much more likely to develop, because the rate used will be insufficient to kill the heterozygote individuals;
- the residual activity of both compounds is nearly the same. Otherwise, the compound with the shorter residual activity will degrade and the component with the longer residual will begin selecting for resistance to it.

Rotations or alternation of pesticides: The alternation of pesticides is another tactic used to manage resistance development. This tactic assumes that (1) pests resistant to both pesticides are rare, hence survivors of the first pesticide application will be killed by the second, and (2) the percentage of resistant pests will decline in the absence of the pesticide because of the relative instability of the resistance mechanism.

As with pesticide mixtures, alternation programmes for fungicides are often based on the use of one 'high risk' and one 'low risk' pesticide, although programmes containing only 'high risk' pesticides are also possible. This tactic depends on the alternating 'low risk' pesticide eliminating any resistant individuals or isolates that survived the previous applications of the 'high risk' pesticide.

Fungicide resistance management tactics: A considerable number of tactics are available for managing resistance to fungicides. The tactics vary for different fungicide groups, target pathogens, crops, and geographic areas, but it is often possible and effective to integrate two or more of them together in a RMP. The tactics described below constitute the foundation for a RMP for fungicides. Specific resistance management strategies have been developed for the various fungicide groups.

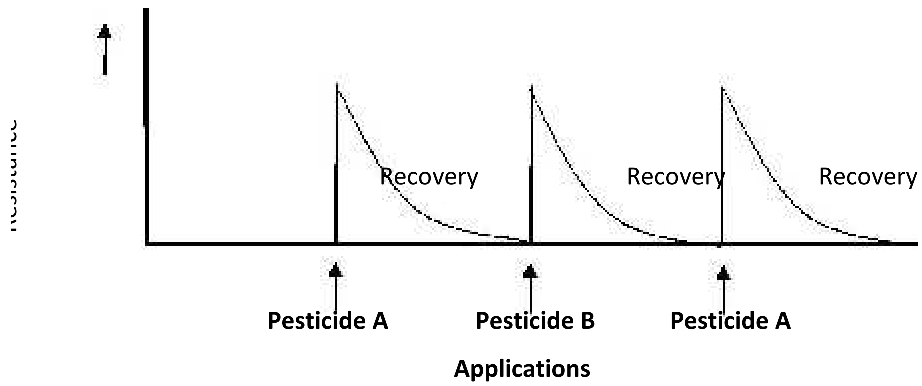

Figure 1. Illustration of the effect of compound rotation on insecticide resistance levels when used in an insecticide resistance management programme.

Implement integrated disease management (integrated pest management): The integrated use of cultural practices and fungicides is not only economically and environmentally beneficial but is also a major strategy for combating crop disease while avoiding or delaying fungicide resistance. Unfortunately, non-chemical methods of disease control may be weak or unavailable, so that fungicide application is the predominant, or even the sole, countermeasure for many diseases, including potato late blight, grape downy mildew, Sigatoka disease of bananas and wheat bunt.

Integrated disease management includes the following:

Cultural practices

- Use disease resistant crop varieties, biological control agents, and basic hygienic practices such as crop rotation and removal of diseased parts of perennial crop plants, to reduce the incidence of disease.
- Avoid growing large areas of the same variety, particularly if it is known to be susceptible.
- Sterilize soil and equipment to help prevent the spread of pathogenic diseases. This can be especially valid for glasshouse crops.
- Extend crop rotation intervals where possible to avoid the spread of soil-borne pathogens.
- Scout fields frequently to monitor the appearance of disease symptoms before the diseases become established.
- Become familiar with the environmental and crop conditions generally associated with disease development.

Fungicide use

- Apply fungicides only when they are really needed.
- Use fungicides at the label rate and ensure that there is good spray coverage.
- Apply fungicides to reduce the build-up of more virulent pathotoypes that may affect even (previously) disease-resistant crop varieties.
- Do not use soil applications to control foliar diseases.

Use pesticides with different modes of action where possible: The availability of different types of fungicide for each major crop disease is highly beneficial both environmentally and to overcome resistance problems. The continued use of one or a very few classes of compounds over many years presents a much greater risk of side effects and favours resistance in the target organisms. Mixtures and alternating applications or blocks of treatments of compounds that are at risk of resistance development with an unrelated companion fungicide are often used in fungicide RMPs to broaden the spectrum of the diseases controlled as well as to manage resistance. The 'companion' or 'partner' compounds applied as either a mixture or a rotation will reduce the selection pressure exerted by the at-risk fungicide and inhibit the growth of any resistant populations. Generally, good partner fungicides are multi-site inhibitors that are highly effective against the pathogen and that have a low resistance risk. However, it is possible to use a single -site fungicide that is known to be unrelated to its partner by cross-resistance or, in the absence of known resistance, by a similar mode of action. Use of a mixture of two single-site fungicides will carry some risk of selecting dual-resistant strains, but the chance of two mutations occurring simultaneously will be very small compared to that of a single mutation.

Restrict the number of treatments per season, apply only when strictly necessary: This approach, like rotation, reduces the total number of applications of the at-risk fungicide and therefore slows down resistance selection to some extent. It can also favour the decline of resistant strains that have a fitness deficit. However, the delay in resistance may not be proportional to the reduction in spray numbers. This is because the treatments which are still applied generally coincide with the most active stages of epidemics when selection pressures are highest. On the other hand a substantial break in use at a time when the pathogen is still multiplying can allow a beneficial resurgence of more sensitive forms.

Use recommended doses: Fungicides must also be applied at the recommended dose in order to ensure their effectiveness under a wide range of conditions. Reducing the dose can enhance the development of resistance.

Avoid eradicant uses: Systemic fungicides can eradicate or cure infections, and this greatly assists their use on a 'threshold' basis, where application is made only when an economically unacceptable, amount of disease has already appeared. However, in certain cases, specifically where the fungicide is a mixture of a systemic and non-systemic component, a curative or eradicant treatment is not recommended as it can apply a very high selection pressure to the pathogen. In particular, eradicant use of phenylamides should be avoided, if they are applied for control of foliar diseases as a mixture with a multi-site companion fungicide. The latter does not work as an eradicant, so that the systemic component is acting alone when the mixture is applied to existing infections, which increases selection pressure. Avoiding the use of fungicides as eradicants can delay resistance for another, more widely applicable reason. To wait until a threshold population of the pathogen appears usually means that many sporulating lesions (occupying up to 5 percent of the foliar area) are exposed to the fungicide. Opportunity for resistance selection is likely to be much greater than if the fungicide had been applied prophylactically to keep the population permanently low.

Herbicide resistance management tactics

The foundation for herbicide resistance management is use of a sustainable system that integrates physical, chemical, and biological control methods and avoids excessive reliance on any one method. In the short term, any management practice that reduces the selection pressure for resistance, for example changing herbicides, will reduce the rate of development of resistant weeds. But in the mid to long term, it is necessary to have a programme that incorporates crop management and strategic use of chemical and mechanical weed control tools. When employed in an integrated approach, these techniques will help to reduce the selection pressure and significantly reduce the chance of survival of resistant weeds.

Crop management: The following well-established crop management techniques should always be used.

- Rotate crops with different herbicide use patterns and/or growth cycles, to avoid successive crops in the same field which require herbicides with the same mode of action to control the same weed species. Different crops will allow rotation of herbicides with a different mode of action and can avoid or disrupt the growth season of the weed. In addition, crops with different sowing times and seedbed preparation can permit the use of a variety of cultural techniques to manage a particular weed problem. Crops also differ in their inherent competitiveness against weeds, and a strongly competitive crop will have a better chance to restrict weed seed production.
- Delay planting so that initial weed flushes can be controlled with a non-selective herbicide.
- Hand weed, cultivate, or plough before sowing to control emerged plants and bury non-germinated seed. These techniques exert no chemical selection pressure and assist greatly in reducing the soil seed bank.
- Use certified weed-free crop seed.
- Encourage post-harvest grazing, where practical.
- Burn stubble, where allowed, to limit weed seed fertility.
- Cut for hay or silage to prevent weed seed set in extreme cases of confirmed resistance.
- Keep equipment clean of weed seeds to avoid mechanically spreading weed seeds.

Chemical tools: herbicide rotation and mixtures: Various studies have provided details regarding the upsides of and requirement for utilizing numerous herbicide methods of activity to keep the onset of resistance and to address prior resistance for a wide range of product/herbicide/weed complexes. The successions contemplated include: utilization of herbicide blends; post-emergence applications utilized as a part of arrangement on a similar crop; pre-emergence uses of soil active herbicides took after by post-emergence active products on a similar product; and the variation of herbicides in various years/distinctive yields inside a crop rotation. However, rotation of herbicides alone is insufficient to keep the advancement of resistance. The chemical rotation must be employed in association with at least some non-chemical weed control measures. No classification of herbicides relating to degradation is yet available and such examples need to be handled on a case by case basis. Products should be chosen from different mode of action groups to control the same weed species either in successive applications or in mixtures.

The following guidelines should be followed for herbicide rotation and mixtures.

- Use less or non-residual herbicides.
- Rotate crops with different growth seasons when possible.
- Avoid continued use of the same herbicide or of herbicides having the same mode of action in the same field unless it is or they are integrated with other weed control practices.

- Limit the number of applications of a single herbicide or of herbicides having the same mode of action in a single growing season.
- Where possible, use mixtures or sequential treatments of herbicides that have a different mode of action but are active on the same target weed. For mixtures to be effective, their active ingredients should each give high levels of control of the target weed.
- Use non-selective herbicides to control early flushes of weeds prior to crop emergence.
- Always use post emergence herbicides at the recommended label rate applied at the recommended timing or growth stage of the weed.

Insecticide resistance management tactics

In managing insect resistance, it is important to keep in mind that the primary objective is to protect the crop or control the vector, not necessarily to kill all the insects. The overall strategy of avoiding overuse of a single insecticidal mode of action should be followed.

Crop-by-pest vs. regional tactics: "Crop-by-pest" resistance management tactics focus on a single crop-pest combination. They can be appropriate when the crop area is large and there is essentially one pest species (e.g. *Helicoverpa* on tomatoes) to be treated with an insecticide. However, in horticultural and agricultural areas there is often a range of crops and a range of pests. In cases where one or more insecticides with a single mode of action are used across this range of crops to control multiple pests that can readily move from crop to crop, the risk of resistance will likely increase. For example, resistance management tactics for diamondback moth on Brassica vegetables could be compromised by widespread use of similar insecticides for diamondback moth control in canola.

General practices: The following management tactics are recommended to reduce the risk of insecticide resistance developing:

Use an integrated approach

Management of insecticide resistance requires a consideration of all aspects of crop production, including agronomic practices, physical and biological control methods, and insect pest biology. Simply complying with the concepts of integrated crop management can help prevent resistance from developing. For example, monitoring and adhering to recommended pest and/or damage thresholds, respecting the usefulness of natural enemies, carrying out simple sanitation measures, removing post-harvest residues in the field, using resistant crop varieties, and simply avoiding continuous year-round cultivation of a single crop can all help to slow and even prevent resistance development.

Protect beneficial organisms

Protect natural enemies of pests insofar as possible. The contribution of beneficial organisms to pest control can be significant in many cropping systems. Beneficial organisms can also play an important part in resistance management as they help control the target pests irrespective of the pests' degree of resistance or resistance mechanism, and thus can help slow down the resistance selection process. Natural enemies can be protected for instance by using selective insecticides, avoiding overdosing or applying non-chemical control options.

Use recommended application rates

Use the recommended rates and treatment intervals as indicated on insecticide labels. Never apply more or less than the recommended rate, as this can result in resistance and/or unwanted effects on non-target organisms and the environment. Always make sure that spray equipment is in good condition, and that nozzles and filters are not blocked, which causes spraying of incorrect rates and can result in resistance development.

Rotate unrelated compounds

Use a variety of compounds registered for the use in question, from unrelated chemical classes that are not cross-resistant; never use a single compound or class.

Use mixtures with caution

Mixtures should be used with extreme caution and are not recommended except in very limited situations, as the incorrect use of mixtures can exacerbate resistance. In particular, mixtures should never be used if the target pest is already resistant to one of the modes of action in the mixture. If mixtures must be used, the active ingredients should be at their recommended application rates and should have similar residual activity to prevent selecting resistance to the component with the longest residual activity.

Use non-specific products

Plant protection products such as oils and soaps that have a non-specific mode of action are good resistance management tools. Where possible they should be used in rotations or mixtures with conventional insecticides, provided they effectively control both susceptible and resistant target pest populations.

Apply products with care

Apply insecticides when the opportunity for control is optimum, i.e. the infestation has reached the action threshold but is not overwhelming. Ensure that coverage is good. Do not use the same compounds with the same mode of action to control a pest that has several generations in the growing season of the crop.

Monitor problematic pests

Monitor problematic pest infestations in order to detect first shifts in sensitivity. In many instances, baseline sensitivity data for representative field populations were established before the products became widely used. Re-examining the insecticide sensitivity of these populations at regular intervals can reveal possible changes in susceptibility. Resistance monitoring carried out at regular intervals is recommended to detect possible changes in pest sensitivity before serious control problems become evident.

In practical terms, an on-farm resistance management plan should include the following elements:

1. Supplementing insecticide with non-chemical control methods (particularly crop rotations).
2. Alternating insecticide with different modes of action.
3. Using economic thresholds when making decisions about spraying. Trying to kill all the beetles with insecticides usually results in killing all susceptible beetles, while resistant beetles survive and quickly build up their numbers.
4. Leaving untreated refuges for susceptible beetles. Economic thresholds cannot be used when insecticide is applied at planting time in furrow or as a seed treatment. Therefore, spatial refuges are required to maintain populations of susceptible beetles.
5. Using full label rate of insecticides. Because resistance is usually incompletely dominant, sufficiently high dose of a toxin will kill the beetles that are heterozygous at the resistant allele.
6. Monitor for the signs of decreasing insecticide efficiency.

Chapter 15

Disease Forecasting for Early and Late Blight of Potato

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Introduction

Potato, like any other crop, is also attacked by large number of pests and diseases leading to crop losses up to 25%. These losses can be contained by adopting three prolonged strategies i.e. by employing chemicals (including disease forecasting), cultural practices, and host resistance in an integrated manner. Cultural practices mainly aim at reducing the initial inoculum load and arresting the disease spread. Practices used for achieving these objectives are use of disease free planting material, burying/burning the infected plant parts, removal of volunteer, collateral/alternate host plants etc. It is possible to manage the disease by applying chemical sprays but the number of sprays required on a susceptible variety would be more than double the sprays required on a resistant variety, which is rather uneconomical for most of the farmers. Even if they are able to apply the required number of sprays, it would result in environmental pollution and also the development of fungicide-resistant strains of the pathogen. Similarly, resistant varieties may be used for managing the diseases but there is a risk of breakdown of resistance if the resistance is governed by major genes. However, if the resistance is broad based, it would still require support of prophylactic chemical sprays. In this context usage of chemicals become inevitable. To reduce the cost of management and pesticide residues, their need based application is the need of the day. In this direction disease forecasting can play an important role. Disease forecasting is a management system used to predict the occurrence or changes in severity of plant disease population. Historically disease forecasting has been attempted in late blight of potato. However, there is dire need to develop forewarning systems for other important diseases as well.

Principle and concept of disease forecasting

Forecasting systems are based on assumptions about the pathogen's interactions with the host and the environment. Forecasting systems can only be designed if there is an understanding on the actual disease triangle parameters. The principles of disease forecasting are based on relationship between the weather parameters and the disease epidemiology. Van Everdingen (1926) for the first time utilized weather parameters (temperature, RH, rainfall, dew) to develop a late blight prediction system, commonly known as 'Dutch rules'. Since then large number of forecasting models based on minimum temperature and RH, moving days concept, severity values, risk values etc. have been developed worldwide but most of them are region specific. Van Everdingen (1926) used dew periods, night temperature, cloudiness and rainfall, known as the "*Dutch rules*", to predict initial appearance of late blight in Holland. Dutch rules were found usually satisfactory but sometimes the blight appeared even when the Dutch rules were not completely fulfilled. Subsequently, these rules were modified for England and reduced to two conditions which were known as '*Beaumont rules*' (Beaumont, 1947). These rules were based on specific temperature and RH periods for two consecutive days. They successfully forecast late blight under UK conditions. Hyre (1954) proposed a concept popularly known as '*Moving days concept*' which uses average temperature for the last 5 days and total rainfall for the last 10 days for determining the initial occurrence of the disease. The initial appearance of late blight is forecast 7-14 days after the first occurrence of ten consecutive blight-favorable days. A day is considered to be blight-favorable when the 5-day average temperature is below 25.5° C and the total rainfall for the last 10-day period is > 3.0 cm. Days on which the minimum temperature falls below 7.2°C are considered unfavorable for blight development. Wallin (1962) developed a forecasting model for predicting the initial occurrence and subsequent spread of late blight based on relative humidity (RH) and temperature. This system is based on the seasonal accumulation of '*Severity values'*. Severity values are numbers arbitrarily assigned to specific relationships between duration of RH periods > 90% and the average temperature during those periods. The first occurrence of late blight is predicted 7-14 days after 18-20 severity values have been accumulated from the time of plant emergence. Ullrich and Schrodter (1966) developed '*Negative prognosis*' concept, which uses measurements of temperature, relative humidity, and rainfall to predict when late blight epidemics are not likely to occur. It has been used in Germany and has been implemented in Europe to predict the timing of the first prophylactic treatment.

Late Blight Forecasting

Development of late blight mainly depends on moisture, temperature and cloudiness. In India, the rains are heavy and the weather is cool and cloudy/foggy during summer in the hills but in plains the weather is generally clear with scanty rains (during autumn or spring) and therefore, the disease epidemic is not a regular feature. The monsoon moves from East to West in the Himalayas. Therefore, the blight occurs early in the eastern Himalayas.

Forecasting for temperate highlands

In the hills, environmental conditions (temperature, RH, rainfall) favourable for late blight appearance are assured. There are plenty of rains during the crop season which led to high RH (>80%) for most of the crop season. Temperature remains moderate and congenial throughout. It is therefore, possible to rely on weather parameters like, rainfall, RH and temperature for making disease forecasts. Taking weather parameters in account, Bhattacharyya *et al*. (1982) developed forecasting models for Shimla (North western hills), Shillong (North eastern hills) and Ootacamund (Southern hills) i.e. i) if the 7-day moving precipitation (30 mm for Shimla, 28.9 mm for Ootacamund and 38.5 mm for Shillong observed to be critical rainfall lines) associated with mean temperature of 23.9^{o}C or less continues for 7 consecutive days, late blight would appear within 3 weeks. Once these conditions are met, then more accurate prediction based on RH and temperature was developed. It states that if hourly temperature remains in between 10-20^{0}C associated with the RH ≥80% for continuous 18 hr for at least 2 consecutive days, late blight would appear within a week. This model has been put to successful use for predicting late blight in Shimla hills since 1983 and it is still working very well.

Forecasting for sub-tropical plains

Late blight forecasting in the sub-tropical plains is different to that of temperate highlands as there are scanty rains during the crop season. In such a situation, role of micro-climate, fog, dew and sunshine becomes critical for the appearance of the disease. A computerized forecasting model 'JHULSACAST' has been developed for western Uttar Pradesh using temperature, RH and rainfall data. It consists of two models, one each for rainy and non-rainy years. For rainy years, if i) measurable rains (0.1-0.5 mm) for a minimum of two consecutive days, ii) 5-day moving >85% RH period 50 hrs or more, iii) 5-day moving congenial temperature (7.2-26.6^{o}C) for 105 hrs or more, blight would appear within 10 days time. For non-rainy years, if 7-day moving >85% RH period 60 hrs or more and 7-day moving congenial temperature (7.2-26.6^{o}C) for 120 hrs, blight would appear within 10 days' time. Besides, decision rules for predicting first appearance of late blight in Punjab under non-rainy conditions have also been developed using JHULSACAST model as template. The model specifies that 7-day moving sum of RH ≥ 85% for at least 90 hr coupled with a 7-day moving sum of temperature between 7.2-26.6^{o}C for at least 115 hr would predict appearance of late blight within 10 days of satisfying the conditions. JHULSACAST has also been calibrated for Tarai Region of Uttarakhand. The model specifies that if 7 day moving relative humidity (≥85%) period ≥ 85 hours and 7 day moving congenial temperature (7.2 to 26.6^{o}C) ≥135 hrs conditions prevail for 7-consecutive days, blight would appear within 14 days. Similarly, JHULSACAST has also been calibrated for plains of West Bengal. The modified JHULSACAST model could predict late blight within 14 days with accuracy of 100% if 7-day moving relative humidity (≥90%) period ≥105 hrs coupled with 7-day moving congenial temperature (7.2 to 26.6^{o}C) ≥150 hrs prevail for 7-consecutive days OR if 5-day moving relative humidity (≥90%) period ≥65 hrs, 5-day moving congenial temperature (7.2 to 26.6^{o}C) ≥105 hrs for 5 consecutive days and sum of two consecutive days rainfall (≥2.5 mm) prevail.

Recently, a wireless sensor network was used for validation of 'JHULSACAST' with other late blight forecasting models in western Uttar Pradesh using human participatory sensing approach and results revealed that 'JHULSACAST' is more accurate than the other tested models (Jagayasi *et al*., 2015). Based on JHULSACAST, Decision Support System (DSS) has also been developed which has three components i.e.(i) prediction of first appearance of disease, (ii) decision rules for need based fungicide application, and (iii) yield loss assessment model.

INDO-BLIGHTCAST: Pan India Model for Prediction of Late Blight

Recently, INDO-BLIGHTCAST, a web based model has been developed to predict first appearance of late blight using daily weather data of meteorological stations. This is an improvement over JHULSACAST model as it is applicable pan India and requires only daily weather data and does not need local calibration for different regions. Hence, it is more robust and its predictions are more broad based. The model involves computation of physiological days (P-days) and mean relative humidity of the night accrued over seven consecutive days.

The model has two modules one for data entry and the other for the users to see the status of late blight forecast. The data entry module is operated by authorised persons for inputting daily temperature and RH data. The user module can be accessed by any stakeholder, including growers, to know about the blight situation in their region through this model. The late blight status is displayed through colour. Green colour indicates that late blight is not likely to appear soon; yellow colour indicates that late blight would appear very soon; and red colour indicates that the weather conditions have become congenial for late blight and it can appear any time within fifteen days. Thus, depending upon the time required for taking control measures, the user may start preventive measures at yellow or red colour indication. The model has been developed and tested using the data on late blight appearance collected at CPRI regional stations and AICRP centres over the past several years. The model was tested at different locations in the plains, tarai region and the hills and the results showed that it predicted late blight appearance at all the locations within the stipulated period of 15 days.

Early Blight Forecasting

Early blight is a serious disease of potato which occurs in relatively warm and humid regions. Among the fungal diseases of potato, it is next only to late blight worldwide as far as economic importance is concerned. Therefore, forecasting of early blight under Indian situations is essential. Recently, a model based on P-days has been developed to predict appearance of early blight. The model specifies that early blight would appear at accumulated P-days of 300 when P- days are calculated with the lower, optimum and maximum cardinal temperatures of 7.2, 25 and 35°C, respectively. The user has to input the daily weather data and start date as well as date of forecast. The software would compute the P-days accrued from date of planting (start date) till the date of forecast according to the cardinal temperatures. As soon as P-days reaches to 300, software would issue an advisory "*watch out for early blight symptoms and spray the crop if it has appeared*". The software advises adoption of control measures only if symptoms are observed because early blight does not spread as fast as late blight.

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Chapter 16

Forecasting of Insect Vectors for Management of Potato Virus Diseases

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Introduction

Potato is the third most important food crop in the world after rice and wheat with a record global production of 365 million tonnes (MT). India is the second largest producer after China with a production and productivity of 45 MT and 23.6 t/ha, respectively. However, it is projected that India need to produce 55 and 122 MT by 2025 and 2050, respectively to meet the demand of the enormously growing population. But, often the potential yield of potato is limited by number of biotic and abiotic factors in hills, plains and plateau regions of potato in India. Among the biotic factors, vector borne potato viruses namely *Potato virus Y* (PVY), *Potato leaf roll virus* (PLRV), *Potato virus A* (PVA), *Potato virus S* (PVS), *Potato virus M* (PVM), *Tomato leaf curl New Delhi virus-potato* (ToLCNDV-potato) and Stem necrosis virus are not only responsible for progressive degeneration of the seed but also limit the potential yield of potato. These viruses are known to cause huge economic losses up to 20-50% under severe infestation. The vectors of potato viruses belong to sucking group of insects adhere mostly on abaxial surface of the leaf and draw the vital plant sap from phloem vessels for their survival and reproduction. The virus in phloem vessels is acquired by the vector in the process of feeding and transmits to the healthy plants. Aphids transmit PVY, PVA, PVM and PVS in a non-persistent manner while PLRV in persistent manner. The whiteflies and thrips transmit ToLCNDV and stem necrosis virus in a persistent and circulative propagative manner. Although there are many strategies for the suppression of pest population, forecasting is one such approach to prevent the damage caused by both vector and viruses either directly or indirectly. In this context, the dynamics and forecasting of insect vectors of potato viruses such as aphids (Green peach aphid, *Myzus persicae* and cotton aphid, *Aphis gossypii*), whitefly (*Bemisia tabaci*) and thrips (*Thrips palmi*) are crucial for healthy potato seed production and also for increased productivity to meet the rising demand of the future generations. Forecasting is the process of making predictions of the future populations of pests/vectors based on past and present data for decision making. This chapter include virus disease forecasting based on vector population in potato with special reference to aphids.

Significance of forecasting in pest and disease management

Adequate suppression of plant pathogens is achieved by integrating a variety of control measures that may differ in efficacy, duration of effectiveness, and cost. When deciding whether or not to apply a pesticide, the manager has to choose between several possible strategies. These strategies are as follows: (a) to never spray; (b) to spray frequently, whether needed or not; or (c) to spray only when needed (Fabre *et al*., 2007) (d) to destroy haulms etc. Because the prevalence of pathogens and the intensity of the diseases they cause vary from year to year and from location to location, rational and cost-effective disease management necessitates the consideration of many factors, which makes reaching a sound, rational decision for disease management a difficult task. The application of disease management measures when they are not needed is inefficient at best, as unnecessary applications entail unnecessary costs to growers, consumers, and the environment (Fry, 1982). To eliminate unnecessary use of pesticides, precise knowledge of the risk of an epidemic at field level is essential. Managers need simple and robust methodologies to assess disease occurrence or risk to judge whether pesticide should be applied. Although it is possible to make decisions, albeit poor ones, in the absence of information, in order to make the best possible decisions, decision makers need to have access to and understand all of the relevant information. The transfer of information from researchers to farmers is often a weak point in the process of improving integrated pest management (IPM), but it is an area in which decision-support systems (DSSs) can contribute significantly. Epidemiological models have been developed using aphid trapping data to improve the timing of control measures.

Population dynamics of aphids in potato

In hills, the vector scenario is being highly influenced by change in the climate. The dominant aphid species is *M. persicae* but rarely *A. gossypii* also reported in hills. The mean temperature is rising during past few years which favour the survival and development of vector population. Earlier, the higher hills of India were found be highly suitable for seed potato production because of the low or no vector population. As a result, the seed potato production used to be exclusively in Kufri hills during 1950s which was the only seed source for Indo-Gangetic plains. The aphid population used to cross critical levels in the beginning of August during which the dehaulming is done to produce disease free seed stocks (Fig. 1). The aphid population movement is also restricted because of high rain fall between mid July and September. Moreover, growing crop used to be strictly monitored for virus infected plants to rouge them out. The aphid population dynamics is changing over the years because of the change in climate and its population cross critical level during 4th week of July. However, strict monitoring of seed crop, rouging of virus infected plants, timely management of aphids coupled with high rainfall sustain the healthy seed potato production in high hills (Pushkarnath, 1976).

Aphids are the vectors of five important potato viruses as mentioned above and economically very important in potato as vectors although they cause considerable direct damage at high densities. Primarily, green peach aphid, *Myzus persicae* has been known to be dominant vector in potato ecosystem in India followed by *A. gossypii*. It has been proved highly viruliferous in transmission of viruses. Besides, 12 other aphid species were know to occur on potato (Sridhar *et al*., 2015). The aphid population is being monitored by yellow sticky traps, yellow water traps, yellow funnel traps and roving survey. The aphid critical limit for most roving survey has been fixed as 20 aphids/100 compound leaves. The vector dynamic scenario is entirely different in Indo-Gangetic plains of India. Aphid population dynamics is under strict monitoring in all CPRI stations as well as in AICRP-potato centres. In general, the aphids first appear during last week of November, and crosses critical limits during first and second week of January and it continues to build up to reach a peak during second week of February. The rate of multiplication of aphid migrants on potato is low in the beginning but high aphid population lasts only for four weeks between mid-January to mid-February and population show a sudden and sharp decline by end of February. The seed potato growers and all the stakeholders related to potato production must adopt their vector management strategies in tune with change in vector dynamics. However, in Jalandhar, Patna and Raipur the aphid monitoring data during the past 2 years revealed that although it first appears on potato during first week of December, its population reaches critical levels during mid-January instead of last week of December. In this case, the dehaulming may be extended by one week with suitable vector management strategies for enhancing the seed potato yield. The vector dynamic study not only help us to forecast the virus disease incidence but also to identify areas for healthy potato seed production but also help us to increase the production and productivity by keeping the vector borne potato viruses under control. Besides, vector dynamics study it also help us to take the timely and effective control measures as well as to restrict the spread of contagious viruses in new seed production areas.

The aphid population survey during crop season for six consecutive years in Kalyani region of West Bengal reveals that the critical aphid level is reached during second week of January in November planted crop (Fig. 2). Thus, a window of 9 weeks low aphid period is available between November and first week of January. Besides, the potato growing areas like Kota, Jorhat, Kalyani and Chikballapur having low aphid period may be exploited for healthy seed production to meet the seed requirement of the country. The low aphid period can be extended by spraying suitable insecticides until dehaulming for seed potato production.

The monitoring of aphids (*Myzus persicae* and *Aphis gossypii*) population on unsprayed potato crop at AICRP (Potato) centers was continued during 2011-14. The data of two years (2011-12 and 2012-13) at Deesa, Dholi and of three years of Kalyani (2011-12 to 2013-14) were used to develop a thermal time model to represent the population buildup. The daily P-days were calculated using the lower, optimum and maximum cardinal temperatures for aphids reported in literature i.e. 6.5, 26.7, 37.3^{0}C respectively and were accumulated from the date of planting of the potato crop at each centre and same were plotted against aphid population. The results showed that the aphid population increased exponentially with increase in accumulated P-days at all the three centres. The degree of fit was also very high as indicated by the high R^2 values. This shows that prediction equations for each location could be developed. The relationship between accumulated P-days and aphid population combined over three locations was also exponential and was represented by the equation $y = 1.206e^{0.0092x}$ with R^2 of 0.7426 (Fig 1). Calculation of the aphid population with this equation shows that at accumulated P-days of 300 the aphid population would be just under 20 aphids per hundred compound leaves. Thus, this study indicates that up to accumulated P-days of 300 the aphid population is expected to be certainly below the critical limit and that we would have to rigorously monitor the aphid population and take control measures as soon as accumulated P-days reaches near about 300 P-days.

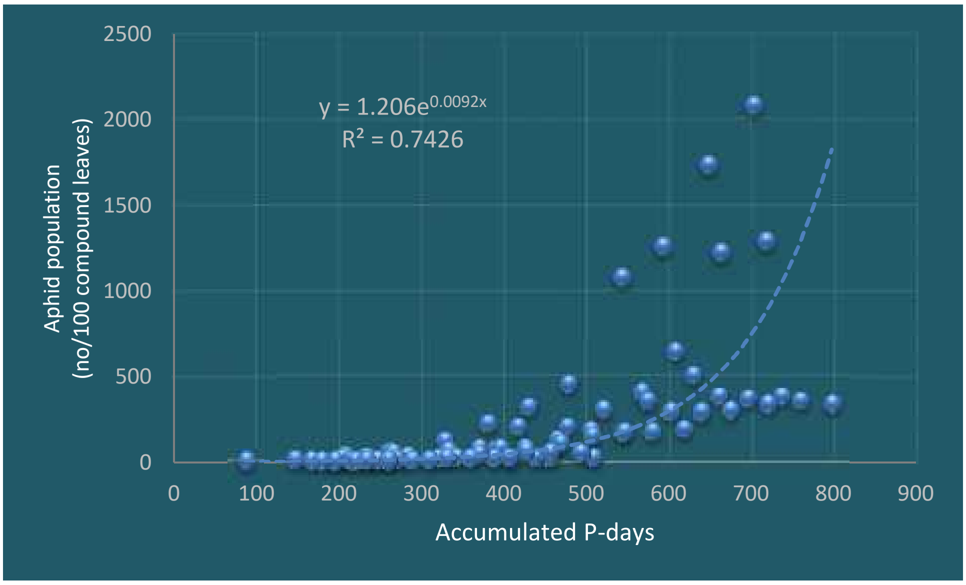

Fig 1: Aphid build up as a function of accumulated P-days at Deesa, Dholi and Kalyani

Forecasting virus disease in seed potatoes using flight activity data of aphid vectors

Model selection techniques were used to regress year-to-year variation in the incidence of potato viruses – largely dominated by PVY – in three susceptible varieties against the abundance of virus vectors (winged aphids), obtained in a suction trap, to identify the most important vector species. The ultimate aim of this study was to develop a decision-support system capable of forecasting virus spread during the current season using trap data of aphid flights. The average virus incidence in the varieties Bintje, Sirtema and Charlotte varied considerably among years, ranging from 1.0% in 2009 to 13.6% in 1989 (N =150–611 seed lots per year). Winter temperature (January–February) was positively correlated with the abundance of *B. helichrysi* in early summer as well as with post-harvest virus incidence. Remarkably, the abundance of *Myzus persicae*, often considered the main vector of PVY, was not correlated with virus incidence. However, the early migrating aphid *B. helichrysi*, rather than *M. persicae*, is the main vector of PVY in Switzerland, and that suction trap data are useful for the design of decision-support systems aimed to optimise virus control in seed potato production (Steinger et al, 2014, 2015).

Aphid Alert

Aphid Alert is an areawide aphid-trapping network operated by the University of Minnesota from 1992 to 1994, and again from 1998 to 2003. It would trap, identify and analyse vector efficiency of aphid species on weekly basis and forewarn and alert potato growers to take timely decisions for management the vector borne viruses which avoid the unnecessary expenditure incurred on management. Information presented in Aphid Alert was used by growers in making pest management decisions, e.g. in timing the application of aphidicide or crop oil or to 'vine-kill' early. For many growers, and even crop consultants and seed certification personnel, much of this information was both new and of immediate practicality.

Merits: Provided excellent aphid control while reducing use of foliar aphidicides by over 90%. Appreciable seed rejections in the NGP due to PLRV have not occurred since 2000.Demerits: impracticality of our handing a greater number of samples. PVY epidemic. PLRV epidemic of 1997–2000.

EPOVIR model

EPOVIR is the first virus epidemic model coupled to a crop growth submodel, which for his part is coupled to a soil water balance submodel. The two submodels are used in three ways: tuber yield and tuber size are calculated, the physiological age of the leaves and the drought stress are used to calculate the susceptibility to virus infections ("age resistance") and fInally, the fraction of soil covered by the canopy is needed to calculate landing rates of the vectors in the potato fIeld. Since the rate of virus spread is a function of plant physiology and phenology as simulated by the crop submodel, the epidemic should react appropriately to changes in plant growth, caused by man or the environment (Nemecek *et al*., 1994).

An inoculation submodel, which calculates vector intensity (after IRWIN & RUESINK, 1986) from vector abundance in the field, vector propensity and vector behaviour. Vector abundance is estimated from suction trap catches. Wingless aphid vectors are considered for PLRV transmission only. The submodel represents the role of the vectors and their relationships to the viruses and the crop. - An infection submodel, which determines the infection of plants and tubers by PVY respectively PLRV, further the fraction of plants serving as infection sources by accounting for the latent period aad the age resistance of the plants to virus infections. The submodel represents mainly the role of the viruses and their relationships to the crop. A crop growth submodel, which calculates the dry mass of leaves, stems, roots, tubers and assimilates, and the physiological state of the canopy. A soil water balance submodel, which calculates the water content of the soil and

the water stress of the potato plants as the ratio of actual and potential transpiration.

TuberPro model

TuberPro is an effective decision supporting system to optimise haulm destruction dates in respect to virus infection and yield development for different potato varieties in Switzerland. It calculates the risk of virus infection based on aphid abundance (suction trap) and meteorological data. It further considers aphid specific virus transmission efficiency, varietal virus susceptibility and initial virus infection within planted fields. It provides very instructive information for the training of seed growers and field visiting inspectors, since it clearly visualises the causes of differerent cultural practises on virus. TuberPro virus infection forecasts closely corresponded in all years to the effective virus infection measured with ELISA technique (Hebeisen and Nemecek, 2001). TuberPro calculates the variables necessary to find optimal solutions at the different levels, especially to determine the haulm killing dates according to the specified goal. Moreover, it has revealed useful for the instruction of farmers and experts and for the evaluation of cultural and virus control measures (Nemecek et al., 1994).

GPA-Cast

GPA-Cast is a computer forecasting system for predicting populations and implementing control of the green peach aphid on potatoes. This system was utilized to predict field populations of *M. persicae*. Predictions showed close agreement with observed field populations until application of the selective aphicide, pirimicarb (Whalon and Smilowitz, 1979).

Conclusion

Forecasting of insect vectors based on their population dynamics through development of models would not only help potato growers in decision making but also save the crop from losses caused by vector borne viruses.

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Chapter 17

Role of Nutrients in Potato Health

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Plant nutrients play an important role controlling and managing plant diseases and mineral nutrients are frequently the first and foremost line of defense against plant diseases and influence all parts of the disease "pyramid" (Huber and Haneklaus 2007, Datnoff et al. 2007). One of the first observations of the effect of nutrients on disease development was that fertilization reduced disease severity when plants were under deficiency, as fertilization optimized plant growth. Effect of soils/ Fields suppressive to common potato scab have been reported in some recent studies, However, the mechanisms of suppression vary and particularly in soils undergoing regular crop rotation the suppressive character may be related to geological origin and soil physico-chemical characteristics (Almario et al 2013). Hence, mineral nutrition seems to play an important role in crop health. Pathogen infection in plants impairs their physiology, and affects nutrient uptake and assimilation, translocation from the root to the shoot and also utilization (Marschner, 1995). Organisms infecting the vascular system of the plants can impair nutrient translocation and utilization. Root infections by soil borne pathogens reduce the ability of the root to provide the plant with water and nutrients (Huber and Graham, 1999). This effect is more serious when the levels of nutrients are marginal and also for immobile nutrients.

The effect of micronutrients on reducing the severity of diseases can be attributed to the involvement in physiology and biochemistry of the plant, as many of the essential micronutrients are involved in many processes that can affect the response of plants to pathogens (Marschner, 1995). Micronutrients play an important role in plant metabolism by affecting the phenolics and lignin content and also membrane stability (Graham and Webb, 1991). Wiese et al. (2003) introduced the term chemically-induced resistance (CIR) to describe the systemic resistance after application of synthetic compounds. This resistance is related to the formation of certain structural barriers such as lignification, induction of pathogenesis related proteins and conditioning of the plants (Graham and Webb, 1991). Systemic induced resistance (SIR) has been found to be induced by foliar sprays of nutrients such as phosphates, K and N. Research findings indicate that the mechanism for resistance is present in susceptible plants and it can be induced by simple inorganic chemicals, and that this induced resistance is not pest-specific. Since the interaction of nutrients and disease pathogens is complex role of important nutrients in relation to plant health with emphasis on potato crop based on available scientific literature and observations is described in this article.

Nitrogen is important for growth of potato vines and leaf formation to ensure optimal photosynthate production in the leaves for high yields. Nitrogen excess causes delayed maturity, excessive top growth, hollow heart & growth cracks, increased susceptibility to biotic diseases, reduced tuber specific gravity and delayed senescence before harvest. There is an extensive literature about the relationship of N nutrition on disease incidence and its role in disease resistance And their the effect of N is quite variable in the literature. These differences may be due to the form of N nutrition of the host the type of pathogen or the developmental stage of N application (Carballo et al., 1994).

Nitrogen can affect the phenolics content of plants, which are precursors of lignin. Potatoes deficient in either N or P are more susceptible to early blight (*Alternaria solani*). It is recommended to spray urea along with fungicides (to improve N status) for better control of early blight in potato However, over fertilization with N stimulates excessive, weak vegetative growth that can increase the incidence of various diseases. Nitrate N can moderate the severity of black scurf (*Rhizoctonia solani*) in potatoes, root rots of beans and peas, and foot rot in wheat, while ammonium N aggravates these diseases. However, soil-borne pathogens such as potato scab (*Streptomyces scabies*) and early dying of potatoes are aggravated by NO_3-N and moderated by NH_4-N. Some work has shown that using a nitrification inhibitor to maintain higher ratios of NH_4-N to NO_3-N has reduced the incidence of *Verticillium* wilt, but increased the incidence of *Rhizoctonia* canker. This may be a desirable outcome if other steps can be taken to control the *Rhizoctonia*. The subject is quite complex and more research is needed to find a specific mechanism that explains these observations. The form of N is also important in plant

Phosphorus is a constituent of many organic molecules of the cell (deoxyribonucleic acid (DNA), ribonucleic acid (RNA), adenosine triphosphate (ATP) and phospholipids) and is also involved in many metabolic processes in the plants and pathogens. Phosphorus affects the tuber number, root and shoot growth and dry matter in tubers. Phosphorus is an essential component for starch synthesis, transport and storage. It produces tubers of uniform size, boosts bulking and increases the tuber dry matter content and starch levels yield of tubers. Improves storage potential of tubers and reduces storage diseases. Potatoes deficient in either N or P are more susceptible to early blight (*Alternaria solani*). Davis et al. (1976) report that growing potatoes without any P fertilizer substantially increased scab compared to the other four P treatments, which ranged from 84 to 336 kg ha^{-1} P_2O_5. However scab could not be reduced by increasing or decreasing the standard rate of phosphorus.

Potassium has an important role in the control of the plant water status and ionic concentrations inside plant tissues, including stomata. As a result of the improved cell strength that potassium provides, stress such as frost can be better tolerated, as study in India shows (Trehan et al. 2007). Under deficiency metabolic functions of K in plant physiology are disturbed metabolic and plants become susceptible to diseases. Under K deficiency synthesis of proteins, starch and cellulose is impaired and low-molecular-weight organic compounds are accumulated. However, potassium decreases the susceptibility of host plants up to the optimal level for growth only and beyond this point, there is no further increase in resistance which can be achieved by increasing the supply of K and its contents in plants (Huber and Graham, 1999). Optimum potassium nutrition has been reported to be associated with reduce the incidence of late blight, stem end rotp,otato mosaic virus and potato leaf roll virus.

Calcium is an important component of the cell wall structure and its deficiency interferes with root growth, causes membrane leakage of low-molecular weight compounds causes deformation of foliage growth tips, and may reduce quality of the tubers. Reduction in calcium concentrations in the tissues increases the chances of infections by the fungi which preferentially invade the xylem Leakage of low-molecular weight compounds, e.g. sugars and amino acids, from the cytoplasm to the apoplast, may stimulate the infection by the pathogens (Marschner, 1995). Plant tissues low in Ca are also much more susceptible than tissues with normal Ca levels to parasitic diseases during storage and calcium-deficient potato tubers have reduced storage capability.). Lambert et al. (2005) suggested a positive relationship between higher periderm Ca content and potato scab. Work with potatoes and citrus trees showed that infection by common scab (*Streptomyces scabies*) in potatoes and *Phytophthora* root rot (*P. parasitica*) in citrus was increased by high levels of K fertilization probably caused a shortage of Ca., Tuber calcium has also been reported to affect the incidence of bacterial soft rot.

Magnesium is a key element in photosynthesis as it is present in the centre of each chlorophyll molecule. It is also involved in various key steps of sugar and protein production as well as the transport of sugars in the form of sucrose from the leaves to the tubers. When Mg is deficient leaves become yellow and brown, wilt and die. The older leaves develop pale interveinal chlorotic patches in a herringbone pattern along the main vein. These patches will turn brown as the deficiency continues. The leaf margin often remains green and may curl up and become brittle. Severe magnesium deficiency can reduce yields by up to 15%. Magnesium-deficient Potato tubers have poor skin finish of the tubers and are more easily damaged during lifting and storage. Excessive magnesium results in reduced calcium uptake, with the symptoms related to calcium deficiency.

Sulfur helps to reduce the level of common and powdery scab. Elemental sulphur and Kieserite fertilization have been demonstrated to improve potato tuber yield quality and showed resistance against *Streptomyces scabies.* The effect on bacterial infection effect was attributed to reduced soil pH (Klikocka 2005). Similarly application of sulphur (900 Kg/ha) to soil brings the soil pH to 5.2 and reduces the incidence of common scab of potato cause by *Streptomyces scabies* (Davis et al. 1974). A decreased in soil pH value due to sulphur supplementation has been reported to be associated with potato tuber resistance to *Streptomyces scabies* pathogen (Grocholl and Scheid 2002) demonstrated that bringing soil pH down through sulphur dressing alleviated the symptoms of tuber infection by common scab by approximately 22%, and by 15% .

Role of micronutrients is well accepted in disease management/control. The usefulness of Cu for disease prevention and correction was well known by the year 1900 even before. Foliar sprays of micronutrients (Zn, Cu, Zn + Cu + Mo) proved effective in reducing late blight in a study conducted by Treahn et al. (1995). This was about 30 years before it was reported to be an essential nutrient. Plants which have low tissue levels of Cu (by nutrient standards) are more susceptible to various diseases. **Copper** can act as direct inhibitor as well as enable plants to better defend themselves from disease and this is evident from a number of copper based fungicides being used for the control of different diseases in crops including potatoes.

Manganese boosts bulking, improves skin finish increases starch levels, dry matter content and increases the yield of tubers and its deficiency results in interveinal yellowing on entire leaflets usually starting on younger leaves. It plays a role in lignin biosynthesis, phenol biosynthesis, photosynthesis and several other functions (Marschner, 1995; Graham and Webb, 1991). Manganese improves disease resistance and is probably the most studied micronutrient about its effects on disease and is important in the development of resistance in plants to both root and foliar diseases (Graham and Webb, 1991; Huber and Graham, 1999; Heckman et al., 2003). Jabonski (2006) observed that rhizoctoniose of tubers increased after simplification of soil cultivation. Although the disease may cause important losses, little work has been done on nutritional effects. Manganese at 62 kg ha^{-1} reduced from 25% to 11% the incidence of *Rhizoctonia solani* black scurf on tubers.

Zinc plays an important role in protein and starch synthesis, and therefore a low zinc concentration induces accumulation of amino acids and reducing sugars in plant tissue (Marschner, 1995; Römheld and Marschner, 1991). Zinc is essential to the integrity and stability of plant membranes and it is thought to help prevent leakage of compounds leakage of sugar onto the plant surfaces, can enhance the successful invasion of fungus and bacteria. Since zinc deficiency causes accumulation of amino acids in plants feeding intensity and reproduction by sucking insects tend to be higher on plants with a higher amino acid content. Variable effects have been observed on disease incidence in different crops in response to zinc nutrition. In most cases, Zn reduced disease severity may be due to the toxic effect of Zn on the pathogen directly and not through the plant's metabolism (Graham and Webb, 1991).

Boron is the least understood essential micronutrient for plant growth and development and its deficiency is the most widespread micronutrient deficiency in the world (Brown et al., 2002;). Boron plays a direct role in cell wall structure and stability and has a beneficial effect on reducing disease severity. The role of that B in reducing disease susceptibility could be due to its role in cell membrane permeability, stability or its role in metabolism of phenolics or lignin (Brown et al., 2002; Blevins and Lukaszewski, 1998). Boron affects the severity of potato wart diseases. Seed treatment with 3% boric acid is a standard recommendation for controlling seed borne diseases.

Although **silicon** is not considered to be an essential element except for members of the *Equisitaceae* family (Marschner, 1995)it is the second most abundant element in the earth's soil and is a component of plants it. Silicon is additions in soils having low soluble Si content show an improved growth, higher yield, reduced mineral toxicities and better disease and insect resistance (Graham and Webb, 1991; Alvarez and Datnoff, 2001; Seebold et al., 2000, 2004). Crops such as rice and sugarcane which accumulate high levels of Si in plant tissue are fertilized routinely with calcium silicate slag to produce higher yields and higher disease resistance. It is believed that Si creates a physical barrier which can restrict fungal hyphae penetration, or it may induce accumulation of antifungal compounds such as flavonoid and diterpenoid phytoalexins which can degrade fungal and bacterial cell walls (Alvarez and Datnoff, 2001; Brescht et al., 2004).

Iron is essential for photosynthesis and plant metabolism. Thus it is important for early leaf development, strong growth and crop productivity. Iron is one of the most important micronutrients for both animals and humans and the interaction between Fe nutrition and human or animal health has been well studied. Iron deficiency results in the interveinal chlorosis while the veins remain green. In cases of severe deficiency, the entire leaf is chlorotic. Iron deficiency symptoms firstly appear on the youngest leaves. Iron deficiency mainly occurs in calcareous soils and in other soils with a high pH-value due to the low availability of Fe. In specific clay soils Fe deficiency is also the consequence of its fixation. The role of Fe in disease resistance is not well studied in plants. In recent study (Sagova et al. 2015) low severity of common scab was associated with low content of soil C, N, C/N, Ca and Fe suggesting that oligotrophic conditions may be favorable to common scab suppression.

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Chapter 18

Seed Plot Technique: An IDM Approach for Quality Potato Seed Production

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Introduction

This technique was developed in 1970s to enable healthy seed potato production in the sub-tropical Indian plains under low aphid period. This technique aided by biotechnological approaches for virus elimination, micro-propagation and effective viral diagnostics has sustained the National Potato Seed Production Programme by producing about 2600 tonnes of breeder's seed annually. This breeder's seed is further multiplied to about 4,32,000 tonnes of certified seed by the State Departments of Agriculture/ Horticulture. Thus, the country saves about 484 million US dollars because most Asian countries like Pakistan, Bangladesh and even China continue to import seed potatoes from Europe. The decentralization of potato breeding from hills to plains in India through the seed plot technique enabled the development of varieties suited to different agro-climatic regions of the country. The area under seed potato production also increased by 12 times and enabled the availability of seed potato throughout the country in proper physiological state. Tissue culture efforts are being made to improve seed health standards and reduce the time required for production of breeder's seed by employing in vitro techniques of meristem culture and micro-propagation. Presently, about 25 per cent of Breeder's seed production programme is fed annually by high-tech seed potato production (micro-tubers, micro-plants and aeroponically produced mini- tubers). It is proposed to produce 100 per cent of breeder's seed through tissue culture propagated material in the years to come. The history, background and principle of "Seed Plot Technique" are given below.

- Aphid (*Myzus persicae*) is major vector responsible for spread of viral diseases in potato.
- However, in the hills they were found either absent or their population was below critical level during the crop season due to cool climate. Therefore, hills became popular for the production of quality seed in India.
- Due to this, the demand for hill seed was increased among the plain states. Seed from Northern hills had higher productivity than the seed produced in spring in the plains. As a result a channel of seed movement from hills to plains was established.
- Therefore, seed stocks from Himachal Pradesh, Jammu-Kashmir, Garhwal hills and Darjeeling were used to be transported to far off states like Maharashtra, Karnataka, MP, UP, WB and Orissa.
- Seed stocks in hills used to be harvested in September- October. Due to their dormant nature these could not be used immediately for planting in the plains during October-November. Therefore, a system of late planting in last week of December (spring) was started in the plains.
- The produce of this crop is used to be preserved in cold stores or at farm houses for next early or main crop. However, due to late planting the crop get exposed to high population of aphids which resulted in accumulation of aphid transmitted viruses in the seed stocks causing poor productivity during subsequent generations

- Keeping in view the limited area for healthy seed production in the hills and infiltration of viruses in late grown spring crop in the plains, efforts were made to survey the important potato growing regions of the country from 1952 onwards.
- During the survey, a remarkable consistency in the aphid population build up was noticed. In the North-Western and Central Indo-Gangetic plains the population remained very low during October to December. Aphids crossed their critical limit (20 aphids per 100 compound leaves) in these regions only after last week of December in North Western plains and second week of January in North-Eastern plains.
- Based on the survey, Central Potato Research Institute developed a technique called "seed plot technique" during 1959. The principle of this technique is growing of seed potato crop using healthy seed during low aphid period from October to first week of January coupled with integrated pest and disease management, roguing and dehaulming the seed crop during the last week of December or second week of January before aphids reach the critical level.
- Thus, this technique opened a window in sub-tropical plains for quality seed production.

Impact of the seed plot technique

- The seed production could be taken up in larger areas under sub-tropical plains.
- Farmers could get right physiological age seed at the time of planting, as it does not have any dormancy problem. Plant emerges within 20 to 30 days from the seed tubers produced in plains and cold stored seed as compared to hill seed where it takes 45 to 50 days.
- The soil-borne pathogens from hills are not carried to the plains.

Pre-requisites for adoption of seed plot technique

- Areas selected for seed production should have low aphid population or aphid free period of 75 days minimum after planting the crop.

Seed crop planting schedule for different locations

S. No.	Location	Planting date
1.	Punjab	15th October
2.	Haryana, Rajesthan and western UP	25th October
3.	Eastern UP, Bihar, WB and Orissa	5th November

Haulms killing

- Irrigation should be withheld 7 to 10 days before haulms killing i.e. third week of December in North-Western plains and first week of January in North-Eastern plains.
- In the seed crop, haulms should be killed before aphids reach the critical level.
- Haulms can be killed by spraying gramoxone @ 2.5 to 3.0 l ha^{-1} or manually by cutting.
- Cover the exposed tubers with soil immediately after haulms killing and check the re-growth of the haulms and remove the re-growth, if any.

Seed crop haulms killing schedule for different locations

S. No.	Location	Haulms killing date
1.	Punjab, Haryana and western UP	end of December
2.	Central UP and MP	10th January
3.	Eastern UP, Bihar, WB and Orissa	by 15th January

Important diseases & their management

1. Viruses

Viruses are extremely small agents, causing disease and can reduce the potato seed yield and quality significantly. Once the plant is infected by virus, it will be transmitted to generation after generation since potato is being vegetatively propagated material. In most practical cases, viruses can only be eliminated by eradication of infected plants in seed production programme. Virus infection are not always visible on plants, several detection methods are available, some more dependable than others. Choice of method depends on the practically desired degree of virus reduction in a field and on a facilities available. There are seven common potato viruses found to infect the potato crop alone or in combination of two or more in India viz., PVX, PVS, PVY(N,O& NTN), PVA, PVM, PLRV, PSTVd and PALCV. Besides these potato stem necrosis (PSN) caused by a tospo virus are also economically important in central India.

Viruses and their symptoms for identification

Name of virus	Symptoms
Potato virus X (PVX) Mechanical/contact	Mild to moderately severe perceptible mottling of leaves with light to dark green patches interspersed with normal green colour. Sometime stunted plant growth with chlorosis. Latent in many varieties.
Potato virus S (PVS) (Contact as well as non-persistently by aphids)	Mild imperceptible mottling of leaves with light green patches interspersed with veinal green colour. Usually latent.
Potato virus M (PVM) (Contact as well as non-persistently by aphids)	Mild mosaic/mottling of young leaves and upward rolling of upper leaves with wavy margins, slight leaf chlorosis.
Potato virus A (PVA) (Non-persistently by aphids)	Mosaic faint mottling, sometimes leaf distortions, top necrosis in some varieties, rarely rugosity, shiny leaves.
Potato virus Y (PVY) (Non-persistently by aphids)	Mottling of leaves with light to dark green patches interspersed with normal green colour and severe mosaic. Production of necrotic spots and veinal necrosis followed by leaf drop streaks. Rugosity, twisting of leaves with slight inter-veinal cuppings
Potato apical leaf curl virus (PALCV) (White-fly transmitted)	In severe cases it can be identified easily, but such symptoms are expressed only when the concentration of virus is very high. However, in many cases the symptoms are recovered as the maximum temperature fall below 28˚C. If the virus concentration is less it produces leaf rolling, which will be just like symptoms caused by Potato virus M
Potato acuba mosaic virus (Aphid transmitted)	Symptoms are observed in old varieties, bright yellow spots/patches on old leaves. Stunting of the plants.
Rugose mosaic (X+Y)	It is due to combined infection of viruses X and Y. Plants show severe mosaic and rugosity of leaves and stunted plant growth. Leaves curl upward while lower leaves show yellowness and necrosis.
Crinkle (X+A)	Caused by combined infection of viruses X and A with heavy blotching of infected leaves which get distorted with wavy margins and the leave lamina shows complete crinkling.
Potato leaf roll virus (Persistently by aphids)	Varying degree of rolling is observed. Lower leaves roll first followed by upper ones. The lower leaves become leathery with bronze margins and on pressing, between fingers they give rustling sound. Stiffness of older leaves.
Potato stem necrosis virus (PSNV) (transmitted by thrips)	Necrosis of petiole, veins and stems at high temperatures. Stem losses turgidity and becomes brittle. Apical necrosis progress downward as browning and drying of foliage. Later on juvenile plants wither and wilt.
Potato spindle tuber viroid (PSTVd) (transmitted by TPS/ aphids/contact)	Shortening of petioles which are sub tended at 45˚ angle, chlorotic with stunted growth, leaflets twisted and tubers become spindle shaped with prominent eye brows.

2. Fungal, bacterial and phytoplasma diseases

There are two types of diseases i.e. foliar and tuber-borne diseases. In foliar diseases late blight, early blight, Phoma blight, Cercospora leaf spots and wilts are common. In tuber borne diseases brown rot, common scab, powdery scab, black scurf, late blight, charocal rot, pink rot, dry rot and wet rot are common. The symptoms of these diseases for identifications are as under

Fungal and bacterial diseases and their symptoms for identification

Diseases	Symptoms
Foliar Diseases	
Late blight *(Phytophthora infestans)*	The water soaked patches with whitish cottony growth along the lesion margins on the underside of leaflets in the early morning hours. Skin of tuber become brown, patchy and shrink. Discoloration of underneath tissue of tuber.
Early blight *(Alternaria solani)*	The brown to black, oval, large and circular spots with concentric rings.
Phoma blight *(Phoma exigua, P. sorghina)*	Small spots are brown to black, oval to irregular with variable size.
Leaf blotch (*Cercospora solani-tuberosi)*	Small chlorotic spots on the upper surface of leaves and a violet mildew on lower surface.
Wilts	
Fusarium wilt *(Fusarium oxysporum)*	Yellowing of margins of lower leaves followed by entire foliage, wilting of few stems followed by entire plant.
Bacterial wilt/brown rot *(Ralstonia solanacearum)*	Dropping and rolling of leaves before wilting, succulent portion of plant becomes flaccid and droops. Wilting becomes permanent. A distinct brown discoloration in the vascular rings of cut tuber with slimy bacterial ooze.
Sclerotium wilt (*Sclerotium rolfsii*)	Light yellowing, dropping and stunting of juvenile plants. Collar region of the stem infected with white mycelium which later on converted into brown mustard like sclerotia. The entire plants wilted and topple.
Tuber borne disease	
Charcoal rot *(Macrophomina phaseolina)*	A high temperature disease at harvest. Tubers show black areas around the eyes and lenticels, flesh show black patches.
Wart *(Synchytrium endobioticum)*	Prominent wart like outgrowth on the tubers which resemble cauliflower.
Common scab (*Streptomyces scabies*)	Small radish or brownish spots on tuber surface, spots enlarge into circular or irregular lesions with sunken corky spot or pitted lesions having deep star shaped cracks or russetting of tuber surface.
Powdery scab (*Spongospora subterranea)*	Small coloured blisters like pimples on tuber surface, pustules become dark and epidermis ruptures releasing brown powdery spore mass.
Black scurf (*Rhizoctonia solani*)	Chocolate coloured, crusty scurf like irregular sclerotial mass on the surface of the tubers.
Dry rot (*Fusarium solani, F. equiseti*)	Small sunken circular, oval or irregular brown lesions, flesh shows light brown discolouration and white cottony fungal growth.
Soft rot (*Erwinia carotovora*)	Water socked lesions on tuber, tissue turns soft and pulpy/slimy, surface discolours with wrinkles and depressions.

Pink rot (*Phytophthora erythroseptica*)	Blackening around lenticels and eyes, discolouration of flesh when cut and turns pink after exposure to air within few minutes and later on turns black.

Phytoplasma diseases and their symptoms for identification

Marginal flavescence (Transmitted by leaf hopper)	Marginal chlorosis of the top leaflets, puckering and slightly rough and thick stunted growth, profuse rooting few tubers at the base of the stem.
Purple top roll (Transmitted by leaf hopper)	Rolling of the basal part of the top leaflets accompanied by purple pigmentation, short internodes and swelling of nodes, numerous auxiliary branches.
Witch's broom (Transmitted by leaf hopper)	Numerous thin stems with simple leaves giving an appearance of 'broom'.
Potato phyllody (Transmitted by leaf hopper)	Petals become green giving a phyllody appearance.

Integrated Disease Management

Chemical control

- Apply phorate 10G @10 kg ha^{-1} at earthing up to control sucking pests and white grubs.
- Drench the ridges with chlorpyriphos 20 EC @2.5 liter ha^{-1} if damage of cutworm is observed.
- Spray the crop with 2.5 kg ha^{-1} mancozeb from third week of June onward at 10 days interval in the hills and 15th November onward in the plains as preventive measures. Apply of mixture of cymoxanil 8%+mancozeb 64% @2.5 kg ha^{-1} when late blight is observed in the crop. Subsequent spray should be need based.
- Spray oxydemeton-methyl 25% EC @ 1.25 liter ha^{-1} and imidacloprid @3 ml per 10 liter of water alternatively to control vectors.
- Spray carbaryl @ 2.5 kg ha^{-1} to control defoliators i.e. epilachna beetle and semi-looper/catterpillars.

The plant protection schedule against diseases and pests are as under:-

Plant protection schedule for raising seed crop

Chemical	Insect/disease	Doses/ ha	Time of application
Phorate	Sucking and soil insect-pest	10 kg	During earthing up
Chlorpyriphos	Cutworms and white grubs	2.5 liter	Drench the ridges when damage is noticed.
Oxydemeton-methyl	Aphids, jassids and white flies	1.25 liter	Every 10 days from third week of May till first week of August in hills. At 10 days interval from second week of November to thrird week of December in Uttar Pradesh, Pinjab, Haryana and first week of January in Madhya Pradesh, Bihar and West Bengal.
Imidaclorpid	Aphids, jassids, white flies and thrips	@3ml per 10 liter of water	One or two spray at 20 days interval alternated with oxydemeton-methyl.
Mancozeb or propineb	Early, Late blight, Phoma leaf spot	2.5 kg	Third week of June and first week of July combined with insecticide at 8 to 10 days interval in hills. Second week of November onward at 8 to 10 days interval in plains.
Cymoxanil 8%+mancozeb 64%	Late blight	2.5 kg	In second week of July on noticing the late blight in hills and on noticing the late blight in plains.
Carbaryl	Epilachna beetle	2.5 kg	As and when damage on foliage is noticed.

Thiodan	Defoliating insects	1.5 liter	As and when damage on foliage is noticed.
Carbofuron	Cyst nematode	65 kg	Soil application at the time of planting.

Cultural practice

The good cultural practices are normally the basis of all efforts to control the diseases and pests. These cultural practices are:

- The soil tillage brings the soil into better physical condition for plant growth and quick emergence, destruction of ground keeper and weeds which carry potato pathogens. It exposes the larvae and pupae of the insect for picking by the birds which help in reducing the insect population.
- **Hot** weather cultivation/summer ploughing of seed plot reduces the population of pathogens and desiccates the eggs of soil pests
- Green manuring not only increases the potato yield but also helps in reducing the incidence of some soil-borne diseases like black scurf and common scab etc.
- It also helps in increasing the population of antagonistic micro-organisms.
- Rogueing is done to remove diseased and off-type plants which harbour different pathogens and insects.
- Rogueing of diseased plants should be done as soon as the symptoms are visible in order to remove the source of infection and to prevent the spread of diseases.
- Haulms destruction is done to avoid spread of diseases caused by fungi (*Phytophthora, Alternaria* and *Phoma*) and viruses.
- The common practice of haulms destructions is manual cutting or killing by spraying of herbicides 15 to 20 days before harvesting.
- It is always advisable to use clean seed free from rotted or partially infected tubers. Seed tubers must be thoroughly checked after withdrawal from cold storage and before planting for disease freedom.

Chapter 19

Production of Disease free Planting Material through Hi-Tech Seed Production

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Introduction

Potato is one of the world's most important non-cereal high yielding horticultural food crop, which is native of Peru-Bolivia in the Andes (South America) and seems to have been introduced in India from Europe by Portuguese in the early 17th century. India has taken a giant leap in terms of potato area (1.96 million ha) and production (45.3 million tons) as compared to 1949-50, the year of establishment of CPRI, when the total production was 1.54 million tons from an area of 0.234 million ha. Currently the national average productivity of potato is 22.76 tones/ha. As of now, country is well placed to meet the emerging challenges for diversifying the potato production and stabilizing its market. At present the country has an area of approximately 1.96 million ha under potato and requires about 4.9 million tons of quality seed at the uniform seed rate of 2.5 t/ha. However, Central Potato Research Institute is producing only about 3500 tons of breeder seed per annum. In potato cultivation, potato seed is most expensive input accounting for 40 to 50 percent of the production cost. Moreover, a high rate of degeneration causes the seed to deteriorate after a few multiplications. Potato seed tuber is vegetatively propagated and most essential input in successful potato cultivation and accounts for about 50% of the total cost of cultivation. Degeneration of potato seed stocks due to virus diseases is most limiting factor in potato seed production. Therefore, seed stocks should be free from viral and other seed-borne diseases. To maintain the higher productivity, it is essential to have a scientifically sound seed production system through which high degree of health standard of the seed crop is maintained

A well-organized scientific strategy of breeder seed production was envisaged in 1962-63 through clonal selection, tuber indexing and stage-wise field multiplication of healthy indexed tubers in subsequent four generations. Indexing of tubers against contagious and insect transmitted viruses is done by ELISA against PVX, PVS, PVM, PVA, PVY and PLRV. Crop inspection, rogueing of diseased plants and immuno-diagnosis are the regular features of the programme to improve the seed quality. The breeder seed produced by CPRI is supplied to various state Govt. organizations for further multiplication in three more cycles' viz., Foundation-1, Foundation-2 and Certified seed under strict health standards. However, the current status of breeder seed multiplication by the state government is not as per the desired seed multiplication chain. There is huge shortage of certified seed in the country. The conventional system has limitations like i) low rate of multiplication ii) requires more number of disease free propagules in the initial stage iii) development of 100% healthy seed stock from infected material is slow and time taking iv) progressive accumulation of degenerative viral diseases is there in each field exposure and v) several field multiplications of initial disease-free material (7 years). The only way-out to overcome the above said limitations is augmentation of seed production through Hi-tech system to improve the quality and to reduce the field exposure. Potato has readily responded to the totipotent nature of plant tissues in micro-propagation and it has become easy to export/import disease free planting material without any risk of importation of deadly diseases and the exchange of plant material.

Needs of Hi-tech seed potato production

- ❖ Tropical countries or for those countries which do not have isolated and virus free potato growing areas.
- ❖ Those countries which want early certification for seed production.
- ❖ Countries having explosive increase in new potato growing areas.
- ❖ Early supply of pre nucleus/nucleus seed to commercial growers by reducing the field exposure time.
- ❖ Improved tuber quality.
- ❖ Reducing the load of degenerative diseases.
- ❖ Utilize the resources and trained manpower year the round.
- ❖ Taking critical decision like choice of propagules, tuber inducing agent, environment, medium components and economics of scale.
- ❖ Vertical growth and reduce pressure on land.

Seed production through hi-tech system has been started by Central Potato Research Institute Shimla in the recent past. Under this system, there are three different sub-systems:

i) Micro-plant based seed production system
ii) Micro-tuber based seed production system
iii) Aero-ponic based seed production system

❖ Under hi-tech seed production system, nucleus planting material will be produced in the laboratory under controlled condition. The virus free plants will be used as mother plant for micro-propagation. The micro-plants/micro-tubers will be planted in net-house conditions for production of mini-tubers (G-0). The mini-tubers produced in generation-0 will be multiplied in generation-I at a spacing of 60 x 15 cm. The produce of generation-I is further multiplied in generation-II. The produce of stage IV and generation-II will be called as breeder seed and supplied to public and private organization for further multiplication in three clonal cycles viz. Foundation-1, Foundation-2, Certified Seed. The adoption of hi-tech seed production technologies developed by the Institute has led to opening of more than 20 tissue culture labs throughout the country. Several private seed companies such as M/s Reliance Life Sciences, Navi Mumbai; Cadila Pharmaceuticals Ltd., Ahmedabad; KF Bioplants, Pvt. Ltd., Pune/Banglore; Transgene Bioplants Pvt. Ltd., Chandigarh; Phulwari Bio-Tech Ltd., Chandigarh; Gufic Bioscinece Ltd., Mumbai; Chamal Agritech Ltd., Chandigarh; Elegant Flower Company Pvt. Ltd., Kolkata; Dayal Biotech Pvt. Ltd., Meerut; Merino Industries Ltd., Hapur; Kalindi Agro Biotech Ltd., Gurgaon; Rose-N-Shine Biotech (P) Ltd., Pune; Hindustan Bioenergy Ltd., Lucknow; Vasantdada Sugar Institute, Pune; Technico Agri Sciences Limited, Chandigarh; Sangha Seeds, Jalandhar; Hindustan Bioenergy Ltd., Lucknow; Pallishree Limited, Kolkata; Pallishree Limited, Kolkata; Devleela Biotech, Raipur; Neva Plantations Pvt. Ltd., Kangra; Krishiraj Tissue Culture Nursery, Jalna; Palm Grove Nurseries, Bangalore; Mahindra Subhlabh Services Ltd., Mohali; Dawar Agritech, Kurukshetra; Bhatti Tissue Tech, Jalandhar are taking virus free in-vitro plantlets from CPRI for further multiplication in their seed production programme.

Micropropagation of disease free mother plant

- Soon after varietal release, 10-20 healthy uniform tubers are selected and planted under controlled conditions in the pots in poly/net house for indexing against the viruses. The ideal temperature for plant growth as well as virus multiplication should be 20-25^{0}C. The plants are tested by ELISA for virus freedom after 6 to 7 weeks of planting or 6 to 8 leaf stage. The infected plants with viruses during ELISA testing should be destroyed and only the healthy plants should be retained for further testing by polymerase chain reaction (PCR) for virus freedom. The infected plants obtained during PCR testing are removed. Finally healthy plants obtained during series of testing will be used as mother plant for micropropagation.

Development of healthy mother plants from virus infected plant

Sometimes we may not be getting even a single plant completely free from viruses after releasing of the variety. In such situation, meristem tip culture coupled with thermotherapy has become a powerful and successful tool for virus elimination from infected plants and has been successfully applied in potato for development of virus-free plants.

The plants are tested against potato viruses and viroids like PVX, PVS, PVA, PVY, PVM, PLRV, PALCV and PSTVd through ELISA, EM and PCR. In case, no plant is found free from the virus infection then the plants that are infected with minimum number of viruses are selected for meristem tip culture. Using nodal/sprout cuttings, the *in vitro* stocks of selected plants are developed and further sub-cultured in Ribavarin (20 ppm) modified MS media for chemotherapy. This culture is then given thermotherapy at 37^{o}C and 16 h photo period (120-200 µmol/m^2/s^{-1}) in the culture room for nearly 20 days. Using stereomicroscope, the apical/axillary meristem (0.2 to 0.3 mm) is excised from *in vitro* plants aseptically with the help of sterile scalpel, needle and blade. The excised meristem is grown in the test tubes containing MS medium with growth regulators and incubated in the culture tubes at 25^{o}C and 16 h photo period (120-200 µmol/m^2/s^{-1}) in the culture room until the meristem germinates. The meri-clones are then sub-cultured through nodal cutting after it attains a height of 4-5 cm and the pedigree is maintained. The fully grown mericlones should be tested against potato viruses like PVX, PVS, PVA, PVY, PVM, PLRV, PALCV and PSTVd through ELISA, EM and PCR. The virus-free cultures should be sub-cultured once in every 3-4 weeks so as to get more number of virus-free micro-plants. The micro-plants should be hardened for 2 to 3 weeks in the poly/net house before planting in the pots filled with peat moss under mist in poly house. The plants are further tested against all above said potato viruses through ELISA, EM and PCR after 40-45 days of planting. Remove the infected plants obtained during testing and retain only the healthy plants. Finally healthy plants obtained during series of testing will be used as mother plant for micro-propagation.

Micro-plant based seed production system

Three to four weeks old helthy microplants are transferred to protrays filled with sterilized peat moss. The microplants can be planted in portray with root or without root (cuttings). For planting with root, the media sticking to the root should be properly washed off. After transplanting, drenching is done with the mancozeb (0.25%) solution. The portrays are then transferred to the growth chambers and kept in dark for 48 h subsequently in 16 h photoperiod for 2-3 days. Once the plantlets are established in portrays (4-5 days), these portrays are transferred to hardening chamber and kept at 27^{o}C for 10-15 days. The hardened plantlets should be removed from portrays along with peat moss and transplanted on nursery beds in mixture of soil, sand and FYM (2:1:1) in rows at 30 x 10 cm spacing under insect proof net house condition.

5% of the plants are tested by ELISA. Rogue out all virus infected plants, off-type plants, abnormal and stunted observed during inspection**.** Allow the microplant crop to mature and harvest the minitubers. Each microplant shall yield 6-8 minitubers. Seed crop should be harvested 15 to 20 days after haulms cutting when the tuber skin is hardened. The seed tubers thus produced are minitubers. Curing is done by keeping the seed tubers in heap for about 15 to 20 days in a cool shady place. After curing, the seed tuber should be graded into >3 g and treat with 3 per cent boric acid solution for 10-15 minutes to prevent surface borne pathogen inoculum. Minitubers harvested from microplants (Generation-0) are called as nucleus seed. Store the minitubers in country store in hills while cold store at 3-4°C in the plains. Minitubers weighing >3 g will be planted in Generation-l in the field during next season. Whereas, <3 g minitubers may be recycled once again in Generation-0 under controlled poly/net house conditions if the crop meets the G-0 criteria, the produce can be used for raising G-1 crop in the field.

Micro-tuber based seed production system

The micro-plants are tested for virus freedom before initiating micro-tuber production. The virus-free stock plants are mass multiplied through nodal cuttings on semisolid MS medium in culture tubes (25 x 150 mm) following the standard procedure up to 10 cycles. 3-4 weeks old explants are transferred into 250 ml conical flasks or culture bottles containing 25-35 ml liquid MS medium without agar. The culture tubes are incubated at 25^{0}C and 16 h photo period (120-200 µmol/m^{2}/s^{-1}) in the culture room. After 3-4 weeks of incubation, the unutilized liquid propagation medium is decant from the conical flask/culture bottle under aseptic conditions and 30 ml of microtuber induction medium is poured into it. The microtuber induction medium is based on MS basal media supplemented with 10 mgl^{-1} N^{6}-benzyladenine (BAP) and 80 gl^{-1} sucrose/commercial sugar. After adding induction medium, the cultures are incubated under complete dark condition at 15°C for 60 to 90 days depending on the genotype. Microtubers develop epigeally at the apical as well as axillary buds of the shoots. In general, 15 to 20 microtubers weighing 50-300 mg are produced in each flask/culture bottles. Before harvesting, greening of the microtubers is done in the culture room by incubating microtuber induced cultures under 16 h photoperiod (approximately 30 µmol m^{-2} s^{-1}light intensity) at 22-24°C for 10 to 15 days. Then carefully remove the cultures along with microtubers from conical flasks or culture bottles and manually harvest the green microtubers. Avoid damaging the microtubers, especially the thin periderm during harvest. The harvested microtubers are then washed and treated with 0.25% mancozeb for 10 minutes, and allowed to dry in the dark at 20^{0}C for 2 days. Grading of microtubers in <4m, 4-6mm and >6 mm should be done while packing. Pack the treated microtubers in perforated polythene covers and store in a refrigerator for 4-5 months until planting. Take out the microtubers from the refrigerator after about one month before planting for breaking the dormancy.

Aeroponic seed production system

The conventional system is quite effective but it has low multiplication rate and higher field exposure increases the risk of viral infection. Production of potato through aeroponics promotes availability of healthy seed potatoes. In addition, aeroponics allows easy identification and roguing of diseased plants. Furthermore, potato seed produced through this method could enjoy accelerated growth due to improved aeration of the roots and optimal nutrient uptake obtained from an atomized nutrient solution. Keeping this in view, tissue culture based system of quality seed production was integrated with breeder seed production programme. The conventional way of producing potato minitubers through micro propagation is to multiply *in vitro* material in insect proof net houses. The conventional method uses substrate made of soil and mixture of various components. This method usually produces 10-12 minitubers per plant depending on cultivar. The aeroponic system offers the potential to increase production in terms of number of minitubers per plant from three to four times. Aeroponics is the process of growing plants in an air mist environment without the use of soil or an aggregate medium. Since water is used in aeroponics to transmit nutrients to the plants. In aeroponics, plants growth is facilitated by suspending them in air, in an enclosed environment, and providing necessary nutrients by spraying on roots. The nutrient solution is continuously re-circulated through the system and monitored for pH and EC and amended whenever necessary. There is a tremendous scope to increase healthy seed production vertically by adopting aeroponic technology of seed system where increase in multiplication rate from 5:1 to 50:1 can be achieved. We do not need any excess area for aeroponic based healthy seed production. Only one percent of conventional water usage is required which is basically recycled water. The top portion of the plant is exposed to the open air and a light source. The aeroponic seed production system has very high productivity. It prevents exposure to unfavourable soil conditions and the minitubers harvested from this system will be free from all soil-borne pathogens. Desired size of minitubers can be harvested sequentially and this could reduce the cost of minituber production.

Various systems adopted for the production of pre-basic seeds of potato, the hi-tech system appears to be the best in many respects. Considering the potential benefits of the system such as rapid production of seed, spacious, healthy and clean material, good nutrient monitoring system, improvement of growth and survival rate of plantlets, constant air circulation and ecologically friendly, this system has a potential of revolutionizing potato seed production industry.

Hi-tech seed production system

Suggested Readings

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Chapter 20

Technology and Extension Interventions for Disease and Pest Management in Potato

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Introduction

Fruit and vegetables cultivation is the most important component of Indian Horticulture. Vegetables provide a major chunk of vitamins and minerals to the masses, thus contribute in securing Food and Nutritional security to the people of India. As per dietary guidelines of Indian Council of Medical Research (ICMR), an adult individual should consume at least 300 g of vegetables in a day which include 50 g green leafy vegetables, 50 g root and tubers and 200 g other vegetables (ICMR, 2011). India is the 2nd largest vegetable producer of the world only behind China. During the year 2014-15, India produced 162.9 million t of vegetable from an area of 9.4 million ha with an average productivity of 17.3 t/ha. Potato is the most important vegetable of the country contributing to the extent of 21% in terms of area & 25.5% of total production of vegetable (Indian horticulture Database, 2014). India is the 2^{nd} largest potato producing country of the world. Potato production in India stood at 45.95 million t during 2014-15 (Directorate of Economics and Statistics, 2016). Among Indian states, Uttar Pradesh is the highest potato producing state followed by West Bengal and Bihar. The yield of potato in India in recent times is hovering around 20-22 t/ha which is very low as compared with many European and American countries. There are several pest and diseases attacking the crop in field as well as storage. They cause a lot of loss in yield by affecting different parts like stem, leaves, tuber etc. Late blight, a major disease of potato can cause very heavy loss to the crop if not controlled timely.

India would require nearly 125 million t of potato in the year 2050 which would need 3.62 million ha area with an average productivity of 34.1 t/ha (ICAR-CPRI vision 2050). Thus, increasing potato productivity from current 22 t/ha to 34.5 t/ha would be a huge challenge. Along with adoption of high yielding potato varieties, disease and pest management will contribute a lot in achieving the targeted production and productivity. In this regard, several technology interventions are required at grass root level for better management and control of diseases and pests in potato by the farmers. Intervention is a project, program, policy, activity, or shock that causes an action meant to generate a desirable change in present situation. Transfer of diseases and pest management technologies to farmers through various innovative extension methods will be key component for increasing potato productivity in the country.

Technology interventions for potato disease and pest management

There are several diseases and pests of potato which need to be managed properly to avoid loss in yield. Late blight, bacterial wilt, common scab, black scurf etc are among major diseases of potato. Aphids, white flies, cut worm, white grubs and potato tuber moths are some main pests of the crop. ICAR-Central Potato Research Institute, Shimla and its seven regional centers are involved in development of technologies for managing these diseases and pests. Some of the important technologies are discussed below:

1. **Development of disease resistant varieties**: CPRI has developed more than 50 high yielding potato varieties for different regions and seasons. Nearly all the potato varieties developed by the institute has medium to high level of resistance to late blight. Varieties like Kufri Anand, Kufri Kanchan and Kufri giriraj are immune to wart disease. Kufri Surya is resistant to hopper burn and also heat tolerant variety. Kufri swarna is highly resistant to potato cyst nematods (PCN) and therefore advised to grow in Nilgiri hills.
2. **Late blight management technology**: The institute has developed several techniques to manage this menacing disease. *Jhulsacast* and *Indoblightcast* models of late blight forecasting have been developed and advisories are sent to the farmers through radio, television, newspapers and other means of communication. Nearly all the potato varieties developed by the institute has medium to high level of resistance to late blight. Moreover, spray schedule of fungicides has been developed for both plains and hilly regions to manage this disease after its appearance.
3. **Management of soil and tuber borne diseases:** Diseases like black scurf, common scab, russet scab etc. can be effectively managed by adopting technologies like soil solarization and seed treatment with boric acid. Soil solarization by using polythene mulch during peak summer increases the soil temperature to 45-61 ^{0}C which kills harmful bacteria and other pathogens. Seed treatment before cold storage to seed potato tubers by 3% boric acid effectively controls black scurf, common scab and dry rot diseases in potato.
4. **Management of virus vectors:** In seed potato production, viruses play a major role. It cause seed degeneration and affects the yield potential drastically. These viruses are mostly spread through aphid and white flies. Seed plot techniques has been developed by the institute in which date of planting was shifted to avoid peak population of white flies in plains. The technology led the way for potato revolution in the country. In addition, spray schedule using Imidacloprid and use of yellow sticky traps is being advised for control of these vectors.

Similarly, for many other diseases and pests like white grubs, cutworm, potato tuber moth etc, technology has been developed by the institute. These technologies are being disseminated to farmers using various extension strategies.

Extension interventions of CPRI for dissemination of potato technologies

Technology developed in lab must reach to maximum number of farmers in order to increase productivity and income of farmers. Technology transfer services should use a variety of extension interventions to facilitate access of information to farmers and other stakeholders. The no. of extension workers in India is very low as compared to many developed countries and it hinders the reach of potato technologies to farmers. The institute uses a number of extension interventions to reach a large number of farmers in the country. Some of the important extension interventions for technology transfer used by CPRI is discussed below:

1. **Organization of Trainings:** Organization of training programmes for various stakeholders involved in potato production, research and development is one of the most important mandate of CPRI. The institute through its headquarter at Shimla and its seven regional stations at different parts of India i.e Modipuram (UP), Jalandhar (Punjab), Patna (Bihar), Gwalior (MP), Shillong (Meghalaya), Kufri (HP) and Ooty (Tamilnadu) organizes a large number of trainings for farmers as well extension functionaries of different agriculture/horticulture departments, NGOs, private companies and other researchers who

are directly or indirectly associated with potato cultivation. Diseases and pests management of potato is a very important aspect covered in almost all training programmes.

2. **On Farm Demonstrations/Front Line Demonstrations:** Laying ou**t** On-farm demonstrations and Front line demonstrations is an effective method for technology transfer in potato. On farm demonstrations on technologies like late blight management, white grub management, cutworm management etc helps in showing them the superiority of these new technology over existing one. CPRI also organizes a large number of demonstrations on potato varieties resistant to diseases, seed plot technique, balanced fertilizer application etc. These demonstrations help farmers to kow and adopt new potato technologies.
3. **Field Day/Potato Day:** Field days provides an opportunity for interaction and learning amongst staff and farmers as a progressive farmer showcase results of new technology among other farmers of nearby area on a particular day. Through the interaction, subject matter specialists get feedback from farmers on performance of displayed technologies. The institute organizes Potato Days in collaboration with KVKs working in different districts of the country.
4. **Live Phone in Program on AIR and Doordarshan**: The scientists from CPRI, Shimla, CPRIC Modipuram and CPRS, Patna are being involved in Live Phone In programmes on Doordarshan throughout the year. Every month, experts of different fields are invited by Doordarshan for taking part in these programmes (Krishi Darshan *etc*). Farmers ask their queries through phone on quality seed potato production, potato planting, diseases and pest management, storage and processing of potato etc. and reply to these queries are provided by potato experts at the same time. Radio talk are recorded on important topics and played by AIR at a particular time. Radio & TV having the maximum reach to the potato growers; these programmes have created a great interest and enhanced the awareness about improved potato technologies among the masses.
5. **Potato School on AIR:** CPRI has been involved in organization of potato school on All India Radio, Shimla and New Delhi regularly. It is an innovative method to disseminate potato technologies to farmers and other stakeholders through Radio. A series of lecture cum discussion are organized on radio at a particular time every week during crop season. All the activities from planting till harvesting and storage are discussed. It's a very useful method for technology dissemination for lakhs of farmers with less effort and time. Besides, it is a cheap method for reaching large number of farmers.
6. **E-Learning Material for farmers:** Use of ICTs (Information Communication Technologies) for diffusion of modern agricultural technologies is need of the hour. Use of computer and internet has now become very important in technology transfer in order to create awareness about improved methods of cultivation of any crop. In case of potato, CPRI has developed many E- learning material such as e-book on potato, decision support systems like Potato Pest Manager, Weed Manager etc. which are very useful to farmers and other users who are well versed with computer and internet. The CPRI website www.cpri.ernet.in is having a lot of information about potato varieties and technologies.
7. **Interface of Research, Extension and Farmers:** The institute organizes and participates in several extension programmes which ensure the participation of extension personnels, scientists and a large no. of potato growers. CPRI has organized a large number of *kisan melas* at Shimla, Modipuram, Shillong, Kufri, Jalandhar etc. In addition to this, CPRI participates in various national and international exhibitions where modern potato technologies are displayed and explained to various stakeholders including farmers. Every year, the institute organizes seminar/conferences etc on problems of potato.

These activities help in increasing awareness and knowledge of potato growers as well as other stakeholders.

8. **Agriculture Technology Information Centre (ATIC):** An ATIC is functional at CPRI Shimla since year 2003. The major function of this centre is to provide advisory services to potato growers of the country through distribution of technical and extension bulletins related to potato to farmers and others as well as reply of farmer's queries via telephone, email or letters. It also provide diagnostic facilities for potato diseases and pests. There are many agencies like ATMA, KVKs, SAUs in addition to CPRI which publishes literature on potato in the form of leaflets, pamphlets, calendar, extension bulletins, books etc. These publications help to create awareness among the potato growers about modern technologies.

Conclusion

The Central Potato Research Institute is primarily engaged in potato research. However, it has developed several technologies which include technologies for diseases and pest management. Based on problems in a particular area, the institute provides technology interventions at field level through various extension methods like training, demonstrations, Potato School on AIR, use of print media and ICT, use of Decision Support System and internet etc. It helps the farmers and other stakeholders in a long way by providing them relevant knowledge and skills about scientific potato cultivation. However, India being a large country, efforts of CPRI is not sufficient in reaching maximum potato farmers. Therefore, there is a need of involvement of other extension agencies as well as more use of information communication technology tools for transfer of new potato varieties, production as well as processing technologies to maximum number of farmers.

Chapter 21

Post-harvest Handling of Potatoes to Reduce Losses due to Pathogens during Storage

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Introduction

Potato contains approximately 80% water and is a semi-perishable commodity. About 90% of the potatoes produced in our country are grown in the Indo-Gangetic plains and are harvested during January to March, the beginning of the long hot summer. This makes it very difficult to store the harvested potatoes, as under these conditions potatoes cannot be stored without refrigeration for more than 3-4 months after harvest because of enormous losses due to rottage, shrinkage, sprouting and attack of different microbes and pests. According to an estimate, a higher proportion of potatoes (16%) in the country is wasted as post-harvest losses (PHLs) than that used as seed (8.5%) or processing (7.5%). This is an unfortunate situation that nearly 1 million t in excess to the total potato production in Canada during the triennium ending 2010 (FAOSTAT) itself was wasted in India. Losses occur at every stage of the supply chain. These losses result due to lack of proper storage facilities, absence of proper handling, transportation, pre- and post-harvest treatment. Besides, the attack of pathogens at conducive temperatures and environment increase the losses tremendously and therefore, proper handling, desired treatments and safe post-harvest environment is required to reduce the losses in potatoes after harvest.

Post-harvest losses

Hot summer temperatures, lack of state of the art cold storage facilities and massive transportation of potatoes from northern to southern states are the causes of the high wastage of potato in absolute terms. Various factors which play key role in post-harvest loss of potatoes are being discussed in subsequent heads.

Pathogenic Factors

Losses in potatoes caused by pathogens are greater than the losses due to physiological causes. Physical damage to tubers during harvesting and handling aggravates the attack of bacteria and fungi leading to quantitative loss. Generally, the more common storage diseases caused by fungi are late blight, dry rot and pink rot. The most severe bacterial disease that causes rotting is soft rot. When infection occurs in the field, rotting begins in the field and continues during storage. When infection occurs after harvesting, it is generally through mechanical injury as in the case of dry rot. High humidity and condensation of water on tuber surface can lead to infection by soft rot. Among the insect pests, tuber moth causes maximum damage during storage and is common in potatoes stored under higher temperatures, as is the case with non-refrigerated storage.

Fungal diseases: Among the diseases of fungal origin, the most important ones causing pre and post-harvest losses are the late blight and the dry rot. **Late Blight** is caused by *Phytophthora infestans* and the disease affects all plant parts, viz., leaves, stems and tubers. Tubers develop reddish brown, shallow to deep, dry rot lesions. The affected tuber flesh becomes 'caramalised' with a sugary texture. Tubers carrying the pathogen are the real carriers and serve as the source of the disease in the subsequent season. When the storage conditions are good, the rot remains dry and doesn't extend. However, when the storage conditions are faulty, the dead tissues open a route to the secondary soft rot. The **Dry Rot** caused by *Fusarium sp.* on the other hand appears during storage. The skin wrinkles forming irregular concentric rings, and in general tuber tissue decay forms pockets of pink, red or bluish colour, which contain spore masses in the mycelium. The disease incidence can be reduced with proper curing and avoiding bruising during harvest and transport.

Tubers infected with late blight and dry rot

Bacterial diseases: Among the main diseases of bacterial origin, Bacterial wilt (*Ralstonia solanacearum*) and soft rot (*Erwinia carotovora var. carotovora* and *Erwinia carotovora var. atroséptica*) are the major threats. **Brown rot** is a destructive disease to the plant and causes rotting of the tubers in transit or storage. The **Soft Rot** causes high amount of losses particularly during storage and every year about 2% losses have been estimated due to rots. Excessive moisture, high temperature, excess nitrogen, tuber injuries and poor ventilation during storage are the important factors helping the disease development and spread.

Tubers infected with brown rot and soft rot

Initially a small area of tuber tissue around lenticel or stolon attachment point becomes water soaked and soft. Under low humidity, the initial soft rot lesions become dark and sunken, while under high humidity, the lesion may enlarge and spread to larger area. Tubers in advanced stages of decay are usually invaded by other organisms and the decaying tissue becomes slimy with foul smell and brown liquid ooze. At harvest, many small rotted tubers with intact skin can be seen. Among the control measures, avoiding excess irrigation and nitrogen, providing proper drainage prevents the spread of the disease. Harvesting the crop before soil temperature rises above 28°C is recommended. The crop should be harvested only when the tuber skin is fully cured. Care should be taken to avoid injury to tubers and bruised injured tubers are sorted out. Treating the tubers with 3% boric acid for 30 min and drying them under shade minimizes infection during storage.

Potato Tuber Moth (PTM): PTM *(Pthorimea operculella)* in larvae state damages foliage mining between the inferior epidermis and superior of the leaves. It is also introduced in the tuber mining burrows and filling them with their excrements. The initial invasion happens in the field and continues in storage. The tunnels formed in the tubers make them unfit for any consumption and in conducive conditions the rottage by secondary pathogens is aggravated. Therefore, in the areas of PTM infestation in traditional and room tempearature storages proper care like removal of infested tubers, restriction of PTM entry into storage and use of dried leaves of some herbs (e.g. Lantana) in storage is recommended.

Losses due to Pre- Storage Factors

The quality during potato storage depends on the quality of tubers reaching the store and its management starts from the production stage itself. Cultural practices affect the quality of tuber, since potatoes grown in improperly prepared fields are mechanically damaged at harvesting and have reduced storability. Adequate pest and disease management is also necessary for producing potatoes with good keeping quality. Hence, management of pre-storage factors that affect the keeping quality of potato is prime step in good storage management and about 3-8% losses have been attributed to these factors. The potatoes need to be harvested in dry weather and irrigation has to be stopped two weeks before dehaulming. Harvesting is done 10-15 days after haulm cutting for facilitating skin setting. Besides this, curing /suberization (the process by which wounds are healed in potatoes under optimum conditions of <25°C temperature and 95% relative humidity) is also important. Potatoes harvested under wet soil conditions must be dried before storage because even little moisture on the surface of the tubers could lead to infection and rotting during the storage. Only mature tubers with good skin setting are ideal for storage under any storage system.

Uncured and a cured potato tuber and curing in field

Losses at Harvesting and Handling

The mechanical damage during harvest is responsible for loss initiation in potatoes in form of cuts and bruises hence care should be taken to ensure that cuts and bruises are minimized and the exposure to sun should be avoided. Exposure from sun heat causes excessive rotting and damages can take place as a result of direct contact with the sun at the time of harvest. This may also occur before harvesting when the plant is dead or cut. Potatoes harvested in hot weather rot more than those removed in more temperate conditions. When air temperature is 32°C or higher, it is not advisable to dry potatoes and optimum temperature of air for drying has been recommended as 26.5°C or less. Proper care at the time of harvesting, curing of potatoes in temporary heaps and careful handling may help in reducing the losses to a great extent.

Losses during Storage

Losses during storage are affected by factors like physiological tuber condition, mechanical damage suffered during harvest and handling, as well as by storage conditions. Mechanical damage (cuts and bruises) facilitates invasion and development of microorganisms that cause illnesses and rotting. It is appreciated that weight loss shows a lineal relationship with regard to nature or magnitude of physical damage. On the other hand, losses by rottage increase exponentially with regard to magnitude of physical damage. In general, it is necessary to reduce tubers physical damage to minimize losses during storage.

Losses during Transport, Marketing and Distribution

Losses to potato crop during transport, marketing and distribution have been estimated to be about 3-8%. It is recommended that transport of potatoes should be completed rapidly to avoid sun damage. Transferring tubers in sacks generate a larger percentage of damages unless the handling is done very carefully. Thus crop handling inside the field or transport to exterior with trucks or trailers has great importance. There are mechanical damages to potatoes before leaving the field. These damages become more evident later during storage. To avoid mechanical damages in all the operations, it is necessary to convince the personnel to utilize proper handling like: Potatoes should be placed inside containers and not thrown from distance, truck drivers should not stand on potato sacks but on the platform of the truck and full sacks of potatoes should be placed in position and not thrown at truck loading and discharging. Use of soft linings is recommended in trailers and trucks that transport potatoes. A straw bed should be used in trucks, or pads can be made with sewn sacks half filled with straw and laying potato bags on these shall significantly reduce the bruising. It is also necessary to securely tie the load to avoid movement of sacks, resulting in bruising. Another point is that potatoes should be handled the absolute minimum number of times possible. All labour involved with potato handling should be supervised carefully to guarantee an appropriate operation.

Storage Practices to Minimize Losses

In India, potatoes are generally stored in cold stores and used for both seed and table purposes. Seed potatoes are best stored in cold store maintained at 2-4°C and at about 95% relative humidity. But cold stored potatoes are not suitable for table and processing purposes. Potatoes stored in cold store accumulated sugars and become sweet in taste and are therefore, less suitable for consumption. Because of high accumulation of reducing sugars, these potatoes produce dark coloured chips which are unacceptable both colour-wise and taste-wise. Thus, the storage requirements of potatoes should be in accordance with the purpose for which potatoes are stored. It is suggested that cold stores maintained at 2-4°C should be used exclusively for the storage of seed potatoes only. Table and processing potatoes should be stored at 10-12°C, after treating the potatoes with a sprout suppressant for long-term storage. For short-term storage of table and processing potatoes, non-refrigerated storage methods like heaps can be used profitably. Handling of potatoes with due care is expected to reduce the post-harvest losses.

Storage of Seed

Seed potatoes are best stored at 2-4°C and 90-95% RH in cold stores, because at this temperature, sprouting does not occur and weight loss is minimum. The farmers have to pay the rent for storing potatoes in these cold stores and they take out these potatoes at the time of planting in the next potato season. The only problem regarding the storage of seed potatoes in cold stores is the uneven distribution of these cold stores over locations and non-regulatory storage charges.

A traditional cold storage and stack of potatoes inside the store

Storage of Table and Processing Potatoes

The potatoes to be used for table and processing purposes have different storage requirement than the seed potatoes. Essentially storage for table and processing potatoes may be divided into two categories viz. Non-refrigerated storage systems and refrigerated storage systems as discussed below.

Non-refrigerated storage systems for table and processing potatoes: These are the storage systems where no artificial refrigeration is used. These storage methods can be used to store potatoes for 3-4 months (i.e. up to June) after harvest in February/March. However, once the monsoon begins, potatoes cannot be stored in a non-refrigerated store because it works only under dry conditions. Short-term storage of potatoes for 3-4 months is good enough because it helps avoid distress sale immediately after harvest and the farmer can get better returns by selling the potatoes in May or June, when potato prices start rising. It is relatively easy to store potatoes under non-refrigerated conditions when they are dormant. Indian potato varieties have a dormancy period of 6-8 weeks. Once the dormancy period is over, sprouting begins. Weight loss in potatoes during storage is mainly due to water loss from the tubers and the weight loss is much more in sprouted tubers. The extent of rotting is high under non-refrigerated storage systems as the temperature and humidity conditions are favourable for aggravating the infection.

A modified potato heap

Refrigerated storage for table and processing potatoes: Fresh potatoes are available for consumption only for a few months, after the harvest. For a major part of the year, potatoes from cold stores are consumed. Though cold storage facility was developed primarily for the storage of seed potatoes, they have been used for the storage of table potatoes as well. But, 2-4°C is not the ideal storage temperature for table and processing potatoes as at this temperature, potatoes become sweet due to sugar accumulation and are not preferred for consumption. Further, cold stored potatoes do not keep well once they are taken out of the store. Therefore, storage of table and processing potatoes is suggested at 10-12°C. This method of potato storage is comparatively new to our country, but a good number of cold stores (approximately 700) are now storing potatoes by this technology and these potatoes are being marketed as low sugar potatoes (table) and depending on the variety stored, potatoes are suitable for processing as well up to about 6-7 months. However, at this storage temperature, potatoes sprout. Therefore, it is necessary to treat the stored potatoes with a sprout suppressant like CIPC (Isopropyl N-(3-chlorophenyl) carbamate). The treated potatoes are safe for consumption after 3-4 weeks of treatment.

A commercial cold store using 10-12°C storage technology, potatoes and chips

Chapter 22

Use of Modelling Tools in Disease Forecasting and Management: Initiatives at ICAR-CPRI

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Introduction

Forecasting the disease in advance is of great help to potato farmers. This can enable them to take prophylactic sprays in time and prevent unnecessary use of fungicides. Weather conditions such as temperature, relative humidity, rainfall, dew, sunshine hours etc. have a direct effect on *P. infestans* therefore, these parameters have been exploited to develop disease forecasting models both in India and elsewhere. Forecasting models for predicting first appearance of late blight have been developed for western hills, eastern hills and southern hills in India and have been exploited for the disease management. For plains, a computerized forecast for late blight named as 'JHULSACAST' has been developed for western Uttar Pradesh, Punjab, Tarai region of Uttarakhand and Plains of West Bengal. 'JHULSACAST' is more accurate than the other tested models. Based on 'JHULSACAST' model, Decision support system (DSS) has also been developed which has three components *i.e*. (i) prediction for first appearance of disease, (ii) decision rules for need based fungicide application, and (iii) yield loss assessment model. Recently, INDO-BLIGHTCAST, a pan-India model, has been developed to predict appearance of late blight across the country.

The details about the development and use of these models have been covered in other chapter/s in this compendium. I shall be focusing on the use of the modelling and GIS tools for impact assessment of climate change in the following sections.

Effect of climate change on late blight outbreak in Punjab, Western UP and West Bengal

The high hills of Himachal Pradesh, Indo-Gangetic plains of Punjab, Haryana, north-western part of Uttar Pradesh, and Bihar are suitable for nucleus and breeder seed production. However, Punjab and western Uttar Pradesh are two major states which supply the potato seed to rest of the country owing to longer crop duration as well as aphid free period available for producing quality potato seed. Besides, in West Bengal, the second largest potato producing state of India, occurrence of late blight is frequent and significantly affects the potato productivity once every two-three years. In case of climate change scenario, the temperature change is likely to affect the late blight out-break in Punjab, western Uttar Pradesh and West Bengal, thus affecting the seed and ware potato production. Keeping this in mind, we had studied the impact of climate change on late blight and number of chemical sprays required to control it in Punjab, western Uttar Pradesh and West Bengal using JHULSACAST. The model was run using districts level data on minimum and maximum temperature (ºC) of Indian Meteorological Department's normals (years 1971 to 2000) for baseline (year 2000) and future climate scenarios (years 2020 and 2055) for entire Punjab state, 23 contiguous districts of western Uttar Pradesh and 11 districts of West Bengal. Hourly temperature (ºC) data required for JHULSACAST was derived from minimum and maximum temperature (ºC). Kriging method was used to interpolate data over geographical area of districts.

The model was run for baseline scenario (year 2000) and future climate scenarios (years 2020 and 2055). IMD district normals of 1971-2000 were used for baseline scenario (year 2000) and for future climate scenarios of the years 2020 and 2055 A1FI scenario of temperature (SRES A1FI pathway) was used. As per the IPCC 4th Assessment report, an increase in temperature ranging from 0.78 ºC during September, October, November to 1.17 ºC during December, January, February is expected under A1FI scenario by 2020 in South Asia. These changes are expected to aggravate and range from 1.71 ºC during June, July, August to 3.16 ºC during December, January, February, *i.e.* the main potato growing season in 2055. It is not possible to predict the daily humidity in years 2020 and 2055 during cropping period, therefore, we assumed that 90% RH would start from a week of emergence of the crop and proceeded with 10 days intervals after the setting of required RH. Thus, the model results are the outcome of the effect of temperature input. To estimate the number of sprays required in seed crop, the daily severity values were calculated on the basis of decision support system developed in this tregard. The accumulation of the severity was started as soon as the prediction of first appearance is occurred. The number of sprays needed in seed crop was calculated by dividing total accumulated severity by 180 for contact fungicides. The value of divisor 180 was taken empirically.

Under the favourable relative humidity in Punjab, the model predicted earliest late blight appearance is during 13th to 25th October in baseline scenario (2000) which is expected to be delayed by 0 to 6 days in 2020 and 12 to 14 days in 2055 scenarios. In western Uttar Pradesh, earliest late blight appearance during the potato crop season was predicted during 13th October to 1st November in baseline year 2000 and is expected to be delayed by 0 to 8 days in 2020 and 10-21 days in 2055. The change in date of late blight appearance and its delay in years 2020 and 2055 is due to expected increase in temperature by 1.08 and 2.98 ºC respectively over the baseline year 2000. In Punjab, there were average 105 late blight favourable days out of 182 suitable potato growth days in year 2000; the number is likely to be increased to 135 and 140 days in 2020 and 2055 respectively in Punjab. In western Uttar Pradesh, potato growing season was warmer which would decrease late blight favorable days by 7 and 27 in 2020 and 2055, respectively. The number of sprays required to control late blight in potato seed crop would be 7.3 and 8 in future scenario (2020 and 2055) in comparison to 6.5 in baseline (2000) in Punjab. In contrast, there would be no change in number of sprays in year 2020 (over baseline year 2000) in western Uttar Pradesh, however, due to further increase in temperature in year 2055, it could be reduced by 2.

In West Bengal, model predicted earliest late blight appearance during 4th to 11th December in baseline scenario (2000) which is expected to be delayed by 3 to 15 days in 2020 under favourable relative humidity. The delay in late blight appearance in 2020 is expected due to increase in temperature by 1.08 over the baseline year 2000. The total number of late blight favourable days ranged from 65 to 88, depending upon the geographical location, with a mean of 73 days in the baseline year (2000) during the potato crop season. However, due to delay in appearance of late blight in the season and reduction in late blight favourable period towards the end of the season, the total late blight favourable period is likely to be reduced by the 3 to 15 days (mean 7.6 days) in the future climate (2020). The study further shows that if there is no change in the population structure of the *Phytopthora infestans*, the mean number of sprays required to control late blight is likely to reduce from 5.5 in 2000 to 4.2 in 2020.

Effect of climate change on survival of *R. solanacearum* in soil as free living cells in potato growing districts of plateau region

Bacterial wilt or brown rot caused by *Ralstonia solanacearum* is a destructive disease of potato prevalent in many parts in India. The pathogen survives through infected tubers, plant debris and in soil. Studying the survival behavior of this pathogen in soil at varying temperatures will help us to visualize the new potato growing areas where this pathogen may establish with the increase in global warming. A study was conducted on the survival of *R. solanacearum* strain RS-2 (potato race, phylotype II bv 2) *in-vitro* in soil (both in sterilized and unsterilized soil) at different temperature regimes. The results revealed that the pathogen could survive for one month at 40 ^{o}C, two months at 37 ^{o}C, four months at 32 ^{o}C and six months at 20 – 28 ^{o}C in sterilized soil. However in un-sterilized soil, the pathogen could survive only for one month at 37 ^{o}C and 4 months at 20-28 ^{o}C, while no growth of *R. solanacearum* was observed at 40 ^{o}C after one month and at 32 ^{o}C and above after two months. Based on these result, a logical mathematical model which give the time (in days) in which the bacterium will not survive in the soil. The model gives the results on the basis of daily mean soil temperature. For baseline survival, IMD normal were used and for future climate, temperature rises for A1F1 scenario of the climate change for 2020 and 2055 were added on the baseline temperature. The presence of *R. solani* in the soil was presumed on 1st of January and the days it will survive in the soil of 60 potato growing districts of eight states in plateau region of India were worked out, based upon soil temperature. The results thus obtained were overlaid on a digitized map and kriging technique was used to extrapolate the date in the GIS environment.

Tamil Nadu and Kerala

Under the baseline climate scenario (2000), the bacterium survived till 18th March in soils of Idukki, Kannur, Malappuram, Pathanammitha, Wayanad districts of Kerala and Dharamapuri, and Virudinagar districts of Tamil Nadu and no changes are expected in 2020. However, in 2055, the bacterium is likely to survive in soil of these districts till 03 March only. The bacterium is likely to disappear 0-05 days earlier in 2020 and 05 to 15 days in 2055.

Karnataka

The bacterium survived in soil till 18 March in Gadag, 7 April in Dharwad, Bidar, Chitradurga, Karwar, Udupi, and 27 April in Rural and Urban Bangalore districts of Karnataka in baseline scenario. In 2020, the bacterium is likely to survival in soil till 18th march in some areas of Dharwad and Chitradurg while in rest of districts, no change is expected. The bacterium is likely to disappear 0-08 day earlier in 2020 and 11-15 days in 2055.

Andhra Pradesh, Maharashtra, Odisha and Chhatisgarh

The bacterium survived in soil from 7 to 27 April in different districts and is likely to disappear 3-8 and 11-25 days earlier in Andhra Pradesh and Maharashtra, 3-8 and 11-20 days in Odisha and 3-5 and 11-15 days in Jharkhand in 2020 and 2055, respectively.

Jharkhand

Under the baseline (2000), the bacterium survived in soil till 27 April in Gumla and 17 May in Ranchi and Singhbhum. No change is expected in Gumla in 2020, however, in Ranchi and Singhbhum, the survival is likely to be up to 6th May only. In 2055, the soil survival period is likely to reduce to 20 April in these districts.

Madhya Pradesh and Gujarat

The bacterium survived in soil from 27 April to 17 May in different plateau districts of Madhya Pradesh and Gujarat in 2000. The bacterium is likely to disappear 3-8 days earlier in 2020 and 5-15 days in 2055 in Madhya Pradesh and 3-5 days earlier in 2020 and 11-26 days in 2055 in Gujarat.

Rajasthan

Under the baseline climate scenario (2000), the bacterium survived in soil till 17 May. The period is likely to reduce by 0-5 days in 2020 and 5-15 days in 2055.

Conclusion

Modelling and GIS tools are effective means to forecast diseases and thus help in their management. It is not possible to conduct field studies in each and every agro-ecological region and there modelling and GIS tools come handy as they are helpful extending the results of one location to others. Moreover, these tools are very effective in predicting the impact of future climate on disease dynamics, thus help us to remain prepared to meet the challenges of future climates.

Chapter 23

Decision Support System for Potato Production

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Introduction

Information Technology (IT) is the mantra of modern world. Today IT has pervaded each and every field of human endeavor including agriculture. Unlike medicine, engineering and commerce, its application in agriculture is much slower primarily due to paucity of IT trained manpower in this sector. The institute has so far developed many decision support systems, viz. Potato Pest Manager (PPM), Computer Aided Advisory System for Crop Scheduling (CAASPS), Potato Growing Period and Yield Estimator, Plausible Potato Growing Season Estimator (PPGSE), Potato Weed Manager (PWM), INDO-BLIGHTCAST, Potato Growing Season Descriptor (PGSD), Potato Variety Tracking software (VARTRAC), etc. The database like digitized photo library of potato and Potato ebook were also developed ICAR-Central Potato Research Institute Shimla.

Decision support systems

Computer Aided Advisory System for Crop Scheduling (CAASPS)

The information on optimum time of planting, the most suitable variety and the expected yield at different dates of harvest are vital for scheduling planting and harvesting times by farmers. These non-monetary inputs in potato farming strongly influence a wide range of aspects including returns, crop rotations, input requirements *etc*., and thus on the overall sustainability of the crop and cropping systems. Farmers usually follow the regional package of practices, which are recommendations based on means of field experiments conducted for several years. These regional packages of practices often fail to meet location specific requirements to the detriment of yield and profitability. Location specific information can be derived from crop models, which simulate crop growth, development and yield with reasonable accuracy under diverse agro-climatic situations. However, use of crop models requires extensive data inputs as well as technical expertise to handle the model. Therefore, world over, models are usually handled by researchers and off take of models by farmers and field level workers is limited. Decision Support Systems (DSS) on the other hand provide a method for delivery of information generated by the simulation models in a user friendly and simple way. Therefore, a DSS called **CAASPS** (Computer Aided Advisory System for Potato Crop Scheduling) was developed with the following objectives:

- To provide information on the expected yields of different varieties planted at different times to enable farmers to decide the planting time and crop duration for their specific needs and locations.
- To help decide the time of harvest based on yield accrued at 60, 70, 80 and 90 days after planting.
- To indicate the varietal performance under different dates of planting and crop durations and thus help choose the appropriate variety.

This DSS consists of a database and a user interface. The database consists of state, district and location names along with INFOCROP-POTATO model derived yield outputs. For wider reach of this tool, it has been made web based.

Potato Pest Manager (PPM)

For the management of diseases and pests two aspects are involved. The first is to establish the identity of the disease/pest and second is to recommend appropriate preventive and management practices to control them. These objectives are achieved in a sequence of steps as discussed below

Step 1: The photographs showing the symptoms of the diseases/pests are arranged in a photo gallery and displayed in sequence. The user is asked to match the symptoms in the photographs with those he has seen in the field and select the most closely matching one.

Step 2: The appropriateness of the selected photograph needs to be confirmed, because the user may not be fully conversant with the symptoms of different diseases or damage by pests. Information about the biotic/a biotic factors prevailing, together with the symptoms, are necessary for a correct diagnosis. This is done through a set of confirmatory questions.

These are questions about the symptoms of the disease/damage by the pest, or conditions which need to be satisfied for the disease/pest occurrence. This information is arranged in a linear fashion. This arrangement allows insertion/deletion of questions/an option to a question at any level without disturbing the overall structure. Furthermore, this information is presented in a format of questions/statements to the user, while answers are given as options to these questions/statements.

Step 3: Once all the confirmatory questions are answered, the name of the disease/pest corresponding to the photograph selected is displayed along with confidence percentage. The confidence percentage is calculated based on answers given to the confirmatory questions relevant to disease symptoms/pest damage. Each confirmatory question/statement is assigned a certain value such that for all the questions if the option corroborating the disease/pest whose photograph is selected is chosen as the answer, the value adds up to 100.

However, the value allotted to each question may vary depending upon its significance.

Step 4: Many potato diseases/pests can only be controlled through preventive measures taken over a period of time before planting the crop and control is not possible once the disease/pest appears. This is especially the case with diseases/pests where symptoms are seen at/after harvest. Therefore, the preventive measure applicable to the disease/pest identified is displayed in this step. The preventive measures are the set of practices, which would have prevented/mitigated the disease/pest occurrence.

Step 5: In this step information required for suggesting control measures on the standing crop is obtained through a further series of questions. For example, information regarding severity of disease/pest damage, age of the crop, *etc*. is invariably required for deciding the chemicals to be used, their dosage, number of sprays *etc*. This information is again obtained from the user by presenting the questions or statements with various options. The questions or statements are arranged in tree structure and depending upon the answers given to each question a path is followed leading to a recommendation which is attached at the end node.

Step 6: This step displays the recommendation based on the options chosen.

This tool/DSS is web based and is developed in ASP.NET and the database is developed in Microsoft SQL. It can be accessed from CPRI web site http://cpri.ernet.in.

Plausible Potato Growing Season Estimator (PPGSE)

"Plausible Potato Growing Seasons Estimator" (PPGSE) tool is developed for estimating the number of growing seasons of potato crop and their duration for any location. The tool screens the maximum and minimum temperature of any location according to maximum and minimum threshold limits set by the user or user can use the default values and extracts those periods which meets the criteria for a period of more than 70 days continuously.

The default rules for screening the database for estimating the start and end of growing period are as below:

i) Maximum temperature should be less than a threshold value (35^oC).

ii) Minimum temperature should be more than a threshold value (2^oC) and less than another threshold value (21^oC) at least from 15 days after planting.

iii) The end of the growing period is upto 120 days from the start of the growing period or when the crop growth is terminated when the threshold temperature values are exceeded.

The model requires mean seasonal maximum and minimum temperatures and solar radiation during the growing period obtained from the above database screening rules.

A spreadsheet with macros was created to process the raw data and extract the information required by the model. Two fields each with 365 records (maximum and minimum temperature) were created in spreadsheet and macros for screening the day as suitable or unsuitable for potato based on threshold limits for maximum and minimum temperature was written. The starting day number, ending day number and the total number of suitable days of the period more than 70 days were obtained, were derived as outputs

Potato Weed Manager (PWM)

A Software for weed management in potato crop "Potato Weed Manager" has been developed. This software gives the recommendation for weed control on the basis of situation of potato field, type of weed flora (major and secondary/associated weeds) and the stage of the potato crop. The database has been created in MS Access in back end and user interface is created in Visual Basic. The effective weed control depends upon the knowledge about the type of weed flora present in the field, intensity of their infestation and the stage of their growth, which in turn is affected presently by the location of the field and the season of the crop, and in future will also depend upon the CO_2 concentration and temperature. The expert advice is generally not readily available. Thus the software is helpful for farmers to get expert advice on weed management in potato, through visual identification of the major and secondary weed flora and on the basis of type of weed flora, situation of the farm and stage of the crop, expert advice is given for efficient weed management.

VI INDOBLIGHTCAST

Late blight is the most dreaded disease of potato causing annual crop loss of about 12 billion € globally. Its appearance and spread is highly dependent on environmental factors. Under favourable conditions its spread is so fast that it can wipe out the crop within a weeks time. In India it is very serious in the hills where it occurs regularly but in the plains it may or may not appear and even if it appears its time of occurrence would vary. The time of its occurrence and severity determines the yield loss which may exceed 40% country wide in some years. Prevention through prophylactic sprays of recommended chemicals is the best option since once it appears it is very difficult to control. This, however, requires information on the likely time of appearance of the disease and hence the importance of disease forecasting.

INDO-BLIGHTCAST- is a web based forecasting model (http://cpri.ernet.in) developed to predict the first appearance of late blight disease using daily weather data of meteorological stations. The INDO-BLIGHTCAST is applicable pan India, since, it is web based, it requires only daily weather and does not need local calibration for different regions. Hence it is very robust and its predictions are broad based. Agromet division of IMD has a country wide network of weather stations while AICRP (Potato) has 17 centers located at different State Agricultural Universities and CPRI has 7 centers. It is proposed to harness these strengths for issuing advisories on potato late blight appearance and its management by CPRI, AICRP and Agromet centers.

Potato Growing Season Descriptor (PGSD)

Potato is one of the most sensitive crops to the environment. Apart from the phenology and growth and yield, the weather conditions during the growing season also affect the size of the tubers as well as its quality. There is also a wide variation in the pest and disease scenario affecting potato primarily due to differences in the in growing season environmental factors in different locations/seasons in which potato is grown in India. Moreover, potato has been adapted to be grown under subtropical conditions in India. This has been possible by the development of resource intensive production technologies. Therefore there is need for careful planning of the production strategy by analyzing the growing season using algorithms to determine the length of the plausible growing season, mean daily temperature, mean night temperature, accumulated growing degree days and accumulated P days during the autumn growing season. The tool also gives the expected yield calculated using a summary model of the autumn crop under constraint free situation. It is expected that these information would be useful for production managers, extension workers and farmers in planning their production strategy.

VARTrac: a computer software for identifying potato varieties through morphological and molecular markers.

Authentic identification of potato cultivars is important for plant breeders, the variety registration and certification agencies, seed producers, merchants, farmers, growers, processors, and other end-users. There is also increasing interest in the descriptive characterization of plant varieties in the context of intellectual property protection rights under the recent agreements within the framework of World Trade Organization. Currently morphological descriptors are being used internationally for variety identification. However, there is a possibility of utilizing DNA fingerprint data to supplement morphological characters in near future. Central Potato Research Institute, Shimla is, therefore, developing both morphological and DNA fingerprint databases for potato cultivars' identification.

Data on 50 different morphological attributes and DNA fingerprints based on 127 alleles from 4 micro-satellite markers are currently being used at CPRI for varietal identification. Manual analysis of such huge data is not easy. Therefore, a computer software named "VarTRAC" has been developed at CPRI for speedy identification of a variety based on the morphological and DNA fingerprint data.

E-Book on Potato

An e-book on potato has also been developed at CPRI. In the case of a normal book the information is arranged in sequence and photographic material content is also minimum. Therefore, such publication has limited utility outside the target users. However, many types of user groups are present with various background. To meet the information needs of such diverse users an e-book has been designed at the institute. In this e-book the information is arranged at various levels of hierarchy. For a generalist the first page of each topic may suffice while a specialist can go deeper and deeper thorough links and sub-links provided in each page. The practical aspects of potato cultivation have also been provided through a link to package of practices for each region. Thus this e-book is a comprehensive database of information on potato catering to a wide range of users.

XI Digital Photo Library on Potato

The creation of photographic database is a very important activity because much information can be presented very easily and concisely through photograph rather than text. Therefore a digitized photographic database was developed. The database contains more than 600 photographs pertaining to all aspects of potato research and development. This database is classified according to different aspects like crop improvement, crop production, diseases, equipment's and instruments, pest and nematode, processing and storage, social science and seed technology. Also alphabetical listing of all the photographs contained in database is provided. The use of database by the personnel does not require any skill.

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