

Principles of disease management in fruit crops

Introduction

India is the second largest producer of fruits in the world, contributing 10% of the total production. But, the total production is quite below (45.496million tons from 37.96million hectares) the requirements at the recommended dietary allowances of 90gm of fruits per capita per day as laid by Indian Council of Medical Research. Accordingly, 90million tones of fruits are required to feed the one billion population of India. Since, it is not possible to attain such a high target, as plant diseases are the major constraints in increasing the productivity of fruit crops. Huge pre- and post-harvest losses are caused by various fruit diseases and unfavorable environments leading to the total failure of the crops. Citrus decline,

apple scab, mango malformation, guava wilt, fire blights, banana bunchy top and wilt, brown rots of stone fruits, crown galls, downy and powdery mildews are the destructive fruit diseases causing huge losses to the fruit industry worldwide.¹ Intensive agriculture provides greatest opportunities for the buildup of many new diseases and insect-pests. Plant protection mainly aims to attain maximum yield by keeping the crops healthy and preventing the losses occurring from diseases and insect-pests. The successful and profitable fruit industry largely depends on the adoption of improved scientific agricultural technology. A principle of plant disease management broadly includes preventive measures and curative measures that cure the plants suffering from diseases. But none of the control methods when applied individually provide satisfactory and effective disease control. Hence, Integrated Disease Management (IDM) is the complete solution of all the disease problems. This chapter describes the role and application of plant pathology to horticulture in managing diseases of fruit crops. The intended scientific information will be beneficial to the students, scientists, researchers, planners and extension personnel for better understanding of various plant protection methods. This better understanding will lead to boost the world fruit industry for prosperity.

Concept of plant disease

It is important to define and discuss the basic terms commonly used in the discipline of Plant Pathology for the better understanding of the events occurring in plant diseases.²⁻⁵ **Disease**—The dictionary meaning of disease is illness, ailment, and disorder. It is a change in the normal function of plants which reduces the growth, development and lowers the production. According to Stakman and Harrar (1957), disease is a physiological disorder for structural abnormality that is harmful to the plant or any of its parts or products that reduces the economic value. **Pathology**—Science of diseases.⁶ **Plant Pathology /Phytopathology**—(Phytos—plants; Pathos—suffering; Logos—knowledge) it is the science of plant diseases in which nature of the disease, its development and control measures are studied. **Pathologists**—are the expert in Pathology. **Pathogen**—is any agent which causes damage. **Host**—is an organism which support the activity of the pathogen or which provides food and energy to the pathogen. **Pathogenicity**—is the ability of the pathogen to cause a disease. **Pathogenesis**—is the series of events which take place from the initial contact between the pathogen and its host in the disease development for the production of symptoms. **Symptom**—are the characteristic sign or indication as a result of the disease. They are one of the important tools for diagnosing the diseases. **Syndrome**—

Volume 4 Issue 5 - 2017

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Received: April 17, 2017 | **Published:** May 16, 2017

disease produces several valuable signs/symptoms and they are collectively called syndrome. **Spore**—is a minute propagating unit responsible for the production of new individuals of the same species. **Inoculum**—is the infectious material or portion of the pathogen that can cause a disease. **Primary inoculum**—is the over wintering or over summering stage of the inoculum that begins the disease in the field and upon favourable condition becomes an infectious agent to cause a disease. **Secondary inoculum**—after disease development, pathogen may produce another crop of spores/infective bodies which cause secondary infection is called secondary inoculum. **Penetration**—is the initial invasion/entrance of an organism into the host. **Infection**—is the establishment of the pathogen inside the host after penetration. In infection a parasitic relationship between the parasite and the host is established. **Incubation period**—time taken by the pathogen to produce symptoms on the host after penetration. **Disease development**—is the series of events taking place between the time of infection and completion of the disease symptoms. **Disease cycle**—is the series of events taking place in disease development. **Parasites**—which live or get its food from someone else. **Obligate parasites**—live only on living tissue. **Saprophyte**—which live on dead tissue? **Facultative parasites**—They are basically saprophytes but with favorable conditions and availability of the host become parasites. **Facultative saprophytes**—are the parasites but with unfavorable conditions forced to live as saprophyte. **Symbiosis**—two living organisms live in association with one another by benefiting each other. **Virulence**—is the capacity of an organism to invade, multiply and reproduce on the host plant. **Susceptibility**—is the inability of the host plant to resist the attack of the pathogen. **Resistance**—is the inherent ability of the plant to resist the attack of the pathogen and its activity. **Virion**—term used for a virus particle outside the cell containing RNA or DNA surrounded by protein coat. **Vector**—an agent that carries a pathogen from one organism to another. The term is usually restricted to animals that act as carrier of virus particles particularly insects, nematodes, fungi, mites, etc.

Cause of plant disease

Plant diseases on the basis of causal factors mainly grouped into three types namely parasitic (fungi, bacteria, mycoplasma and spiroplasmas, nematodes, algae, protozoa, parasitic flowering plants) non-parasitic (a biotic agents such as unfavorable weather conditions, nutritional deficiency, air pollution and many edaphic conditions) and viral diseases.^{2-5,7} The dimensions used in measurement of fungi and

bacteria is micron (u), for viruses mill micron (mu); and for internal structure of the microorganism Angstrom unit (Å) where 1mm=1,000 microns (u), 1u=1000 mill micron (mu or nm) or 10⁻⁹ meter, 1mu=10 Angstrom units (Å) or 10⁻¹⁰ metre.

Symptomatology in plant disease

Plant diseases produce various types of symptoms in the field. For their accurate diagnosis, and better understanding the various terms are used to define the symptoms in the diseases. *Damping-off* – killing of young seedlings. If they are killed before they reach soil surface called pre-emergence damping-off. In post-emergence phase infection of young tissue of the collar take place at ground level. The seedlings show toppling, wilting or collapse symptoms in nursery beds. *Leaf spots and Blights*–Blight is the sudden and extensive damage to the leaves. In blight large area of leaf or whole leaf or plant is involved. In contrast, in leaf spot limited area is covered by the pathogen. Peach leaf spot, citrus ring spot and blight. Potato late blight, Fire blight of apple and pear. *Anthracnose*–is term used to dark brown necrotic spots or patches on leaves, stems and fruits. These lesions have black necrotic area in the centre. Anthracnose of mango, citrus and guava. *Malformations, galls and abnormal growth*–terms are used for excessive abnormal growth or swelling of shoots, leave or roots like mango malformation, peach leaf curl, witch's broom in lime, crown gall of stone fruits. *Rusts*–a plant disease showing rust coloured spots. *Defoliation*–is the sudden dropping of leaves by disease infection. *Canker*–a canker is diseased area on leaves, branches, stems or fruits. The death of the infected area is clearly visible. *Wilt* – is a general term used for diseased plants showing water deficiency or total loss of water called desiccation. The uptake of water become inadequate and plants show loss of turgidity and death. Dutch elm disease, Guava wilts, Panama disease of banana are the wilt diseases. *Scab*–conspicuous raised lesions form a corky layer. Apple, Citrus and Potato scab. *Mildews*–minute growth of the fungi on the host surface. *Powdery mildews* where fungus lives on the host surface like moulds or white powder and *Downy mildews* in which fungus penetrate deep into host tissue. Powdery mildew of apple, grapes, beer and mango and Downy mildew of grapes are the classical fruit diseases. *Necrosis*–is death of cell or group of cells and dead tissue turn dark brown. *Mosaic*–is the irregular pattern of light and dark green area on the leaf blade of plant due to pathogen infection. Citrus mosaic, Apple mosaic, Papaya mosaic, Plum and Peach mosaic. *Chlorosis or yellowing*–is uniform change of colour of leaf blade. Peach phony disease, Citrus stubborn, peach yellow, lethal yellow of plum. *Vein banding*–dark green area along the leaf veins. *Vein clearing*–veins become clear, transparent or show chlorosis, necrosis or cracking. Citrus tristeza virus, citrus greening *Epinasty*–curling of leaf from tip downward. Citrus exocortis viroid. *Cupping*–curling of leaf margin upward. *Enation*–is out growth from the leaf blade.

The basic requirements for management of plant disease are: disease free clean and healthy seeds/planting materials; clean field or pathogen free soil; prevention of entry and infection by the pathogens in standing crop and precaution during harvesting and storage of the produce. Various components of Integrated Disease Management in controlling fruit diseases are discussed below.

Horticultural practices

These non-chemical practices can successfully be exploited in managing many fruit diseases. These practices greatly improve the efficiency of control methods and in conjunction with other methods

help in maximizing the fruit yields. Use of disease free healthy seeds and elite propagating material, orchard density, nutrition, irrigation, pruning, crop rotation, intercropping, nucellar embryony, orchard sanitation by removal of diseased plant parts, wild and alternate/collateral hosts and their proper destruction are the important practices in managing the diseases.^{8,9} These practices are safe, cheaper, environmentally safe and effective in reducing the incidence of various diseases. The practices like crop rotation, green manuring and intercropping always indirectly reduces the diseases by enhancing saprophytic soil microbiota thereby reducing pathogen inoculum and disease occurrence. Different approaches of these practices are:

Use of disease free seeds and elite propagating materials

Disease free planting material is the backbone of Fruit Industry. Disease free nursery should be raised by taking propagative materials from disease free healthy plants that are marked, indexed and identified by making surveys of various fruit orchards.¹⁰⁻¹² The disease free elite material should be preserved for mass multiplication and distribution of healthy saplings for raising healthy fruit orchards. Fruit plants like mango, citrus, guava, grapes, pome and stone fruits, banana, pomegranate, strawberry etc. are mostly multiplied by budding, grafting, cuttings, suckers/rhizomes etc. If the mother plant carries a transmissible disease, by vegetative propagation it is passed to the offspring. Such infected nursery plants serve as one of the important reservoirs for the introduction and spread of diseases and new pathogens into the virgin area. Citrus viruses (psoriasis', tristeza, exocortis, greening, ring spot, xyloporosis, stubborn, vein yellow, mosaic, witches's broom), banana (bunchy top, mosaic, infectious chlorosis, Panama & moko wilt), grapes (leaf roll, little leaf, stem pitting, fan leaf, yellow mosaic, vein bending, necrosis, corky bark, Pierce's disease, bacterial canker), mango malformation and canker, apple (mosaic, chlorotic leaf spot, star crack), pineapple wilt virus, mulberry (mosaic, yellow net vein, ring spot, dwarf), plum line pattern virus, plum and peach mosaic, peach X disease, peach root knot nematode are readily transmitted and spread through the use of infected planting material (scions or rootstocks) and propagating tools for nursery production. These diseases can spread especially long distance and internationally by the importation and use of infected bud wood and its propagation in nurseries. Therefore, the production of disease free elite bud wood and sapling are very important to manage the vegetative transmitted diseases.

Horticultural practices like infected clonal rootstocks, top working of existing tree with infected scion cultivars and using infected tree as source for propagation material have resulted worldwide distribution of virus and virus-like diseases of fruit crops. Most of the diseases in fruit crops are dispersed mainly by person engaged in propagation through bud-wood or scion cultivars from infected plants.

Use of virus free bud wood for citrus nurseries propagation and certified elite planting material has been recommended and considered adequate to control the spread of citrus viruses such as tristeza, greening, ring spot, exocortis, mosaic, witches broom etc.¹³ The introduction and spread of root knot nematode and crown gall bacterial disease of grapevine in virgin areas can be checked using certified healthy planting materials. The use of disease free seeds have been suggested to manage citrus psoriasis virus, mango malformation, papaya ring spot virus, mulberry ring spot virus, mango bacterial cankers and malformation.¹⁴ When plants are propagated by seeds, these should be treated with fungicides. The latent infection in banana

suckers results in the introduction of banana bunchy top and mosaic viruses in new plantations. Precaution must be taken not to introduce peach plants infected with root knot nematode for planting new orchards. Extraction of seed from healthy fruits is recommended for raising *Phytophthora* free citrus nursery. The fruit should be harvested from the tree at height of 4 feet or more to avoid the disease infection from soil near ground level. Strict sanitary measures should be followed while extracting and cleaning the seeds.¹⁵

Orchard density/spacing

Proper recommended spacing in fruit crops prevents development of high humidity on plant surface which favor many diseases like mango sooty mould, citrus canker and *Phytophthora*, grapes downy mildew, powdery mildew and anthracnose. Narrow spacing (10x10ft) in Kin now mandarin trees have more sooty mould build up than widely spaced (22x22 and 25x25ft) trees.¹⁶ Affected fruits are more prone to sun burn injury and are also drop prematurely. North-west facing (shady) site of Kin now mandarin in 10x10ft spacing have more incidence of sooty mould than South west (Sunny) site due to more development of congenial environment in shady sites. The incidence of sooty mould is more in dense orchards of mango. Tree exposed to Eastern side have less incidence of sooty mould while the tree in the centre of the orchard have incidence as high as up to 95%.¹⁷

The shade of tree canopy and build up of humidity in dense orchard increases the incidence of citrus *Phytophthora* and downy mildew of grapes. Similarly, closely spaced banana plants are more prone to sigatoka disease. Grapes powdery mildew, downy mildew and anthracnose can be reduced by checking overcrowding and dense growth of the grapevines. Damping-off diseases in fruit nurseries causes severe damage when seedlings are overcrowded. In contrast, incidence of pineapple wilt virus was recorded maximum in wider (135X75X37.5cm) and minimum in (90X60X30cm) closer spacing.

Nutrition

Nutrition is one of the environmental factors that affects plant diseases, their survival, and virulence of pathogen, vigour and resistance of plants and also favor biocontrol agents. Good nutrition has been recognized as preventive measures for ailments where as wrong or excessive applications are inviting the problems. In addition to C, H and O, thirteen mineral nutrients are generally essential for plant growth, development and production of good yield.¹⁸

In general, high nitrogen levels increases susceptibility to many diseases while potassium increases resistance and the role of phosphorous is variable. Severely nutrient deficient plants are also more vulnerable to the attack of the diseases than that fertilized with recommended rates. The incidence of apple canker (*Nectria galligena*) is higher in trees applied with 250KgN/ha annually than 100KgN.¹⁹ Incidence of white root rot of apple (*Rosellinia necatrix*) increases with the addition of commercial nitrogen fertilizers. Addition of organic amendments or reduced dose of fertilizers helps in reducing the disease. Nitrogen deficient stone fruit trees are more susceptible to *Leucostoma* canker than those fertilized well. Application of optimum dose of nitrogen fertilizer helps in managing peach leaf curl disease. In contrast, high nitrogen doses favor the Panama disease of banana.

The spread of guava wilt could be checked by judicious amendments of N, Zn, oil cakes and Lime whereas under green managing, no incidence of wilt was noticed.²⁰ The incidence of wilt was less at 630ppm N but was more at both higher and lower levels. Application

of phosphate was effective in reducing the attack.²¹ More incidence of the guava wilt was recorded in Lateritic soil pH 6.5²² and in clay and sandy loam soil.²³ The floral malformation in Dusehri mango can be reduced by increasing the rate of N from 100–300gm/plant/year.²⁴ In contrast, P or K (P+K) application increased the malformation drastically and their regular uses should be discouraged. The incidence of bunch rot or grey mould of grapes can be reduced by controlling excessive vegetative growth by judicious N fertilizations.²⁵ Normally high nitrogen application favors virus multiplication but also reduces disease severity or symptoms. Nitrogen deficient or below the optimal level plants are more damaged by viral infection. A high rate of nitrogen usually increases resistance to facultative parasites (causing necrotic leaf spots) in fresh, green, young plant tissue. Thus diseases caused by obligate and facultative parasites exhibit quite opposite reaction to high nitrogen fertilization.²⁶

Excessive application of nitrogen increase citrus canker, *Xanthomonas citri*.²⁷ Neither form of nitrogen prevents infection of stone fruits by *Xanthomonas pruni*, although NH₄-N reduced bacterial cankers of *Prunus* by hastening periderm development, so that cankers healed more promptly. In contrast, NO₃-N reduced defoliation of peaches and plums. Excess nitrogen and deficient zinc, iron and magnesium increased the susceptibility of grapevines to bacterial canker disease, *Xanthomonas campestris* pv. *Viticola*. The time of application of nitrogenous fertilization also may have a pronounced effect on disease expression. “Side” – Dressing of nutrients to post emerged seedlings avoid the attack of damping-off diseases (*Rhizoctonia* or *Pythium*) but may increase *Fusarium* (*Gibberella*) and other root rots due to mechanical injury to root system or plant parts. Application of various levels of NPK result difference in incidence of pineapple wilt virus.²⁸ Addition of high phosphate fertilizers in pots favored growth and parasitism by *Thielaviopsis besicola* by reducing growth rate of citrus plants.²⁹

Application of optimum doses of potassium helps in managing the *Alternaria* blight of apple. The grapevines with potassium deficiency are more susceptible to *Botryodiplodia theobromae* showing negative correlation of K status of vines with the disease.³⁰ Potassium has been found to reduce apple scab; likewise K is also responsible for aggravating apple fire blight (*Erwinia amylovora*). Addition of farm yard manure (FYM), poultry manure, coffee and cherry husk and pulp fruit skin (waste) in the mandarin trees basin reduce the citrus *Phytophthora* and increase the biological agents, *Trichoderma* spp.³¹ Incorporation of composed tree bark in the soil mixture for raising nursery stocks in containers of fruit plants provide effective control of soil borne diseases caused by *Pythium*, *Phytophthora*, *Rhizoctonia*, *Thielaviopsis* and *Fusarium*.

The damping-off citrus seedlings can be managed by modifying soil pH with adding certain fertilizers. A pH of 4.0–5.5 has been found to be most congenial for avoiding the disease; this pH range is maintained by applying 500 lbs ferrous sulphate with 10,000lbs of sulphur per acre and ploughing deep (15cm) into the soil.³² This pH level is also favorable for biocontrol agents, *Trichoderma* spp. that parasites the citrus damping-off fungus, *Rhizoctonia solani*.³³ Higher doses of nitrogenous fertilizers should be discouraged to force growth. Ammonia and nitrate in higher concentration injure or kill the tender plants.³⁴

Irrigation

Careful water management in orchards and nurseries helps in

minimizing damping-off, *Phytophthora*, *Pythium*, *Rhizoctonia*, *Fusarium* diseases of fruit crops. Damping-off of papaya and citrus is more severe in warm and wet weather and the disease causes heavy mortality when seedlings are overcrowded. Raised seed bed or polyethylene bags or plastic trays with proper drainage facilities should be used for raising nurseries or transplanting of young seedlings.¹² For controlling citrus damping-off, nursery should be raised in soil having pH 4.0–5.5 which also favor the biocontrol agent *Trichoderma* spp. which parasitised *Rhizoctonia solani*. Frequency and interval of irrigation prevents lethal infection of *Phytophthora* spp. in citrus. New planting should be done on raised berms to help drainage of water away from tree trunk and root zones. Citrus foot and root rot caused by *Phytophthora* spp can best be controlled by keeping bud union least 6–9 inches above soil line at the time of planting so that irrigation water does not come in direct contact with the scion portion which are most susceptible.³⁵

Citrus *Phytophthora*, moko and panama diseases of banana, guava wilt, papaya foot rot and damping-off seedlings in nursery beds and white root rot of apple are the important fruit disease that can be easily controlled by managing the irrigation water. Flood irrigation helps a lot in increasing the incidence and spread of citrus foot rot/gummosis by the movement of water from the infected plants to healthy plants. That is why number of plants showing foot rot/gummosis symptoms are always found neighboring to affected plants in the orchards. The incidence of citrus foot rot, guava wilt, Panama disease of banana, moko bacterial wilt of banana and white root rot of apple is more and spread is accelerated with flood irrigation and with the onset of monsoon. White root rot of apple is serious in water logged and heavy soils of Himachal Pradesh and in U.P. Hills at pH 5.5–7.0. The grape anthracnose is severe in warm and wet weather and with increase in RH and precipitation during monsoon the disease showed its maximum effect.³⁶ The survival of grape canker bacteria can be reduced from 45 days to 25 days by deep ploughing the infected fallen leaves in moist soil conditions.³⁷

In contrast, flood-fallowing the soil for longer period after residue deep ploughing enhances the control of Panama disease of banana and sclerotia of *Sclerotium sclerotiorum* where as better drainage helps in reducing the moko bacterial disease of banana. Proper and adequate drainage of soil reduces the number and activity of some soil borne pathogen like *Pythium*, *Rhizoctonia*, *Phytophthora* and nematodes. Drought conditions during winter also prevent the development and survival of the apple scab fungus on scabby leaves.³⁸ Flooding field for longer period or drying fallowing also helps in reducing the pathogen like *Fusarium*, *Rhizoctonia*, *Pythium*, *Phytophthora* and nematodes. In general, tree receiving drip irrigation suffered less damage than flood irrigated trees. Bacterial canker in vineyards and citrus *Phytophthora* incidence was recorded less in trees receiving drip irrigation than flood irrigation. Drought condition favour peach leaf curl disease and periodic irrigation of tree helps in managing the disease.

Pruning

It is one of the important mean for plant protection and easiest and best tool for reducing the primary inoculum of various fruit diseases. Being the perennial nature of the fruit crops, a number of disease cycle are produced depending upon favorable weather and availability of susceptible host plants. Thus reservoir of inoculum develops which helps in the fresh occurrence and dormant survival of the pathogen.

The effective fungicidal control is difficult, when the diseases are well established through perennial infection within the orchard. The only viable practice to reduce the inoculum is the pruning of diseased plant parts like leaves, twigs, branches, fruits, etc. and their proper destruction help in reducing the carrier organism.

Pruning should be performed in warm dry weather to promote rapid wound healing. Pruning should be well planned each year to avoid large cuts and injuries which heal more slowly. All infected, dead and weakened wood should be pruned. Pruning of parts to open the center of the tree for better light penetration helps in managing the shade loving diseases. Infected plant parts (cankers) should be removed in the season when tree heals promptly. For surgical treatments, scrap the affected diseased bark portions of the tree trunk, branches and limbs along with 3–5cm healthy bark with the help of sharp tools (knife). The scrapped diseased bark and pruned wood should be collected and destroyed completely to avoid the re-occurrence of the disease from raked pruned dead wood. Pruning tools like knives, shears, saws, secateurs should be disinfected between cuts in disinfectant solution (alcohol or mercuric chloride). Large cankered or dead limbs should be removed by cutting 10–15cm below the canker margin. Surgery sites, cut ends or wounds should be covered with fungicidal preparation like Bordeaux paste or paint etc. After pruning spray of Bordeaux mixture helps in rapid wound healing and control of dormant inoculum. Dormant protective sprays of Bordeaux help in managing the diseases of deciduous fruit crops.

The incidence of apple, citrus, mango and grapes cankers; citrus scab, brown rot of stone fruits, mango malformation, anthracnose, post harvest fruit drop in citrus, powdery mildew of fruit crops can successfully be reduced by pruning of infected plant parts. Removal of infected leaves helps in reducing or removing the inoculum potential. Pruning of infected plant parts before the commencement of new flush reduces the primary inoculum potential of citrus diseases like cancer, anthracnose, scab, post harvest drop, pink disease and powdery mildew. Pruning of dead wood and branches showing greening disease symptoms will help in minimizing the disease and its secondary spread by psyllid vector. Pruning of mildew twigs in dormant stage/shoot before green tip stage are effective in reducing the apple powdery mildew in current season as well as next season crop.³⁹ Removal of lower infected leaves at 2–3 months interval and destruction of previous crop debris are useful in reducing the inoculum thereby reducing the sigatoka disease of banana.⁴⁰

Removal of infected twigs, shoots and leaves and their destruction by burning helps in reducing the grape powdery mildew and anthracnose in current season as well as during coming season.⁴¹ Improvement in sunlight by removing excessive vegetation in grapevine will improve the microclimate in reducing the incidence and spread of powdery mildew and downy mildew diseases. Removing of over wintered mummified berries from grapevine and ploughing mummies into the soil are beneficial in the control of grape downy mildew. Pruning of infected canker branches and uprooting of dead and severely infected vines provide control of crown gall of grapevine.⁴²

Time of pruning also greatly affect the disease intensity of grape bacterial canker. Pruning during 1–15 September is highly vulnerable for the disease development and spread in Maharashtra and North Karnataka due to frequent rains during this period. Pruning of vine after second week of October is recommended because monsoon becoming dry from second week of October onwards which is unfavorable for

the disease development. Collection and burning of diseased twigs and leaves helped in managing mango powdery mildew and anthracnose as they serve potential perennation. Pruning has been found effective for curing mango malformation disease. The diseased vegetative and floral malformed parts should be pruned along with the basal 15–20 cm apparently healthy portion and burnt.⁴³

Leaf pruning is the useful practice for reducing the damage from *Graphiola* leaf spot disease of date palm. Pruning of deadwood and pasting of cut ends are the only effective methods to combat the mango die-back (*Botryodiplodia theobromae*). Regular inspection for a fresh infection, judicious pruning followed by spraying/pasting greatly helps in controlling the disease.⁴⁴ Clipping of scabby and cankerous leaves during July helps in minimizing disease severity of citrus scab and canker and their further spread in the citrus orchards and nurseries. Pruning of dead wood during January–February before the start of new growth in citrus helps in reducing the incidence of anthracnose, *Diplodia*, *Alternaria* and sooty mould diseases. Spray of Bordeaux mixture followed by Bordeaux paste and paint to cut ends control this disease effectively. The productivity of disease infected declined orchards (rejuvenation) can be increased with pruning/head backing followed by prudent management of irrigation and nutrition.

Intercropping

Inter-cropping with certain crops helps in reducing the inoculum of the diseases or population of root knot nematode in the fruit crops. These crops either produce chemical substances which are inhibitory to the micro-organism or affect the population so that main crop escapes from damage. Intercropping the grapevines with marigold (*Tagetes* spp), asparagus or sun hemp was effective against root knot nematode, *Meloidogyne incognita*.⁴⁵ These antagonistic plants release toxic substance in soil that helps in reducing the population of plant parasitic nematodes. In contrast, cucurbits as intercrop help in outbreak of banana mosaic. The susceptible weed flora and intercultivation of cucurbits should be stopped to reduce the incidence of papaya mosaic virus.

Trap plants are also used against nematodes which attracts the nematode from the main crop. They help to reduce the amount of inoculum or population of nematodes reaching the main crop. *Crotalaria* trap plants, traps the juveniles of root knot nematode. Bacterial canker diseases of mango, grapevines, citrus, banana moko, stone and pome fruit are generally spread by wounds/mechanically injuries during various orchard operations like ploughing, planking, pruning and other tractor drawn operations. Care must be taken to avoid such wound/injuries to the fruit plants. Bark injuries attract more insects and develop more infection than intact bark. Most of the soil diseases also enter the plants through wounds or injuries like citrus *Phytophthora*.

Crop rotation

The cultivation of the same crop (orchards) or related crops for longer period leads to the continuous survival of the pathogen in soil or on plant parts which gradually increases the disease intensity. As a result soil becomes “sick” and creates replant problems in certain fruit crop like peaches and citrus. Crop rotation completely control the diseases of crops that only survive on living plants or as long as their residue available for their saprophytic activity. Crop rotations for 3–4 years with non-hosts crops reduce the incidence of Panama disease of banana. Soil fallow or crop rotation with non-host crops

for 12 months for strain B and 6 months for strain SFR are refereed to control the moko disease of banana. Rotation of fruit crop with wheat appears to be beneficial for reducing the population of ring nematode.

Fallowing is helpful in reducing the inoculum during hot summer. Fallowing for 6–12 months before replanting helps in reducing the citrus *Phytophthora* in the soil. Host free period or fallow for 1–4 years should be allowed before replanting of new vines infected with root knot nematode in the orchard. The population of ring nematode should be kept under check because they predispose the peach and French Prune trees to bacterial canker.

Orchard floor management

Freeze injury in grape vine helps in development of crown gall bacterium. Management practices that reduce injury are useful in managing the disease. Burying of young vines in fall reduce the freeze injury. “Hilling” of trunks with soil in the fall is practiced to protect crown tissue from cold temperature. Another common practice, the use of multiple trunk vines in Northern United states to overcome the problem of bacterial crown gall. Out of various training system of grapes, Head system showed least development of grape anthracnose.⁴⁶ In contrast bacterial canker is late and less in Telephone system and maximum in bower system. Number of canes per unit area also favored the disease if were kept more than recommended ones. Training of Kin now and sweet orange plants and grapevines by removing the low lying braches and canes helps in controlling the citrus *Phytophthora* fruit rot and grape anthracnose. Training of grapevines should be performed in such a way that splashes of wet soil during raining season may not reach the foliage, canes, and branches to reduce the incidence of anthracnose, canker, and downy mildew diseases. Training of branches even removal of foliage covering fruit bunches reduces disease intensity and improves chemical control. Over crowded canopy leads to early incidence and outbreak of grape bacterial canker. This also restricts the bactericides to reach the targets.

Bearing citrus tree affected by foot and root rot can be saved by earthing up or enarching of root stocks.⁴⁷ For earthing, the dead and affected bark is removed along with healthy bark and the surgery sites (trunk portions) are earthen up. Soil is kept moist for the regeneration of roots from the healthy trunk portion and root zone area is also drenched with effective fungicides. For enriching, 1–4 seedlings of resistant rootstocks are grown near the affected trunks and then grafted on the trunk to give strength to root system of damaged plants. Pre-harvest fruit rots caused by various fungi in date palm are the major problems worldwide. High humidity and rain at *Khalal* stage to fruit maturity can cause yield losses upto 65.12% in variety Khuneizi at Bikaner centre. Pre/post-harvest fruit rots can be reduced by inserting wire rings in bunches prior to the *Khalal* stage to facilitate ventilation and rapid drying of wet fruits. Paper wrappers should be used in early *Khalal* stage to protect the bunches from rains.⁴⁸

Nucellar embryony

This is another important method used for the control of viral diseases. Citrus viruses are rarely seed borne and are generally restricted to the vascular tissue particularly the phloem. Since there is no direct vascular link between the parent and either the nucellar embryos. The virus particles are eliminated in the seedling offspring.⁴⁹ Most of citrus varieties produce two distinct types of embryos. The gametic (nucellar) embryos are produced asexually from somatic cells of seed parents and lie along the normal embryos. These nucellar

embryos are similar in genetic characteristics of mother plants and seedlings are therefore true to type. Nucellar seedlings from the virus infected parent trees are free from the viruses. Bud wood from the nucellar seedling can be exploited for the mandatory bud wood certification programmed. For the selection of nucellar seedling, *Poncirus trifoliata* is used as pollen parents, as it imparts a dominant trifoliate leaf character to all hybrid seedlings which can thus be eliminated. Nucellar seedlings have certain drawbacks like they have more thorns, bear late and produce poor quality fruits. However these can be overcome by using apical parts or bud wood from old nuclear limes.

Orchard sanitation

The most important, cost effective and environmentally safe disease management practice in fruit diseases is to identify and eradicate infected plant source that helps in further spread of the disease in new plants/groves. Once any tree gets infected with a virus and virus like agents, there is no practical method to eliminate the virus. The only remedy is to uproot and destroy the infected plants and replant with certified healthy plants. Removal and destruction of unproductive trees infected by citrus viruses (tristeza, greening, exocortis, ring spot, mosaic, psoriasis⁵¹) and replanting with certified elite planting materials free from these viruses on tolerant root stocks as recommended. This will also prove helpful in checking the further spread of the viruses in the grove⁵⁰⁻⁵². Similarly, other viral diseases of banana, grapes, papaya, pome and stone fruits, can be managed by removing the source of infection of infected plants and replanting with healthy nursery plants.

Sanitation is the destruction of diseased plant material in the form of plant parts in the field or crop residue after harvest. Ploughing of infected plant parts like leaves, stems, trunks, tubers, rhizomes, roots and left over fruits in soil help to cover the inoculum in soil which facilitate in quick disintegration (rotting) of plant materials. Removal and destruction of diseased plants, over-wintering and over-summering hosts and alternate/collateral or wild hosts are useful in plant disease management. Rogueing of infected plants should be performed routinely in nurseries, green houses and orchards to prevent the spread of diseases which serve as ready source of inoculum. Eradication programme is the best approach to eliminate and eradicate the citrus canker completely in USA, South America, New Zealand and Australia by destroying millions of canker infected trees with the adoption of mass eradication campaign. The eradication campaign of banana bunchy top virus had been successful in keeping the disease spread in check. Exclusion of the disease by destroying diseased plants helps in checking the spread of banana bunchy top virus from plant to plant by aphid. Similarly, banana mosaic plant must be removed out from the field to avoid further spread by aphid.⁵³

The most practical way of combating apple scab (*Venturia inaequalis*) is disturbing the over-wintering cycle of the pathogen responsible for ascospore production which serves as primary inoculum. Removal and burning of fallen leaves help in controlling the disease as the fungus survives saprophytically on the diseased leaves. Ploughing of diseased leaves in soil prevents the subsequent development of ascogenous stage of the fungus. Application of 5% urea at leaf fall helps in the formation of pseudothecia, thus reducing primary inoculums.⁵⁴ Removal and proper destruction of infected plant parts like mummified fruits, dead twigs and pruned wood greatly reduces the canker of apple, mango, grapes, citrus, and sweet cheery. Removal of infected shoots in winter and affected fruits during

thinning aids in controlling powdery mildew of stone fruits, apricot, plum, cherries peaches, nectarines. The ignorance of removing Peach X disease infected tree results in much higher incidence than the removed trees. The removal of peach root knot nematode (*Meloidogyne* spp.) infected plants and old roots in replant situation, helps a lot in managing the disease.⁵⁵ Raking of fallen and dried leaves and their destruction help in reducing the incidence of peach leaf curl (*Taphrina deformans*).

The crown gall bacterium (*Agrobacterium tumefaciens*) survives in vineyards within the galls and vine parts. Proper destruction of diseased vines and its parts especially roots are important in reducing the disease. Similarly, root knot nematode infected declined vineyards must be removed with the cutter below the crown, not to pull out with chain which usually breaks off the trunk at ground level. Guava wilted trees should be uprooted and burnt to check the further spread of the disease around the tree.⁵⁶ Destruction of infected plant parts, regular inspection and seedling certification have been recommended as preventive measures for mango bacterial canker.⁵⁷ Diseased leaves, twigs, fruit lying on orchard floor should be collected and all infected twigs from the tree should be pruned and burnt for the effective control of mango anthracnose, *Colletotrichum gloeosporioides*. Collection and burning of all the infected inflorescence and spathes helps in reducing the incidence of Khamedj disease/inflorescence rot (*Mauginiella scattae*) of date palm.

Destruction of alternate/collateral hosts

Some diseases of the perennial crop overwinter or over summer mainly on wild plant or alternate/collateral hosts. Eradication of these hosts helps in elimination of the source of inoculum. The destruction of wild grasses, sedges and lilies as well as wild grapevines helps in reducing the Pierce's disease bacterium in California. Similarly, elimination of wild *Prunes* and grasses, especially Johnson grass control the Phony peach disease as they serve as breeding and over wintering grounds for the vector, sharpshooter leaf hopper. Removal of rose bushes highly susceptible to powdery mildew in home garden has effectively controlled the disease without protective spray of fungicides.

Various citrus hosts like Meyer lemon and *Evodia hupelensis* are the symptom- less carriers of tristeza virus. They should be removed and eradicated from the orchards as they act as foci for the secondary spread of the virus. Collateral hosts like Curry leaf (*Murraya* spp.) should be destroyed and not grown in vicinity of citrus nursery and orchards as they serve hosts for citrus psylla (greening vector) breeding and multiplication. Removal of collateral/alternate hosts for both bacterium and psylla vector will help in minimizing the greening disease of citrus.

Elimination of leguminous hosts and wild *Prunus* species is useful for control of primary inoculum of anthracnose of stone fruits. The wild Chocherry and Bitter cherry are the important reservoir host of Peach X disease in California and their removal within 200m of peach orchard significantly reduce the disease. Elimination of known hosts (balsam root, dandelion, plantain) of Cherry rasp leaf virus reduces the virus incidence. Cherry rasp leaf virus and Peach rosette mosaic virus are seed born in *Chenopodium quinoa* and their removal helps in managing the disease. Avoidance in cultivation of tobacco, tomato, cape berry, Zinnia and various weeds near papaya plantation helps in reducing the spread of leaf curl virus by whitefly. The papaya nursery should be raised in an isolated place free from whiteflies. Cultivation of papaya near cucurbits should be avoided to reduce the incidence

of papaya ring spot virus.⁵⁸ The fungus of pink disease of citrus (*Corticium salmon color*) forms its basidiophores on collateral hosts. Removal of these hosts near orchard is recommended for the effective control of the disease. Banana moko wilt disease has many weed hosts and strains. Killing of weed hosts and plants of *Heliconia* spp. away from main orchard helps in reducing the moko disease of banana.⁵⁹

Vector control

Insect-vectors serve as an important means for the dispersal of various plant pathogens. They affect plant diseases indirectly by acting as agents of dispersal of plant pathogens. Some pathogens can propagate and multiply inside their body, while other does not. All insects carrying plant viruses function as agents of dispersal and inoculation. Pollinating insects disperses bacteria of fire blight disease. The injuries caused by insects at the time of transmission of some pathogen may also serve as entry points for the penetration of other pathogens. *Fusarium*, *Alternaria*, *Colletotrichum* enters into plants through wounds caused by insects. Many fruit diseases are effectively transmissible by insect-vectors like citrus tristeza virus, banana bunchy top and mosaic virus, papaya mosaic and ring spot virus by aphids; Pierce's disease of grapes and Phony peach by sharp shooter leaf hopper; grape fan leaf virus by nematode; citrus greening by citrus psylla; citrus canker by citrus leaf minor; brown rot of stone fruits by Orient fruit moth, borer and fruit fly; moko disease of banana by insects; cherry rasp leaf and peach rosette mosaic by dagger nematode; sooty mould by honey dew secreting insects; papaya leaf curl by whitefly; pineapple wilt virus and little cherry virus by mealy bugs and cherry mottle leaf and peach mosaic by bud mite. The successful control of these diseases largely lies on the proper management of insect-vectors responsible for their spread from plant to plant with in the grooves.

The bunchy top virus of banana could be reduced by eliminating the aphid (*Pentalonia nigronervosa*) with insecticidal sprays, dusts, injection or in capsulation *in situ* before destroying the plants. Application of insecticides+weedicide (2,4-D) is highly effective in killing the aphid and diseased plants including stools. Similarly, incidence and spread of citrus tristeza virus can be reduced by controlling population of aphid vector. Bacterial wilt of banana could be managed by removal of male buds which help in transmission of the disease. Insect vector visiting the flower should be killed with proper insecticides. A single citrus psylla can transmit the greening disease and 5 or more psyllid per plant can transmit the disease up to 100%.⁶⁰ The psylla is more active during March–April and July–September on new growth flushes of citrus and sprays of insecticides during the active period give effective control. Biological control of psylla by parasites, predator and microbes can also be exploited.⁶¹

The sooty mould disease of fruit trees occurs in association with honey-dew secreting insects like aphids, whiteflies, psyllid, scales and mealy bugs, etc. Sooty mould of mango in Siyana blocks of Bulandshahar (UP) and citrus especially in Kin now mandarin and sweet oranges in Punjab are of serious concern. Application of suitable insecticides in combination with fungicides helps in reducing the disease incidence.⁶² Sharpshooter leaf hopper (*Xylella fastidiosa*) and Spittal bugs are the insect vectors of Pierce's disease of grapes and Phony peach. Growing of grapevine in California, away from hot spots area are effective in controlling the disease. Cherry mottle leaf virus and peach mosaic are transmitted by bud mite (*Eriophyes inequalis*) and control of mite reduces the disease incidence. Mite is wind borne and helps in spread of viruses in groves. In California, Brazil and Eastern United States, the success of control of brown rot

of stone fruits (*Monilinia* spp.) largely depends on the management of Orient fruit moth, Peach twig borer and Mediterranean fruit fly.⁶² The surgical treatments in fruit trees are generally performed in cool weather when vectors are inactive. *Ceratocystis* canker in stone fruits are mainly spread by Nitidulid beetle and Drosophila fly vectors. These insects are attracted to fresh bark wounds where they deposit the spores of the pathogen and then they feed on resultant fungal colonies. The disease is controlled by excluding them from fresh wound.

Bark injuries attract more vectors and develop more infection than uninjured bark. Cherry rasp leaf virus and peach rosette mosaic virus are transmitted by Dagger nematode. Use of fumigants for the control of nematode vector help in reducing the viruses in the orchard. Control of mealy bug helps in reducing the incidence of little cheery virus which act as its vector. Rigorous spraying for aphid may delay the spread of plum pox virus. Incidence of papaya ring spot virus can be reduced by planting new plants at least 375ft away from the main orchard.⁶³ Physical barrier to avoid any contact by winged aphids with papaya seedlings postpones the occurrence of PRSV when susceptible cultivars are grown. Papaya should be grown in an isolated area having limited cucurbits or old papaya so that plants are subjected to low viral inoculum.

Spraying suitable insecticides for the control of mealy bug vector and ants could reduce the incidence of pineapple wilt virus. Some time sticky yellow polyethylene sheets are used around the main crop for attracting and sticking of air borne vector (aphids and whitefly). It helps in reducing the incoming population of vector as well as disease inoculum reaching the main crop.⁶⁴ Red lady variety of papaya can be successfully grown under protected condition and plants remained completely free from Papaya leaf curl virus due to protection from white fly transmission.⁶⁵ Spray of fosmite for white fly control was effective in reducing the disease incidence.

Use of disease resistant varieties

Use of resistant varieties is the most effective and safest means of controlling the crop diseases. Several diseases resistant varieties have been developed in fruit crops but still a lot of to be achieved against many important diseases. To overcome conventional breeding, molecular breeding has been developed by which disease resistant gene can be identified, cloned and transferred to the desirable cultivars. Any gene, from wild or unrelated plant species which confers resistant to the pathogen can be cloned and transferred to cultivars and resistant varieties can be developed.^{66–68} The desired genes are introduced into plants to alter the quantity and quality of their produce as well as to make them resistant to the pathogens. Peach rot knot nematode can be managed by using resistant rootstocks like Nemaguard, Floridaguard, Shalil, S-37, and Okinawa Higamaand Nemared. Plum mariana and Myrobalan 29C also confers resistant to specific root knot nematode. A peach cross (Okinawa X Nemaguard) also exhibits resistance to root lesion namatode (*Pratylenchus penetrans*) and root knot nematode. Plum on Lovel peach and French pume on Nemaguard rootstocks gets less damage from bacterial canker. Several apple scab resistant cultivars viz, Co-op-12, Co-op-13 (Red free), Prima, Priscilla, macfree, Liberty and Sir Priz have been reported showing complete field resistance to the disease in Kallu Valley.⁶⁹ *Malus baccata* from Kashmir and Shillong remained free from scab and powdery mildew diseases of apple.⁷⁰ Crab apple cultivars and Maharaja Chunth and Golden Chiense have been found resistant to apple powdery mildew.⁷¹ McIntosh, Ec-38729 and Ec-38730 are moderate resistant to powdery mildew. Lucknow-49 and Allahabad Safeda, Chinese and Philippine guava is tolerant to wilt disease of guava. Use of resistant rootstocks,

Psidium cattleianum var. *lucidum* and *Syzgium cumini* (jamun) could be an effective method of controlling guava wilt.⁷² Florida and Costa Rico named Tainung No.5 is tolerant to papaya ring spot. Use of resistant hybrids, Allahabad Safeda X Banarsi Surkha and Apple color showed resistance to guava anthracnose.

Seedless lime and Lime kharna (rootstock) are resistant against citrus bacterial canker. Sweet oranges, mandarin (Kin now) and tangeloes are more susceptible, whereas Marsh seedless grapefruit, baramasi lemon and kagzi lime are comparatively resistant to the infection of citrus ring spot virus.⁷³ Trifoliolate impart resistant gene for citrus viruses. Trifoliolate and its hybrids, Rangpur lime, Citranges, Citron, Kharna khatta are susceptible to exocortis viroid. In contrast to Rough lemon, Cleopatra, Mandarins, Sweet oranges and Sour orange are tolerant. The incidence of the disease is low in India due to the frequent use of the tolerant rootstocks. Rough lemon, Rangpur lime, Tangelos, Trifoliolate oranges and its hybrids, Troyer, Yuma citrange, Volkameriana has imparted resistance to tristeza.^{74,75} However, many tristeza resistant rootstocks are also susceptible to other diseases like exocortis, blight and *Phytophthora*.

Kagzi lime Selection, RHR-L-49, 122, 124 and 149, Tenali, Purma Local and Hybrid ALH-77 (Kazi lime X Nepali Round lemon) has been found tolerant to citrus canker and tristeza virus.^{76,77} Tenali selection was also found free from citrus canker and *Phytophthora* diseases.⁷⁸ Sour orange and Trifoliolate oranges are highly tolerant to citrus *Phytophthora* but sour orange is susceptible to tristeza where as trifoliolate are to exocortis. Strains of Rough lemon (Akola) and Rangpur lime (Akola) have showed better resistance to citrus *Phytophthora*. Intergenic hybrid of citrus, CRH-12 (Rangpur lime X Trifoliolate orange) CRH-47 (Cleopatra mandarin X Trifoliolate orange), CHR-57 (Rough lemon X Trifoliolate orange) and Fortunella mandarins (Narangi and Calamondrin) are highly resistant to citrus *Phytophthora* and nematodes.^{79,80} He cultivar Pisang lilin (AA), Sanna chenkadli (AA), Elarazhiai and Kapoora-valli (AAB) are moderately tolerant to sigatoka disease of banana. Cavendish banana remains free from the attack of Panama wilt. All the *Vitis* species except *Vitis vinifera* have shown resistance to grape bacterial canker. Transgenic Papaya Plants resistant to papaya ring spot virus (PRSV) can be evolved by Coat Protein Medicated Protection (CPMP) through the transfer and expression of PRSV Coat Protein (CP) gene. Four transgenic papaya plant lines containing PRSV Coat Protein (CP) gene showed resistance to the virus and one line was completely resistant.⁸¹ Of the Zaijadi, Hallawi, thory, Barhee, Degletnor, Khalasa, Shamran, Hayani, Khadrawi and Medjol date palm cultivars, Zahidi was found resistant where as Medjol was found highly susceptible to the *Graphiola* leaf spot diseases.⁸² Out of the eight different rootstocks screened against citrus *Phytophthora* foot rot, Pectinifera was found resistant while Cleopatra was highly susceptible to the disease.^{83,84}

Thermotherapy

Heat treatments have been used for reducing or eliminating the inoculum in propagative plant parts or their products and in the soil by sterilization and solarization. Soil is sterilized in the container by passing steam under pressure. Most of the pathogen is usually killed at temperature between 60 to 72°C. Chemotherapeutic treatments are given through steam under pressure, hot water, hot air and moist hot air. Apple chlorotic leaf virus can be managed by thermo-therapeutic treatment at 37°C for 4weeks or more. Exposure of infected bud-wood at 50°C for 10minutes helps in controlling Plum line pattern

virus. Plum and Peach mosaic virus can be eliminated by keeping infected plants at 36°C for 4weeks. Dipping of bunchy top infected banana suckers in hot water at 70°C for 120minutes able to reduce the disease upto 10%. Banana mosaic virus can be controlled by exposing infected suckers to heat therapy at 38–40°C for 14days prior to meristem culture.⁸⁵ Dry heat treatment at 40°C for one day found effective in curing the infected suckers.

Citrus greening bacterium in the infected bud wood can be controlled by exposing the bud sticks to moist hot air at 47°C for 2 or 4hours or by keeping the pot plants at 38–40°C for three weeks. Moist hot air exposure at 45°C for 120minutes helps in eliminating the citrus ring spot virus from the infected buds. Treatment of citrus nursery stock with hot water helps in killing the nematode (*Radopholus similis*) present inside the rootstocks. Low temperature treatments (refrigeration) inhibit or retard the growth and activity of pathogen and helps in managing the post harvest diseases of fruit crops. Perishable fruits like Peach; Plum should be refrigerated soon after harvest. Sanitary selection combined with heat therapy is a powerful tool in reducing the incidence of Grape fan leaf virus. Dormant grape cuttings when immersed in water at 45°C for 3hrs, kills the Pierce's disease bacterium (Goheen and Hopkins, 1998). Hot water treatment of infected seedlings at 45°C for one hour helps in reducing the apple white root rot disease. Artificial ripening at 35°C is used in Australia to control brown rot of stone fruits. Pineapple wilt virus infected planting material could be freed from virus by exposing them to hot water (50°C for one hour) or dry heat (55°C for one hour) treatments. Solarization of soil during bright sunny days in summer months by covering the soil with polyethylene sheet may helps inactivating the soil borne diseases caused by fungi, bacteria and nematode near the soil surface. The temperature of polyethylene covered moist soil is increased 10–15°C than to uncovered soil.

Quarantine and legislations

Quarantine is the legal restriction on the introduction, movement and spread of a new pathogen to the disease free virgin area. Mandatory Bud-wood certification, crop inspection and establishing orchards in region unfavorable for pathogen are the quarantine measures which helps a lot in preventing the spread of the diseases to new unaffected area. The term quarantine means 'A forty day period'. Earlier this was used for the period of detention of ship arriving from countries where diseases like bubonic, plague, cholera and yellow fever were endemic. The plant quarantine can be defined as "the utilization of knowledge by an authority constituted by law, to prevent the entry or spread of injurious plant pests as a service in the public interest". Without quarantine measures a new pest, disease or weeds enter a new country and can multiply and spread to become dangerous to the crop in that country. Many fruit diseases like Downy mildew of grapes (*Plasmopara viticola*) from America to France, Chestnut blight (*Endothia parasitica*) from Asia to USA, Fire blight of apple and pear from England to India (established in U.P.), Bunchy top of banana from Sri Lanka to India (established in Kerala, Orissa, West bengal and Assam), Apple scab (*Venturia inaequalis*) from small area of Jammu and Kashmir to wide spread in Himachal Pradesh, Crown gall of apple and pears from England to India, Powdery mildew of grapes USA to England and Citrus canker from Asia to USA have got introduced from one region to other causing serious damage to fruit industry. The legislative measures to prevent the entry of crop pests and diseases were enacted in 1914 under the DIP Act (Destructive Insect and Pests Act) and were passed by the Government of India

on February 3, 1914. The DIP Act rests with the Director of Plant Protection Quarantine and storage under the Ministry of Agriculture. This organization looks after the bulk import and export of seed and planting materials and having recognized 26 ports (9 sea ports, 10 air ports and 7 land frontiers) for efficient functioning. This DIP Act has the responsibility to take necessary steps and to regulate the interstate movement of plants and planting material in order to prevent the further spread of destructive pests that have already entered the country.

To pass through the quarantine ports, carried plant material or products from a particular country should be accompanied with the *Phytosanitary Certificate* issued by the competent authorities. The Government of India also approved three other institutions; NBPGR—National Bureau of Plant Genetic Resources, New Delhi, FRI—Forest Research Institute, Dehradun and BSI—Botanical Survey of India, Kolkata for quarantine measures. The NBPGR involves in processing of germplasms, seed, plant material of agriculture, horticulture and silviculture crops, while FRI for forests plants and BSI for other economical plants. The Embryo Quarantine ban the import of plant material from a particular country having disease while Domestic Quarantine prevents the entry of pathogen from one state to another within the country. Presently, domestic quarantine against four diseases namely potato wart from 1959, Banana bunchy top from 1959, Banana mosaic from 1961 and Apple scab from 1979 and two pests; Fluted scales from 1959 and nematode *Globodera rostochiensis* from 1983 exists and prevent the spread of these pests from infected to unaffected area. Fortunately, by timely action plan of domestic quarantine has prevented the spread of golden nematode and wart disease of potato to other parts of India. With certain limitations, banana bunchy top has spread at a fast rate in Kerala. Restriction in the movement of planting materials like potato seeds (wart) from West Bengal and golden nematode from Nilgiris of Tamil Nadu, Kathae disease of cardamom from Anamali hills of Kerala, banana bunchy top and mosaic infected suckers from Gujrat, Maharashtra and Kerala and apple scab from Himachal Pradesh has resulted in the checking the spread of these diseases to other unaffected areas of India.^{86,87}

In India, we have no specific regulation for nurseries and certification of plants used for nursery propagation and their sale to the growers. For the production of citrus plants a number of unauthorized nurseries are operating in the Punjab state without having certified “Mother or Foundation Block” for bud wood. More over they are not also having sufficient Rough lemon plants (*Citrus jambhiri* Lush) for raising of rootstocks seedlings that imparts resistance to number of citrus diseases. Strict legislative measures should be enforced on the unauthorized nurseries and sale of nursery plants raised by unscientific means. Mandatory Bud wood Certification Programmed should be strengthened in India for reviving the citrus industry.⁸⁸ Rising of citrus nurseries free of *Phytophthora* on tolerant rootstock helps in minimizing the introduction of the disease in virgin area. The pathogens survive in the soil and along with earthen ball (Gachi) for new planting, get introduced in to the disease free area.

The most dramatic and successful examples of fruit virus control by quarantine is banana bunchy top virus. Strict quarantine measures also helps in exclusion of panama *Fusarium* wilt disease of banana as the primary inoculum comes from the infected rhizomes. Phytosanitary measures are necessary to prevent the spread of moko bacterial disease. Fruit should not be transferred from one country to another. Pierce's disease of grapevines spread can be checked following restriction in

the movement of infected planting material in California. Prohibition on the importation of little cherry infected ornamental cherries and use of virus free planting material have greatly reduced the spread of little cherry virus in British Columbia. In Australia, all introduction of grapevines propagative material are treated with hot water and grown in quarantine for inspection of bacterial wilt blight (*Xanthomonas ampelina*) to avoid the inadvertent introduction of the disease.

Biological control

The natural death of the pathogen is the best means for checking various crop diseases. Biological means usually exploit the microorganism for the control of harmful pathogens causing plant diseases without disturbing the ecological balance. Use of parasites and predators (biocontrol agents) which can eradicate or reduce the pathogen inoculum are helpful in managing the crop diseases. Various biocontrol agents like *Trichoderma* spp., *Gliocladium*, *Verticillium* spp., *Fusarium* spp., *Aspergillus* spp., *Bacillus subtilis*, *Agrobacterium* spp., *Pseudomonas* spp. has been used successfully for the control of orchard and forest pathogens.⁸⁹ The excellent control of bacterial crown gall disease of grapevine, pome and stone fruits by biological agent has been achieved by the use of strain of K 84 and its derivatives K 1026 of *Agrobacterium radibactor*. The endophytic bacteria from xylem sap of grapevine showed antagonistic activity against a range of tumorigenic bacterium, *Agrobacterium tumefaciens*.⁹⁰ These strains produce Agricin 84 that kill *A. tumefaciens* and prevents the disease. Commercial preparation are available that provides a therapeutic treatment for galls. *E. agglomerans*, *Rahnella azuatalis* and *Pseudomonas* spp have been found strongly inhibitory to *Agrobacterium vitis* which produces gall in grapevines.

Bioagents are more suited for the control of soil borne pathogens (*Pythium*, *Phytophthora*, *Rhizoctonia*, *Fusarium*, *Sclerotium*) and *Trichoderma* spp and *Gliocladium* spp. are the most extensively used mycoparasites. They occur in soil worldwide and are effective in controlling soil borne diseases like root rot, damping-off, wilt etc. Oospores of *Pythium*, *Phytophthora* and downy mildew fungi are vulnerable to a great variety of *Dactylella* spp. and *Trochoderma* spp. etc. *Trichoderma harzianum*, *T. viride*, *T. koningi*, *Pseudomonas putida* and *Myrothecium roroidum* provided effective control of citrus *Phytophthora*. *Pseudomonas putida* reduced the citrus *Phytophthora* soil population (41–66%) and root infection (22 %) for three month in citrus nursery.⁹¹ Integration of these bioagents with specific fungicides (metalaxyl, Fosetyl Al–Aliette) improves the efficiency in controlling the disease. *Trichoderma* parasitize the other fungi and lethal action is by the secretion of antibiotic substances like ‘viridin’ and ‘gliotoxin’. Citrus root rot can be reduced by using *T. viride* which killed 30 % of the fungus *Armillaria mellea*. Panama wilt of banana can be controlled by exploiting *Pseudomonas fluorescence*. Colonization of banana wilt fungus (*Fusarium oxysporum* f sp. *Cubense*) race 4 by bacterium *Burkholderia cepacia* has also been found.⁹² Similarly, moko bacterial wilt of banana control by using *P. fluorescence* and *Bacillus* spp.⁹³ The *Paecilomyces lilacinus*, fungal bioagents also effectively reduced root knot nematodes in banana.⁹⁴ Various fungal antagonist, *Ophiostoma* spp, *Chaetomium* sp, *Aureobasidium* sp. and *Phoma* spp. inhibit the growth of the apple scab fungus.⁹⁵ *Bacillus subtilis* and *Trichoderma koningii* have been used for controlling apple canker.⁹⁶ These agents suppress the ascospore and conidial production of apple scab fungus in fallen and growing leaves. *B. subtilis* and *P. fluorescens* significantly lowered the disease symptoms of citrus mal secco disease (*Phoma tracheiphila*) and the stem inoculated sour orange

seedlings maintained higher population of these bio-control agents of the host plant.⁹⁷ *B. subtilis* isolated from xylem fluid of chestnut suppressed the growth of chestnut blight pathogen (*Cryphonectria parasitica*) and reduced the lesion area on stem when applied 3 days prior to fungal challenge *in vitro*.⁹⁸

The rhizobacteria fluorescent *Pseudomonas* have been successfully used as seed inoculants for the control of plant pathogens. The mechanism of control has been found to be competition for iron between the biocontrol agent and plant pathogen. They produce extracellular 'Siderophores' (microbial iron transport agents) which complex the iron and make it less available for the plant pathogens. *Pseudomonas fluorescens* is antagonistic to *Rhizoctonia solani* and *Sclerotium* spp. and can be used for commercial applications. Seed can be coated with this bioagent and is called seed bacterization.⁹⁹ Application of *Pseudomonas fluorescens* to citrus plants is found to reduce the incidence of bacterial canker drastically.

For the control of chestnut blight (*Endothia parasitica*) hypovirulent strains was applied on the trees to cut down the disease incidence within ten years. Virulent strains of the pathogenic fungus can be converted into hypo virulent strain by transferring the hypovirulent character from a hypo virulent strain to virulent strain of the fungus using virus transmission factor (mycovirus). The mycovirus can cause hypovirulence (decrease in virulence of the pathogenic fungi) or even death of the fungus. In grapevines, wounds dressing preparation of *Trichoderma* are used for the control of Chlorotic vine leaf curl. Inoculation of pruning wounds with non-pathogenic *Bacillus subtilis* reduced the apple canker (*Nectria galligena*) disease to 80 %.

Cross protection is also used to protect a plant inoculated with mild strain from infection of severe strain of the same virus that causes more severe symptoms and losses. The susceptible cultivars are cross-protected against the more challenging isolates. Cross protection has been successfully used for the control of Citrus tristeza virus, papaya ring spot virus and banana bunchy top virus. Citrus tristeza control with mild strain of citrus trustees virus has been used on Peru Sweet orange in Brazil, Grapefruit in Australia, Grapefruit and Sweet orange in South Africa and Hassaku Dwarf in Japan. In India, Acid limes are cross-protected against severe strain of CTV and gave more yield than un-inoculated control and severe strain.^{100,101} In Northern India, existence of mild strain might be giving cross protection against severe and devastating strains. Citrus Improvement Programmed in South Africa supplies the cross-protected trees of high quality of Grapefruit and Sweet orange under bud-wood certification

programmed to the growers. The combined use of preimmunized grapefruit with mild isolate of tristeza and tolerant rootstock has protected the Grapefruit industry in South Africa from devastation. To date, cross protection appear to be more promising in preventing stem pitting damage from CTV. The mild strain (G₆-G₉) of citrus greening pathogen provided cross protection against severe strain (G₂) when inoculated to pineapple sweet orange and grapefruit seedlings. The protected seedlings showed more height, girth, leaves and inter-nodal distance.¹⁰² A mild strain of bunchy top virus of banana is wide spread in Fiji and can be used for cross protection.¹⁰³ This natural mild strain protection has probably been greatest salvation of banana industry in Fiji. Cross protection has also been tried for papaya ring spot virus.

Chemical control

Application of chemicals is still the principle method of managing number of plant diseases. Chemicals are used as fungicides throughout the world for combating various diseases. For the demand to feed the increasing population and to get more return per unit area, have increased the necessity for the regular use of fungicides. The invention of Bordeaux mixture (copper sulphate+lime) by Millard in France in 1882 for the control of downy mildew of grapes gained the importance of using fungicides. This unique and versatile mixture was later found effective against several diseases and is still widely used to control the number of diseases of many fruit crops. This mixture, besides controlling number of fungal diseases, is also found effective in reducing the incidence of certain bacterial diseases like citrus canker. Since then a number of fungicides belonging to different chemical groups have been developed and effectively applied for the control various plant diseases.^{104,105} About 150 different chemicals are used as fungicides throughout the world. The important different fungicides used in managing various fruit diseases are given in (Table 1). The chemicals used in crop protection are called *Pesticides* and depending on the kind of pathogen they affect, the chemicals are called fungicides-fungi; bactericides-bacteria; viricides-virus; insecticides-insects; acaroids-mites, rodenticides-rats, molluscicides-snails and slugs, weedicides-weeds and antibiotics-fungi, bacteria, viral, mycoplasmal infection.¹⁰⁶ An ideal pesticide should be fool proof, highly toxic to pathogen at lower concentration but safer to human beings or animals, cheaper, easily available, persistent, easy spreading nature, easy to handle and application, stable, simple to prepare, have high tenacity on the host surface and compatible with other materials used in plant disease control.¹⁰⁷⁻¹¹¹

Table 1 List of agro-chemicals generally used in managing the various fruit diseases

Group	Name of chemicals	Disease control
I. Surface protectants		
1. Sulphur fungicides		
a. Inorganic Sulphur Fungicides		
Elemental sulphur	Dust and wettable sulphur	Powdery mildew of apple, citrus,
	Mixture of Ca-polysulphide	grapes, mango, beer, peach brown rot, apple scab etc.
Lime sulphur	& Calcium thiosulphate	
b. Organic sulphur fungicides	Ziram, ferbam, thiram, Zineb, Nabam, dithane	Leaf spots, blight, anthracnose, rusts, damping-off, cankers, brown rot, leaf curl, root rot, short hole, downy mildew.
2. Copper fungicides		

Table Continued

Group	Name of chemicals	Disease control
a. Copper sulphate	Bordeaux mixture, paste, paint, Burgundy mixture, chestnut compound	Scab, leaf spots, blight, anthracnose short hole, downy mildew, cankers and foot rot/gummosis
b. Copper carbonate	Chaubattia paste	
c. Copper oxychloride (COC)	Fytolan, blitox, blue copper	
d. cuprous oxide preparation	Perenox, fungimar	
e. Copper hydroxide	Kocide	
3. Mercurial fungicides		
a. Inorganic	Mercuric & mercurous chloride	Seed and soil borne diseases of fruit crops
b. Organic		
Ethyl mercury chloride	Ceresan, granosen	
Phenyl mercury chloride	Ceresan, gallotox	
4. Quinone fungicides	Chloranil, Dichlone	Apple scab, peach leaf curl, anthracnose
5. Heterocyclic nitrogenous compounds	Captan, foltaf, captafol (difolatan)	Scab, leaf spots, rots, leaf curl, blights, moulds, cankers, anthracnose, Phytophthora
II. First generation systemic fungicides		
a. Benzimidazole fungicides (MBC)		Citrus fruit drop, wilts, blight, anthracnose, downy & powdery mildew, damping-off, root rot, collar rot, fruit rot, seed and soil borne diseases
Benomyl	Benlate	
Carbendazim	Bavistin	
b. Thiophanate methyl	Topsin M, Roko	
c. Thiabendazole	Mertect	
d. Oxathiins (Carboxanilides or anilides)		Smuts, rusts and root diseases
- carboxin	Vitavax	
- oxycarboxin	Plantvax	
e. Hydroxypyrimidines	Etherimol, ditherimol, Bupirimate, fenarimol	Powdery mildew of grapes, apple, peach, sigatoka of banana
f. Organ phosphorous	Triamophos, kitazin, hinosan	Powdery mildew, blast diseases
g. Morpholines	Tridemorph-calixin, dodemorph	Powdery mildew, rusts, leaf spot
III. Second generation systemic fungicides		
a. Phenyl amides	Ridomil, apron patafol, ridomil gold, parlay	Citrus Phytophthora, mildew, damping-off downy
Metalaxyl, furaxaxyl, benalaxyl, ofuracecyprofuram		
b. Cyanoacetamideoximes	Cymoxanil (Curzate m 8)	Citrus Phytophthora and downy mildew of grapes
c. Alkylphosphonates	Aliette	Citrus Phytophthora, grapes downy mildew
Fosetyl aluminum		
d. Cinnamic acid derivatives	dimethomorph	Phythium & root diseases

Table Continued

Group	Name of chemicals	Disease control
e. Carbamates	Prothocarb, propamocarb	Phythium, Phytophthora and fruit downy mildews
f. Sterol Biosynthesis Inhibitors (SBIs or EBLs)		
a. Triazoles	Triadimefon – Bayleton	Powdery mildews of apple, ber, grapes, mango, citrus & scab,
	Bitertanol - Baycor	Apple & citrus scab, leaf spots,
	Etaconazol	Leaf spots, scabs, die-back
	Propiconazole –Tilt	Powdery mildews, scab, leaf spot Grapes powdery mildew
	Hexaconazole - Contaf	
	Penconazole - Topas	
b. Imidazole	Imazalil	Post harvest fruit dips
c. Triforine	Piperazine	Powdery mildew, scab, brown fruit rot
d. Pyrimidine	Fenarimol	Powdery mildew of grapes, apple, Peach, apple scab, banana sigstoka
e. Phenyl carbamates	Diethafencarb, MDPC	Apple scab and MBC resistant pathogen
f. Benzene compounds	Dinocap –Karathane	Powdery mildews grapes, mango, beer
		Apple scab, peach leaf curl, brown rots
	Dodine - cyprex	Apple powdery mildew
		Apple powdery mildew
	Binapacryl – morocide	Apple scab, anthracnose, Phytophthora
	Chinomethionate-morestan	Root rots, collar rots, damping-off
	Fluazinam	
	Quintozone – brassicol,	
	PCNB, chloroneb	
IV. New generation fungicides with novel modes of action		
a. Strobilurins obtained from wild mushroom <i>Strobilurus tenacellus</i>	Kresoxim – methyl Trifloxystrobin	Apple scab, powdery mildew and downy mildew of grapes
b. Anilinopyrimidines	Mepanipyrim, pyrimethnil	Apple scab, grapes fruit rot
c. Oxazolidinediones	Famoxadone (DPX-JE 874)	Grapes downy mildew, leaf spots
d. Phenoxyquinolines	Quinoxifen (DE -795)	Grapevine powdery mildew
e. spiroketalamines	Spiroxamine (KWG-4168)	Grape powdery mildew
V. Antibiotics		
a. Aureofungin	Aureofungin Sol	Citrus gumosis & fruit drop, fruit rot, coconut wilt, apple white root rot, peach brown rot, cankers, mildews
b. Cycloheximide	Actidione	Leaf spots, powdery mildews
c. Griseofulvin	Griseofulvin	Mango powdery mildew
d. Streptomycin sulphate	Phytomycin, streptocycline	Citrus & stone fruit cankers
e. Tetracyclines	Terramycin, aureomycin, actinomycin	Citrus greening, coconut yellow, peach X disease, pear decline
f. Agrimycin –100	Streptomycin sulphate + terramycin	Bacterial diseases, cankers
g. Bacterimycin 2000	Bromonitropropane, bionol –100 G	Citrus canker
VI. Others		
a. Soil Fumigants	Formalin, carbon disulphide, chloropicrin, methyl bromide, DD mixture, dzomet	Soil borne diseases of fungi, bacteria, nematodes etc.
b. oils	Mineral oils, glyceride oil of plants, synthetic oil	Sigatoka of banana, citrus greasy spot, grape downy mildew, sooty mould
c. Plant activators	Benzothiadiazole –Bion	Sigatoka disease of banana
d. Homeopathic drugs	Thuja, cedron	Papaya viruses, citrus ring spot, citrus greening
e. Plant products/ extracts	Neem & sorgham extracts	Citrus ring spot virus

For the control of various fruit diseases, fungicides are applied as sprays, dusts, treatment of seed/planting materials, soil treatment, tree wound/surgery sites treatments, trunk injection applications and post harvest treatments of fruits. Currently, the term Biointensive Integrated Pest Management (BIPM) is used to lay major emphasis on conservation and enhancement of natural enemies and utilization of all compatible methods for achieving effective, economical and safe pest suppression.

Acknowledgements

None.

Conflict of interest

The author declares no conflict of interest.

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