7 Subtropical and Temperate Fruit Crops

7.1 Subtropical Fruit Crops

7.1.1 Mango, *Mangifera indica*

7.1.1.1 Anthracnose, *Colletotrichum gloeosporioides*

Anthracnose, also known as blossom blight, leaf spot and fruit rot, is a widespread and destructive disease of mango both in field and storage. Young plantations of Bombay Green cv. were completely wiped out from the Terai region of Uttar Pradesh as a result of severe wither tip.

i) Symptoms

The pathogen infects leaves, twigs, inflorescence and fruits (Fig. 7.1). On leaves, symptoms appear as brownish black sunken spots which later increase in size and coalesce, giving blighted appearance leading to shedding of leaves. On the twigs, brownish black necrotic lesions appear which later coalesce, showing twig blight and dieback symptoms. The fruit infection at early stage appears as black necrotic spots. These spots later coalesce resulting in reduced fruit growth and size. On mature fruits, the spots become more conspicuous resulting in reduced market value of the produce.

ii) Biomanagement

Bacillus subtilis was found relatively effective by controlling 50 % of the disease on fruits at post-harvest. Anthracnose disease of mango is biologically controlled by *B. subtilis* LB5 through inhibiting conidial germination (Ruangwong et al. 2012). *B. subtilis* isolated from the avocado phylloplane has been successfully exploited for control of preharvest (Korsten et al. 1992) and postharvest diseases of mango (De Villiers and Korsten 1994).

Koomen and Jeffries (1993) found that among 121 isolates antagonistic to the anthracnose pathogen, only *P. fluorescens* gave significant reduction of mango anthracnose. Pre-harvest foliar application of talc-based fluorescent pseudomonad strain FP7 supplemented with chitin at fortnightly intervals (5 g/l; spray volume 20 l/tree) on mango trees from pre-flowering to fruit maturity stage induced flowering to the maximum extent, reduced the latent infection by *C. gloeosporioides* besides increasing the fruit yield and quality (Vivekananthan et al. 2004).

7.1.1.2 Canker, *Xanthomonas campestris* pv. *mangiferaeindicae*

Bacterial canker is known to be present in Australia, Brazil, Japan, Kenya, Malaysia, Pakistan, South Africa, Sudan, Venezuela, Taiwan, Reunion Island, Somali Land and many other countries. In India, it is widely prevalent throughout the country, especially severe in North India. The loss ranges from 10 % to 80 % depending upon the severity and stage of infection. Its

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Fig. 7.1 Anthracnose on mango leaves and fruit

incidence and intensity ranged from 0.52 % to 60.0 % and 15.0 % to 90.0 %, respectively.

i) Symptoms

The disease attacks leaves, petioles, twigs, stems and fruits. Small water-soaked lesions appear in groups on any part of the leaf blade. They increase in size and turn brown to black surrounded by a yellow halo (Fig. 7.2). Several lesions may coalesce to form large necrotic patches which are often rough and raised. As the disease further advances, the infected leaves drop off. On young fruits, water-soaked lesions develop which also turn dark brown to black. Infected fruits may develop cracks in the skin, and those badly affected drop prematurely. The canker stage also invites the secondary infection from saprophytic fungi.

ii) Biomanagement

Bacillus coagulans is a potential bioagent which reduced the disease incidence to the extent of 75 % (Kishun 2003). Antagonistic bacteria like *B. coagulans*, *B. subtilis* and *B. amyloliquefaciens* (Pruvost and Luisetti 1991) and fluorescent pseudomonads (Tzeng et al. 1994) have been found to be effective biocontrol agents against the disease.

7.1.2 Grapevine, *Vitis vinifera*

7.1.2.1 Crown Gall, *Agrobacterium tumefaciens*

Crown gall is an important disease of wine grapes when they are grown in cold climates. Incidence may range from a few vines in a vineyard to 100 % of the vines.

i) Symptoms

Gall formation on the aerial parts of the vine is the most common symptom associated with this disease. The bacterium which causes crown gall may be present in plants that do not show any symptoms. Galls are usually noticed as swellings near the base of the vine and up the trunk (Fig. 7.3). Galls on roots of grape are not typical; however, the bacteria can induce a localized necrosis of roots. Young galls are soft, creamy to greenish in colour, with no bark or covering. As they age, the tissue darkens to brown. The surface becomes open and the texture becomes

Fig. 7.2 Bacterial black spot on mango leaf and fruit

Fig. 7.3 Aerial crown gall on grapevine

moderately hard and very rough. The surface tissue of the galls turns black as it dies, but the bacterium remains alive in the vine.

ii) Biomanagement

Control of *A. tumefaciens* by its relative *Agrobacterium radiobacter* strain K84 (Moore and Warren 1979) is achieved by immersing the roots of cuttings into a bacterial suspension (*A. radiobacter*) before transplanting them in the fields. *A. radiobacter* actively colonizes the roots of treated cuttings, preventing infection by *A. tumefaciens*. *A. radiobacter* produces a bacteriocin called Agrocin 84, which is thought to be responsible for the antagonistic effect (Slota and Farrand 1982). Commercial formulations of *A. radiobacter* include Galltrol-A, Nogall, Diegall and Norbac 84C.

7.1.2.2 Grey Mould, *Botrytis cinerea*

It is one of the principal causes of postharvest spoilage in storage.

i) Symptoms

In early stage, tissue just beneath the surface of fruit is infected loosening the skin from the flesh. The affected area turns light brown. The fungal infection advances into the inner flesh resulting in a soft watery mass of decayed tissue. Under

Fig. 7.4 Grey mould symptoms on grape berries

moist atmosphere, the fungus sporulates on the surface of the fruit and the typical powdery grey mould stage becomes evident. Infected fruits shrivel and turn dark brown (Fig. 7.4). The disease starts in midseason and continues to develop until harvest in the absence of rain. The fungus infects stigma and style and becomes latent in the necrotic stigma and style tissues at the stylar end of the berry. In a compact infected bunch, fruits inside may split during growth. Infection of such fruits results in bunch rot. Even a single field infected berry may cause 'nest rot' in transit and storage.

ii) Biomanagement

An endophytic plant growth-promoting rhizobacterium, *Burkholderia phytofirmans* strain *PsJN* colonizes the roots of grapevine and protects it from the grey mould disease. *B. phytofirmans* is the host bacterium of grapevine that protects the host plant by tightly attaching to the plant and extracellular alkalization. However, a non-host bacterium *Pseudomonas syringae* pv. *pisi* attached tightly primes plant with extracellular alkalization and by a two-phase oxidative burst, with a Hypersensitive Reaction (HR)-like response (Bordiec et al. 2011).

7.1.2.3 Root-Knot Nematodes, *Meloidogyne incognita*, *M. javanica*

In India, *M. javanica* is most prevalent in the northern part of the country and *M. incognita* in the southern part. *M. incognita* is also reported in some parts of Haryana. *M. incognita* was responsible for 55 % loss in fruit yield of grapes, while *M. javanica* caused 53 % loss in yield.

i) Symptoms

Patches of poorly branched vines with scant foliage, pale and small leaves and poor bearing are the indications of root-knot nematode damage. In young plants, premature decline and weak vegetative growth are commonly associated with nematode attack. The root system shows typical localized swellings particularly on feeder roots and young secondary roots, and females may be found on internodal trunk just below the ground level. *M. incognita* has been reported to stimulate the production of many new fine rootlets above the site of nematode infection resulting in 'hairy root' condition. Depending upon the variety of grape, *M. javanica* forms galls of varying size and shape and distorts the normal appearance of roots (Fig. 7.5).

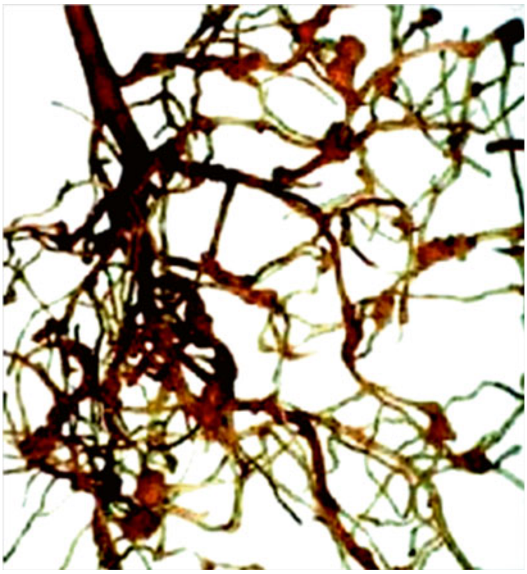

Fig. 7.5 Root-knot nematode on grape roots

ii) Biomanagement

Sundarababu et al. (1999) observed that the commercial formulation of *P. fluorescens* reduced root-knot nematode population effectively and enhanced yield in grapevine.

iii) Integrated Management

(a) *Cultural methods and bioagents*: Pruning (during July) and soil application of 4 g talc formulation of *P. fluorescens* (containing 15 × 10^8 cfu/g)/vine around root-knot-infested grapevine roots at 15 cm depth in the basin significantly reduced root galling due to *M. incognita* (39 %), number of egg masses (250 %) and increased fruit yield (166 %) (Santhi et al. 1998) (Table 7.1).

7.1.2.4 Root-Knot, *Meloidogyne incognita*, and Wilt, *Fusarium moniliforme*, Disease Complex

i) Symptoms

Simultaneous inoculation of nematode and fungus resulted in the greatest reduction of shoot length (40.6 %) and shoot weight (63.9 %). Wilt disease was observed when both *M. incognita* and *F. moniliforme* were inoculated or when the fungus was inoculated alone. The incidence of wilt disease (35 %) was higher in vines inoculated with nematodes a week prior to fungal inoculation.

ii) Integrated Management

(a) *Bioagents and botanicals*: Soil application of *P. fluorescens* at 100 g and FYM at 20 kg/vine gave effective management of disease complex and improved the plant stand by reducing the final soil nematode population (56.9 %), root gall index (1.8) and per cent disease incidence (15.67 %). This treatment also increased the number and weight of fruit bunches (17.83 and 155.40 %, respectively) and fruit quality (more TSS 13.53 Brix, TSS/acid ratio 14.87, lower acidity 0.91 %). The bunch weight of grapevine increased by 155.4 % compared to untreated control (Senthil Kumar and Rajendran 2004).

7.1.3 Guava, *Psidium guajava*

7.1.3.1 Anthracnose, *Gloeosporium psidii*

The disease is a serious problem in Uttar Pradesh, Punjab and Karnataka. This is a serious postharvest disease of guava.

Table 7.1 Field evaluation of biocontrol potential of *Pseudomonas fluorescens* against *Meloidogyne incognita* infecting grapevine

Treatment (dose/vine)	No. of galls/5 g roots	No. of egg masses/5 g roots	Root colonization (cfu/g + 10^8)	Yield (MT/ha)
P. fluorescens – 1 g	428c	94c	24	12.07b
P. fluorescens – 2 g	390b	85b	36	15.41c
P. fluorescens – 4 g	326a	72a	58	22.07d
Carbofuran 3G – 60 g	300a	67a	–	31.65e
Control (untreated)	535d	180d	–	8.33a

Figures with different letters are significantly different from each other at 5 % level by analysis of variance test

i) Symptoms

The plant shows dieback symptoms. Pinhead spots are first seen on the unripe fruits which gradually enlarge measuring 5–6 mm in diameter (Fig. 7.6). They are dark brown to black in colour, sunken and circular and have minute, black stromata in the centre of the lesions which produce creamy spore masses in moist weather. Several spots coalesce to form bigger lesions. The infected area in unripe fruits becomes corky and hard and often develops cracks in case of severe infection. On ripe fruit, the infection causes softening of tissue, and lesions attain a diameter of 10–20 mm. Unopened buds and flowers are also attacked and cause their shedding. Spread of infection is very rapid on fully mature green fruits, while young fruits do not normally take infection, perhaps due to the differences in the concentration of K ions in the tissues.

ii) Biomanagement

P. fluorescens was found effective in checking the spread of pathogens on fruits compared with the pathogen-inoculated control.

B. subtilis was found relatively effective by controlling 50 % of the anthracnose disease on fruits at postharvest stage.

Actinomycetes of cow dung have been identified as having potential against anthracnose of guava (Garg et al. 2003).

7.1.4 Pomegranate, *Punica granatum*

7.1.4.1 Root-Knot Nematode, *Meloidogyne incognita*

The root-knot nematodes were responsible for 24.64–27.45 % loss in fruit yield of pomegranate.

i) Symptoms

Heavy root galling and visible damage to pomegranate trees in young orchards under irrigation is frequently encountered (Fig. 7.7).

ii) Biomanagement

P. fluorescens at 20 kg/ha was found to be most effective in reducing the root-knot nematode population (*M. incognita* race 2) (31.28 %) and number of root galls/5 g roots (29.28 %) and increasing the fruit yield (18.99 %) with benefit/cost ratio of 2.37 (Table 7.2) (Pawar et al. 2013).

7.2 Temperate Fruit Crops

7.2.1 Apple, *Malus pumila*

7.2.1.1 Scab, *Venturia inaequalis*

Scab is the most destructive disease of apples and is present in all the countries of the world where apples are grown. The disease is particularly severe in high rainfall and humid areas.

Fig. 7.6 Anthracnose on guava fruits

Fig. 7.7 Pomegranate roots infected with *Meloidogyne incognita*

Table 7.2 Effect of bioagents and chemicals for the management of root-knot nematodes infecting pomegranate

Treatment	% decline in nema popn	% decline in root galling	Yield (MT/ha)	Benefit/cost ratio
Pseudomonas fluorescens at 20 g/m^2	31.2	29.2	18.4	2.37
Trichoderma viride at 20 g/m^2	28.3	23.9	18.0	2.33
Cartap hydrochloride at 0.3 g a.i./m^2	27.2	20.4	17.6	2.27
Carbofuran at 0.3 g a.i./m^2	29.8	25.1	17.8	2.27
Untreated control	–	–	15.4	–
CD ($P=0.05$)	2.99	2.30	1.17	–

Fig. 7.8 Apple leaf and fruits infected with scab

In India, it is present in all the apple growing areas of Jammu and Kashmir, Himachal Pradesh, Uttar Pradesh, Sikkim, Arunachal Pradesh and Nilgiris. The first epidemic of scab in Kashmir valley in 1973 completely ruined the apple crop worth US$ 540,000. During 1983, it rendered 10 % apple crop (30,000 MT) unfit for consumption in Himachal Pradesh which has to be destroyed, and as a result the state suffered a loss of Rs. 15 million.

i) Symptoms

Scab may appear on leaves, fruits, petioles and green twigs. The most striking symptoms of scab are commonly observed on leaves and fruits. Fruits may show small, rough, black, circular lesions on their skin (Fig. 7.8) while on the tree or after keeping in cold storage. Fruits picked from infected trees appear apparently healthy but are too sticky to keep even in cold storage. Such fruits soon develop scab symptoms even at low temperature and may not last long in storage. The affected fruits rot due to secondary infection of the lesions. Secondary infections on leaves are so numerous that the entire leaf surface appears covered with scab, commonly referred as sheet scab. Lesions on young fruits resemble those on leaves but turn dark brown to black and become corky or scab-like with time. Infections are often limited to one or two spots per fruit. Secondary infections are clumped together.

ii) Biomanagement

Flavobacterium sp., *Cryptococcus* sp. and two unidentified actinomycetes were found to be most antagonistic against scab (Heye and Andrews 1983).

Fig. 7.9 Apple root showing signs of the white root rot fungus

iii) Integrated Management

(a) *Bioagents and chemicals*: Integrated control of apple scab by modifying the nutrient status of overwintering leaves is well established. Treatment of senescent apple leaves on trees shortly before leaf fall or of fallen leaves on the orchard floor with a solution of 2 % urea greatly reduced ascospore production in the spring. Urea treatment of fallen apple leaves greatly increased the antagonistic bacterial populations found on decaying leaves. Fluorescent pseudomonads increased greatly in number on urea treated leaves. Pseudothecial development may be reduced directly by antibiotics produced by fluorescent pseudomonads on decaying leaves or indirectly by degeneration of leaf structure due to enhanced degradation of leaf material in the presence of higher bacterial populations induced by treatment with a good nitrogen source (Burchill and Cook 1971).

7.2.1.2 White Root Rot, *Dematophora necatrix*

i) Symptoms

This is a soilborne disease which is most important as the fungus can cause death of plants (Fig. 7.9). The disease appears on underground plant parts and causes complete rotting of the roots. The fine roots are attacked first which are completely devoured and infection spreads to the main root through the secondary root system. Lateral roots turn dark brown and become infected with white flocculent fungus during monsoon months. Bronzing of leaves and stunted growth and size are important above-ground symptoms. Root rot affected trees are usually associated with a heavy blossom and fruiting next year. However, in succeeding years, few leaves emerge and much of the immature fruits fail to reach maturity. Infected trees often persist for 2–3 years depending upon infestation of fungus.

ii) Biomanagement

Charcoal-based seed treatment (200 g of charcoal-based *Bacillus licheniformis* CKA1 culture per kg of seed) followed by seedling dip (at 1 l/500 seedlings) gave 20–25 % increase in apple seedling biomass and significant improvement in plant root and shoot parameters and controlled white root rot and gave 20–35 % increase in apple fruit yields.

Using antagonists like *Enterobacter aerogenes* and *B. subtilis* is effective for the management of white root rot.

iii) Integrated Management

(a) *Physical methods and bioagents*: Use of antagonists like *Enterobacter aerogenes* and *B. subtilis* along with soil solarization has been found to protect the plants from root rot infection.

(b) *Bioagents and chemicals*: Application of *E. aerogenes* + carbendazim (0.1 or 0.05 %) showed more than 92 % disease control when applied as pre-inoculation to the pathogen. In simultaneous inoculation, 0.1 % carbendazim in combination with *E. aerogenes*, completely prevented the appearance of the disease; however, 0.05 % carbendazim in combination with *E. aerogenes* gave 90.4 % disease control (Gupta and Sharma 2004).

(c) *Bioagents/botanicals and physical methods*: Soil solarization in combination with organic amendments and biocontrol agents in general gave good control of the disease in nursery. However, cent per cent control of the disease was achieved in plots where *Bacillus* sp. was incorporated in combination with soil solarization (Table 7.3).

7.2.1.3 Collar Rot, *Phytophthora cactorum*

The disease is also known as crown rot and trunk canker is universally present in all the apple growing regions of the world including the USA, the UK, Canada, New Zealand, the Netherlands, Germany, Australia and India. On susceptible varieties, it causes extensive losses even resulting in death of apple trees within a few years.

i) Symptoms

The above-ground symptoms are often confused with white root rot. The infection starts from the collar region and spreads to the underground parts. Bark at the soil level becomes slimy and rots resulting in cankered areas (Fig. 7.10). The attacked trees are recognized by chlorotic foliage with red colouration of veins and margins.

Table 7.3 Effect of soil solarization, organic amendments and biocontrol agents against white root rot disease in apple nursery

Treatment	White root rot (%)
Soil solarization	1.15
Soil solarization + neem cake	0.00
Soil solarization + deodar needles	3.75
Soil solarization + *Bacillus* sp.	0.00
Unsterilized soil + neem cake	4.50
Unsterilized soil + deodar needles	7.75
Unsterilized soil + *Bacillus* sp.	2.01
Unsterilized soil	22.82

Fig. 7.10 Crown rot on apple

ii) Biomanagement

Biological control of collar rot on apple with *B. subtilis* and *Enterobacter aerogenes* is feasible and requires commercial exploitation (Sharma et al. 1999).

iii) Integrated Management

(a) *Physical methods and bioagents*: Use of rhizobacteria like *E. aerogenes* and *B. subtilis* along with soil solarization has been found to protect the plants from collar rot infection.

(b) *Physical methods and botanicals/bioagents*: Cent per cent control of the disease was achieved in plots where *Bacillus* sp. was incorporated in combination with soil solarization. Collar rot pathogen was highly sensitive to the biocontrol agents and organic amendments both in solarized and unsolarized soil (Table 7.4).

7.2.1.4 Fruit Rot, Blue Mould, *Penicillium expansum*, and Grey Mould, *Botrytis cinerea*

i) Symptoms

In early stages, the rotted area is light in colour and soft and watery in texture. The rotted area does not become sunken although it is very soft in texture. The rot advances rapidly. In humid

Table 7.4 Effect of soil solarization, organic amendments and biocontrol agents against collar rot disease in apple nursery

Treatment	Collar rot (%)
Soil solarization	0.00
Soil solarization + neem cake	0.00
Soil solarization + deodar needles	0.00
Soil solarization + *Bacillus* sp.	0.00
Unsterilized soil + neem cake	1.00
Unsterilized soil + deodar needles	0.75
Unsterilized soil + *Bacillus* sp.	0.00
Unsterilized soil	2.05

atmosphere, grey blue cushions of fruiting bodies of the pathogen appear on the diseased skin (Fig. 7.11).

ii) Biomanagement

A saprophytic strain of *Pseudomonas syringe* was shown to provide biological control of all pathogens responsible for fruit rot on wounded Red and Golden Delicious apples in co-inoculations with individual pathogens (Jeffers and Wright 1994). The strain (*P. syringe* ESC-11) is currently registered for postharvest application to apples and is marketed as the product Bio-save 110.

Treatment of wounded fruits of apple (inoculated with *Penicillium expansum*) with most effective antagonist, *Pseudomonas syringae* pv. *lachrymans* isolate L-22-64 (increased in population at the wound site during 30 days of storage at 2° or 24 °C), controlled *P. expansum* (Fig. 7.12) (Janisiewicz 1988).

P. syringae (10 % wettable powder) in the modified packing line was sprayed at the rate of 10 g/l over apple fruit to control blue and grey moulds of apple. The population of antagonist increased in the wounds more than tenfold during 3 months in storage (Janisiewicz and Jeffers 1997).

B. subtilis applied to wounded apples reduced fruit rot (Leibinger et al. 1997).

iii) Integrated Management

(a) *Two bioagents*: Combined application of *Pseudomonas* sp. and *Acromonium breve* gave complete control of *P. expansum* and *B. cinerea* on apple (Janisiewicz 1988). A co-application involving the bacterial antagonist *P. syringe* and the yeast *S. roseus* applied in equal biomass provided control of blue mould that was superior to that obtained by treatment with the individual agents applied separately (Janisiewicz and Bors 1995).

(b) *Bioagents and chemicals*: Combination of *Pseudomonas syringae* MA-4 at $1–3 \times 10^7$ cfu/ml with cyprodinil at 5–10 μg/ml controlled both blue and grey mould by more than 90 % on apple, demonstrating that the integration could not only improve disease control efficacy but also extended the degree of control to more than one important disease (Zhou et al. 2002).

Fig. 7.11 Blue and grey mould on apple fruits

Fig. 7.12 Management of blue and grey mould on apples by *Pseudomonas syringe. Left* – control, *right* – treated

Fig. 7.13 Hairy root symptoms on apple

Table 7.5 Effect of soil solarization, organic amendments/biocontrol agents against hairy root disease in apple nursery

Treatment	Hairy root (%)
Soil solarization	2.25
Soil solarization + neem cake	4.15
Soil solarization + deodar needles	2.00
Soil solarization + *Bacillus* sp.	0.00
Unsterilized soil + neem cake	7.00
Unsterilized soil + deodar needles	9.45
Unsterilized soil + *Bacillus* sp.	3.15
Unsterilized soil	16.00

7.2.1.5 Hairy Root, *Agrobacterium rhizogenes*

i) Symptoms

At the union between scion and root piece, an enlargement somewhat resembling a newly formed crown gall appears. From this arise numerous roots, fleshy or fibrous in texture, with many containing numerous branches (Fig. 7.13). The surface of these enlargements bears numerous convolutions with fissures extending deep into the interior of the enlargements.

ii) Integrated Management

(a) *Physical methods and botanicals/bioagents*: Soil solarization in combination with organic amendments and biocontrol agents in general gave good control of hairy root disease in nursery. However, cent per cent control of the disease was achieved in plots where *Bacillus* sp. was incorporated in combination with soil solarization (Table 7.5).

7.2.1.6 Crown Gall, *Agrobacterium tumefaciens*

i) Symptoms

Crown gall bacterium enters the plant through wounds in roots or stems and stimulates the plant tissues to grow in a disorganized way, producing swollen galls. Galls are present all year round. Crown gall is identified by overgrowths appearing as galls on roots and at the base or 'crown' of apple (Fig. 7.14).

Fig. 7.14 *Agrobacterium tumefaciens* induced galls on apple roots (crown gall)

ii) Biomanagement

Satisfactory and nearly cent per cent control of crown gall is achieved by dipping seeds or root system of nursery plants or the rootstocks up to the crown region in *Agrobacterium radiobacter* strain 84 suspension (Kerr 1980). This biocontrol agent occupies the infection sites and produces a bacteriocin Agrocin 84 which is inhibitory to the pathogen. A derivative strain of K 84, designated as K 1026, is superior to its original K 84 strain (Jones and Kerr 1989).

iii) Integrated Management

(a) *Physical methods and botanicals/bioagents*: Cent per cent control of the disease was achieved in plots where *Bacillus* sp. was incorporated in combination with soil solarization (Table 7.6).

Table 7.6 Effect of soil solarization, organic amendments and biocontrol agents against soilborne diseases in apple nursery

Treatment	Crown gall (%)
Soil solarization	4.00
Soil solarization + neem cake	1.50
Soil solarization + deodar needles	0.50
Soil solarization + *Bacillus* sp.	0.00
Unsterilized soil + neem cake	3.00
Unsterilized soil + deodar needles	6.55
Unsterilized soil + *Bacillus* sp.	5.25
Unsterilized soil	8.00

7.2.1.7 Replant Problem

The living pathogens may include fungi, nematodes and bacteria; the nonliving factors can range from nutrient imbalances to herbicide residues to compaction. Synergistic interactions of fungi, bacteria and nematodes were found responsible for causing apple replant problem.

i) Symptoms

The symptoms commonly seen are decreased growth both above and below ground, delayed productivity and even tree death.

ii) Biomanagement

Application of Bact-I, EBW4, *B. subtilis* and B8 soil drenches increased tree growth in apple replant disease sick soils.

7.2.1.8 Fire Blight, *Erwinia amylovora*

i) Symptoms

The intensity of blossom infection with consequent loss of crop and the possible loss of some branches as a result of cankering would be very serious (Fig. 7.15). Primary infection frequently occurs as a result of transfer of the bacteria by pollinating insects to open blossom. At that time (April) in North India, temperature above 24 °C and plentiful rains occur which favour infection and rapid spread of the disease. The presence of naturally occurring hosts (pear) in the vicinity of the apple orchard constitutes a permanent reservoir of infection.

ii) Biomanagement

Biological control of the blossom blight phase of fire blight has been obtained in the field using *P. fluorescens*, Pf-A506 (Blight Ban) (Vanneste and Yu 1996). This agent multiplies rapidly and colonizes open flowers to the extent that it excludes any significant subsequent colonization by the fire blight organism. If this antagonist is applied after *E. amylovora* is already

Fig. 7.15 Fire blight on apple

present or even as a mixture with the pathogen, it is not effective.

The second promising bioantagonist is another bacterium, *Erwinia herbicola*, strain C9-1, which is a common epiphyte on apples. In addition to the competition for space that occurs with Pf-A506, *E. herbicola* C9-1 also produces an antibiotic of its own that inhibits the multiplication of the pathogen. Like its A506 counterpart, this second bioantagonist must also be present in the flower before the arrival of the pathogen for it to be effective.

E. amylovora causing fire blight of apple infects through flower and develops extensively on stigma. Colonization by antagonist at the critical juncture is necessary to prevent flower infection. Since flowers do not open simultaneously, the biocontrol agent *P. fluorescens* has to be applied to flowers repeatedly to protect the stigma. Nectar seeking insects like *Aphis mellifera* can be used to deliver *P. fluorescens* to stigma. Bees deposit the bacteria on the flowers soon after opening due to their foraging habits.

iii) Integrated Management

(a) *Bioagents and chemicals*: Studies conducted with *P. fluorescens* A506 in combination with antibiotic (streptomycin/oxytetracycline) applications (7 days after application of the antagonist) suggest that the control achieved is likely to be additive in nature (Lindow et al. 1996).

7.2.2 Peach, *Prunus persica*, and Plum, *Prunus salicina*

7.2.2.1 Brown Rot of Fruits, *Monilinia fructicola, M. fructigena, M. laxa, M. laxa* f. sp. *mali*

i) Symptoms

Symptoms of the disease are blighting of blossom and leaves, canker production on woody tissues and rotting of fruits. Blossom blight is the first symptom during spring, and attacked parts turn grey to dark brown. The fungus spreads through the peduncle and reach branches causing twig blight. Stem cankers usually develop from blighted twigs or fruit spurs. Fruit rot is the most destructive phase of the disease. Rotted fruits either fall down or hang as firm mummies. Conidia and ascospores produced on the mummified fruits and canker spots serve as a source of primary infection.

ii) Biomanagement

Brown rot of peaches in storage was controlled under simulated commercial conditions by incorporating the antagonist *B. subtilis* into wax used in the packing process (Wilson and Pusey 1985).

B. subtilis gave excellent control of brown rot caused by *Monilinia fructicola* in storage in peach and plum. No fruit treated with 10 cfu/ml of suspension developed brown rot (Fig. 7.16) (Wilson and Pusey 1985).

iii) Integrated Management

(a) *Bioagents and chemicals*: Biocontrol agents can be used in combination with fungicides in controlling rots on peach, in cases where *B. subtilis* (B3), effective against brown rot (incited by *M. fructicola*), was combined with dicloran used for the control of *Rhizopus* rot (Pusey et al. 1988).

Zhou et al. (1999) reported that the addition of 0.5 % calcium to cell suspension of *Pseudomonas*

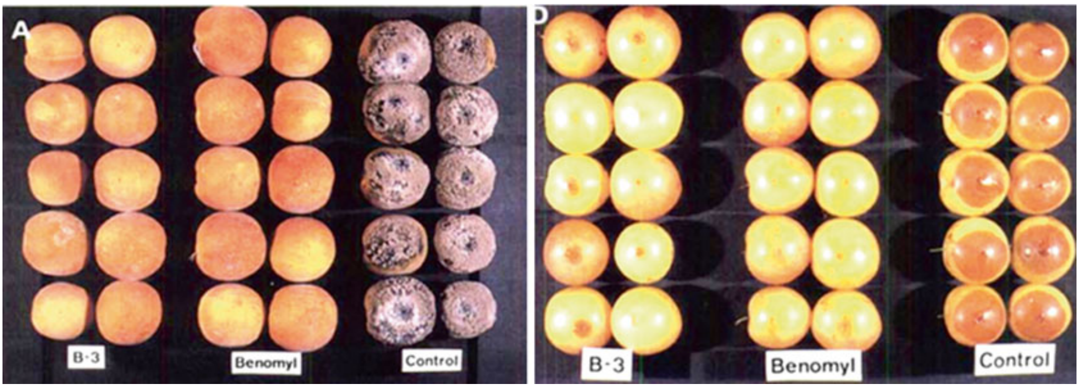

Fig. 7.16 Wounded peaches and plums after treatment with *B. subtilis* (B-3), benomyl and water (control)

syringae MA-4 resulted in a greater reduction of peach brown rot incidence when sprayed on peaches naturally infected with *M. fructicola*. Preharvest application of *P. syringae* MA-4 with a foliar calcium fertilizer also significantly increased biocontrol efficacy against peach brown rot (Zhou and Schneider 1998).

7.2.2.2 Crown Gall, *Agrobacterium radiobacter*

i) Symptoms

Small outgrowth appears on the stem and roots. At the young stage, the galls are soft, spherical, white or flesh coloured. The galls vary in size from 7 to 10 mm in diameter. On woody stems, the galls are hard and corky (Fig. 7.17). They are generally knobby and knotty and become cleftier as they grow older. The affected plant may become stunted with chlorotic leaves.

ii) Biomanagement

A nonpathogenic strain of *A. radiobacter* (strain 84) is employed to control crown gall, and 99 % success has been achieved in case of peach crown gall.

7.2.2.3 Ring Nematode, *Criconemella xenoplax*

It is ectoparasitic and is an economically important nematode which is one of the factors in bacterial canker and peach tree short life (PTSL) disease. The estimated losses that occurred in peach orchards suffering from PTSL in Georgia were 30–70 % after 5 years. *C. xenoplax* was responsible for 33 % loss in fruit yield of peach. It is distributed in Himachal Pradesh and Haryana.

Fig. 7.17 Crown gall on peach seedlings

i) Symptoms

Parasitism of *C. xenoplax* causes chlorosis, leaf drop, stunting and loss of vigour on top of peach trees. Peach roots showed lesions, pits and fewer feeder roots (Fig. 7.18). The roots are predisposed to bacterial canker caused by secondary infection of *Pseudomonas syringae*.

ii) Biomanagement

Treatment of peach seedlings with a strain of *Pseudomonas aureofaciens* isolated from suppressive soil inhibited infection by the ring nematode in soil (McInnis et al. 1990).

Fig. 7.18 Peach roots infected with *Criconemella xenoplax*

7.2.3 Pear, *Pyrus communis*

7.2.3.1 Grey Mould, *Botrytis cinerea*

i) Symptoms

Grey mould and its many strains cause death of flower parts, leaves, buds, shoots, seedlings and fruits (Fig. 7.19). The disease needs moisture as one of its criteria for infection. The wetter the plant is, the more likely the grey mould will show up on plants. Not only are the numbers of infected areas increased but also are the numbers of plants attacked as well as the severity of the infections (quicker growth of the disease and death of tissue).

ii) Integrated Management

(a) *Bioagents and chemicals*: In a packing house trial, combination of Bio-Save 110 (*Pseudomonas syringae*) or Aspire (*Candida oleophila* strain 1-18) with TBZ at 100 µg/ml (about 17.6 % of the label rate) provided control of blue mould and grey mould of pears, similar to that of TBZ alone used at the label rate (569 µg/ml) (Sugar and Spotts 1999).

Fig. 7.19 Grey mould on pear fruit

7.2.3.2 Blue Mould, *Penicillium expansum*

i) Symptoms

The rotted areas are soft, watery and light brown in colour. The surface of older lesions may be covered by bluish-green spores that initially are nearly snow white in colour. The lesions are of varying shades of brown, being lighter on the yellow or green varieties. Two characteristics are of importance in the recognition of *P. expansum*, the most common species, namely, the musty odour and the formation of conidial tufts or coremia on the surface of well-developed lesions.

ii) Biomanagement

Application of *P. syringe* at 2.7×10^6 cfu/ml gave effective control of blue mould on pear (Fig. 7.20).

iii) Integrated Management

(a) *Bioagents and chemicals*: In a packing house trial, combination of Bio-Save 110 (*Pseudomonas syringae*) or Aspire (*Candida oleophila* strain 1-18) with TBZ at 100 µg/ml (about 17.6 % of the label rate) provided control of blue mould and grey mould of pears,

Fig. 7.20 Management of blue mould rot on pear by *Pseudomonas syringe*. *Left* – control, *right* – treated

Fig. 7.21 Brown spot on pear leaf

Fig. 7.22 Fire blight infection on pear tree and fruit

similar to that of TBZ alone used at the label rate (569 μg/ml) (Sugar and Spotts 1999).

7.2.3.3 Brown Spot, *Stemphylium vesicarium*

i) Symptoms

The pathogen attack leaves (Fig. 7.21), fruits and occasionally twigs of pear.

ii) Biomanagement

Montesinos et al. (1996) showed the antagonism of *Erwinia herbicola* and *P. fluorescens* to brown spot of pear. They found that *P. fluorescens* strain EPS 288 was the most effective and could reduce disease incidence by 57 %.

7.2.3.4 Fire Blight, *Erwinia amylovora*

i) Symptoms

The term 'fire blight' describes the appearance of the disease, which can make affected areas appear blackened, shrunken and cracked, as though scorched by fire (Fig. 7.22).

ii) Biomanagement

P. fluorescens strain A506 effectively controlled fire blight of pear (Wilson and Lindow 1993).

iii) Integrated Management

(a) *Bioagents and chemicals*: Lindow et al. (1996) reported that use of *P. fluorescens* strain A506 in combination with streptomycin and oxytetracycline could reduce pear fire blight by 40–50 %.

7.2.4 Almond, *Amygdalus communis*

7.2.4.1 Crown Gall, *Agrobacterium tumefaciens*

i) Symptoms

Rough, abnormal galls appear on roots or trunk. Galls are soft and spongy (Fig. 7.23). The centres of older galls decay. Young trees become stunted; older trees often develop secondary wood rots.

ii) Biomanagement

Dipping of younger (2 months old) and older (10 months old) almond seedlings in a suspension of either *Agrobacterium radiobacter* strain K 1026 or strain K 84 and planted in soil infested with a pathogenic *A. tumefaciens* biovar 2 gave effective control of crown gall disease (Jones and Kerr 1989) (Table 7.7).

7.2.5 Apricot, *Prunus armeniaca*

7.2.5.1 Brown Rot, *Monilinia fructicola*

i) Symptoms

Fruit rot first appears as small, circular brown spots that increase rapidly in size causing the entire fruit to rot. Greyish spores appear in tufts on rotted areas. Infected fruit eventually turn into shrivelled, black mummies that may drop or remain attached to the tree through the winter.

ii) Biomanagement

B. subtilis gave excellent control of apricot brown rot in storage. No fruit treated with 10 cfu/ml of suspension developed brown rot (Fig. 7.24) (Wilson and Pusey 1985).

Fig. 7.23 Crown gall on the crown and roots of a young almond tree

Table 7.7 Effect of *Agrobacterium radiobacter* strains on crown gall of almond

Plant age (months)	Treatment	No. of plants surviving	% plants galled	No. of galls/plant
2	Water	12	100	9.33
	K 84	14	14	0.21
	K 1026	12	25	0.33
10	Water	15	100	46.33
	K 84	15	20	0.20
	K 1026	15	27	0.67

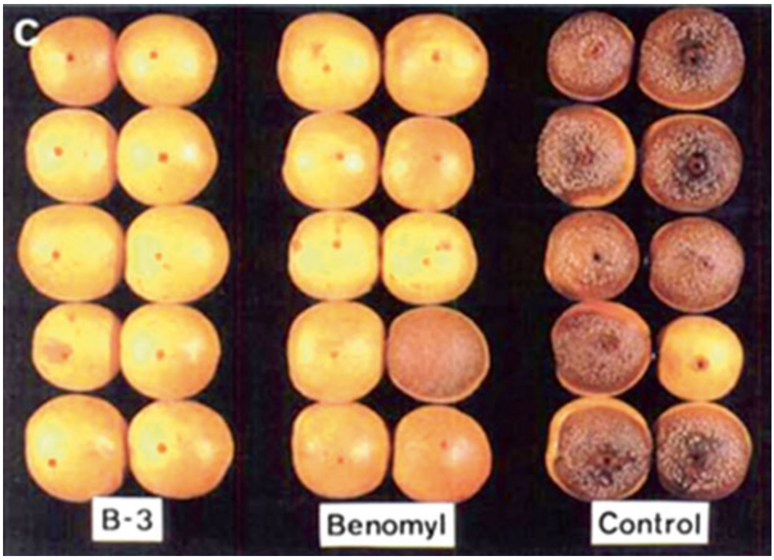

Fig. 7.24 Wounded apricots after treatment with *B. subtilis* (B-3), benomyl and water (control)

Fig. 7.25 Symptoms of strawberry *Verticillium* wilt

7.2.6 Strawberry, *Fragaria vesca*

7.2.6.1 Wilt, *Verticillium dahliae*

i) Symptoms

Symptoms resemble drought stress. Infection and severe disease occurs mostly in first year of growth. Outer leaves develop brown necrotic areas between veins and on the edges during early spring. Interior leaves of diseased plants usually remain alive and blue green in colour. Infected plants wilt rapidly under stress (Fig. 7.25). Diseased plants may occur singly or in patches.

ii) Biomanagement

Dipping of strawberry roots for 15 min in bacterial suspension of *P. putida* (2×10^9 cfu/ml) isolated from strawberry rhizosphere reduced *Verticillium* wilt of strawberry by 11 % compared to untreated control (Berg et al. 2001).

Significant reduction of *Verticillium* wilt with root dip treatment in *Streptomyces albidoflavus* or *P. fluorescens* was recorded in the greenhouse and fields naturally infected by *V. dahliae*. The relative increase in yield ranged from 113 % by *S. albidoflavus* S1 to 247 % by *P. fluorescens* P6 and correlated with a suppression of pathogen in

Fig. 7.26 *Fusarium* wilt affected crown with brown discolouration of water conducting tissues

field trials integrated in commercial strawberry production (Berg et al. 2000).

Dipping plants in a suspension of *Serratia plymuthica* prior to planting reduced *Verticillium* wilt by 24.2 % and increased the yield by 296 % (Berg et al. 1999).

The *B. subtilis* strain TS06 has a broad antifungal application to severe plant disease of strawberry (*Fragaria ananassa*), which is caused by *Verticillium* wilt (Zhang et al. 2012).

7.2.6.2 *Fusarium* Wilt

i) Symptoms

Symptoms consisted of wilting of foliage, drying and withering of older leaves, stunting of plants and reduced fruit production. Plants eventually collapsed and died. Internal vascular and cortical tissues of plant crowns showed a brown to orange-brown discolouration (Fig. 7.26).

ii) Biomanagement

The *B. subtilis* strain TS06 has a broad antifungal application to severe plant disease of strawberry (*Fragaria ananassa*), which is caused by *Fusarium* wilt (Zhang et al. 2012).

iii) Integrated Management

(a) *Bioagents, botanicals and AMF*: Combined use of AMF *Gigaspora margarita* and 3–15 % charcoal compost (which contained antagonistic microorganisms such as *B. subtilis*, *Thermomonospora* sp. and *Thermoactinomyces* sp.) drastically reduced *Fusarium* wilt in strawberry. Moreover, AMF and charcoal compost stimulated rooting and increased the root volume and hence plant growth (Kabayashi 1989).

Fig. 7.27 Grey mould on strawberry fruits

7.2.6.3 Grey Mould, *Botrytis cinerea*

i) Symptoms

Infection usually begins on berries touching the soil. However, infection may start in that part of a berry that touches another decayed berry or dead leaf (Fig. 7.27). Grey mould often starts on blossoms and green fruit injured by frost. Sometimes disease affects flower stalks enough to prevent the development of fruit.

ii) Integrated Management

Combined application of *Pichia guilliermondii* (yeast) and *Bacillus mycoides* (B16) reduced the infection of *B. cinerea* by 75 % on fruits in strawberry plants grown commercially under greenhouse conditions. But the individual application of either antagonist resulted in 50 % reduction of strawberry fruit infection. Population of yeast increased when applied as mixture rather than single application (Guetsky et al. 2002).

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