Manoj Kumar · Vivek Kumar
Neera Bhalla-Sarin · Ajit Varma *Editors*

Lychee Disease Management

Springer

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Preface

"Lychee Disease Management" is a stand-alone book dedicated to the global agriculture community facing problems in production and commercialization worldwide.

This book is a comprehensive compilation of biotic and abiotic factors seemingly affecting lychee production and its commercialization. The book comprises disease management for its causal agents conferring leaf mite (*Aceria litchii* Keifer), leaf miner (*Conopomorpha cramerella*), fruit borers (*Conopomorpha cramerella*, *Platypeplus aprobola* Meyer, and *Dichocrocis* sp.), leaf webber/roller (*Platypeplus aprobola* Meyer), lychee bug (*Tessaratoma javanica* Thunberg), bark-eating caterpillar (*Indarbela quadrinotata*), shoot borer (*Chlumetia transversa*), etc.

Specialized chapters of the book uncover the statistical data at international level and recommend potential ways for lychee export, further illustrating the scope to increase the quantum of export; more so because the harvesting season is quite different in other parts of the world.

It also sheds light on systematic research for identification of additional potential areas and development and refinement of technologies for enhancing the productivity and quality of lychee. This book comprises the managerial understanding on post-harvest handling, processing and value addition, development-tolerant varieties, high yield, and processing. It includes explicit insights through a comprehensive visionary documentation addressing scientific and economical aspects for all the neglected fruit enhancements.

Noida, Uttar Pradesh, India — Manoj Kumar
Noida, Uttar Pradesh, India — Vivek Kumar
Delhi, India — Neera Bhalla-Sarin
Noida, Uttar Pradesh, India — Ajit Varma

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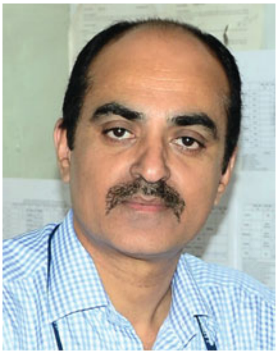
About the Editors

Manoj Kumar, Ph.D. Dr. Manoj Kumar is a scientist with sanguine behavior who is adoring about research and development, with a commitment to lifelong learning. He is determined on high-quality science that contributes broadly to increasing intellectual knowledge of both plant development and the ecological niche. He has a high level of professional desire for intellectual pursuits and the potential to fulfill his dream of high-impact publications and future recognition of these by academic peers. Dr. Kumar has pursued his Ph.D. in plant biotechnology at the prestigious Jawaharlal Nehru University and then been awarded two postdoctoral fellowships consecutively: DBT-PDF from IISc Bangalore in 2005 and then NRF-PDF from the University of Pretoria. Dr. Manoj Kumar is a researcher of plant biotechnology in the Division of Microbial Technology at Amity University, Uttar Pradesh, India. Recently he has accepted the affiliation from Ton Duc Thang University, Vietnam. Until recently, he was a coordinator of the Bio-resource Chapter (Northern India) and served on editorial boards of five international journals. Dr. Kumar has published several research papers, books, and review articles of international repute. During a decade of academic acquaintance, he has guided several research projects and dissertations and collaborated internationally. His diverse research background attracts global readers and researchers.



Vivek Kumar, Ph.D. Dr. Vivek Kumar is a scientist who is involved in teaching, research, and guidance, with a pledge to enduring knowledge. Dr. Kumar is working in the Division of Microbial Technology at Amity University, Uttar Pradesh, Noida, India. He is serving in the editorial board of reputed international journals, viz., *EnvironmentAsia*, the *International Journal of Biological and Chemical Sciences*, the *Journal of Advanced Botany and Zoology*, and the *Journal of Ecobiotechnology*. He is also reviewer of the *Journal of Hazardous Materials, Science International, Acta*

Physiologiae Plantarum, the *International Research Journal of Plant Sciences*, the *International Journal of Microbiology*, the *African Journal of Microbiology Research*, the *Journal of Microbiology and Antimicrobials, Environmental Science and Pollution Research*, and *Rhizosphere*. He has published 61 research papers, 19 book chapters, 6 review articles, and 2 books. Dr. Kumar has also served as a microbiologist for 8 years in the Department of Soil and Water Research, Public Authority for Agricultural Affairs and Fish Resources, Kuwait. Dr. Kumar's research areas are plant-microbe interactions, environmental microbiology, and bioremediation. He has been credited with first-time reporting and identification of pink rot inflorescence disease of date palm in Kuwait caused by *Serratia marcescens*. He has been awarded the "Young Scientist Award" for the year 2002 in "agricultural microbiology" by the Association of Microbiologists of India (AMI). Dr. Kumar is establishing an "unearthing and deliverance system," where a balance is being strived between the development of drought- and salinity-resistant microbiome for better crop production in rain-fed and saline areas. In the bioremediation research program, the isolation and characterization of autochthonous microbiome from textile dye effluent and soil performed very well in the remediation of dyes under laboratory conditions. The selected microbiome will be further employed in the bioremediation of textile dyes at a larger level.

Neera Bhalla-Sarin, F.N.A.Sc. Prof. (Dr.) Neera Bhalla-Sarin is working as professor and group leader at the School of Life Sciences, JNU, New Delhi. She has served the organization as professor and dean. She has set academic milestones as a chairperson of many academic councils at university level. Prof. Sarin has a proven record in plant developmental biology and accomplished numerous research projects sponsored by the government of India and international research funding (Indo-Switzerland, Indo-Korea, Indo-Australia, Indo-USA). She has guided more than 40 doctoral and postdoctoral researchers with her sanguine research capability. Her remarkable research and academic contributions in science and technology have been acknowledged nationally and internationally.

Ajit Varma, Fellow, AvH and NAASC Prof. Ajit Varma is distinguished scientist and professor of eminence at the Amity Institute of Microbial Technology (Amity University, Uttar Pradesh). He has been leading an international research group on microbial technology in collaboration with several prestigious institutions worldwide. He is also holding several other responsibilities in Amity University, like vice-chairman of the Amity Science, Technology and Innovation Foundation and chairman of the Faculty Research Council at university level. He has pursued his doctorate at Allahabad University in 1964 and then started his academic and scientific journey in the Indian Agricultural Research Institute, New Delhi, and then retired as an eminent professor at the prestigious Jawaharlal Nehru University in 2004. Since then, his leading role incepted in Amity University to harness the Amity Research at international level. Prof. Varma has numerous national and international research and academic awards to his credit and headed several councils in the plant-microbial world. He has visited several countries as a visiting scientist, professor, and academician for his world novel discovery *Piriformospora indica* – a magic fungus which has been popularized as ROOTONIC. Apart from the abovementioned facts, Prof. Varma has achieved academic height with several national and international accreditations.

Lychee (*Litchi chinensis* Sonn.): Pre- and Post-harvest Disease Management

1

Bhupendra Koul and Pooja Taak

Abstract

Lychee (*Litchi chinensis* Sonn.) belongs to the family Sapindaceae and is an esteemed member amongst the commercially important fruit crops. This delicious fruit is widely grown in tropical and subtropical regions of the world and is famous for its sweet fragrance, pleasurable taste and attractive colour. China is the largest producer of lychee in the world followed by India and Taiwan. Lychee tree is susceptible to various biotic stresses which include algae, fungi, insect pests, etc. These factors often become a hindrance for profitable fruit production. Moreover, post-harvest damage such as pericarp browning and desiccation ultimately declines the commercial value and shelf life of the fruit. Effective and timely approaches and post-harvest management practices are prerequisites in order to sustain the premium fruit quality, fruit yield and shelf life and also to control the pre-harvest diseases. Development in biotechnological techniques also provides an alternative approach for the crop improvement by introducing exotic genes with desirable characters. These genetically modified varieties hold a promising potential to upgrade the fruit quality standard in terms of disease resistance, increased shelf life and seedless character. The post-harvest practices in lychee production and their impact on fruit quality need more improvement. This chapter encompasses various diseases that downturn the yield, quality and market value of the lychee fruit and the strategies to check the pre- and post-harvest crop losses.

Keywords

Lychee • Fruit crop • Pre-harvest • Post-harvest • Shelf life

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Abbreviations

AA	Ascorbic acid
AFLP	Amplified fragment length polymorphism
FAO	Food and Agriculture Organization
GFP	Green fluorescent protein
GMO	Genetically modified organism
Ha	Hectare
HCl	Hydrochloric acid
IPM	Integrated pest management
PCR	Polymerase chain reaction
RAPD	Random amplified polymorphic DNA
RT-PCR	Reverse transcriptase PCR

1.1 Introduction

The lychee fruit (*Litchi chinensis* Sonn.) is a popular export commodity because of the attractive colour of its pericarp and exotic flavour. It is grown as an important commercial crop in China, South Africa, Madagascar, the USA, Australia, Mauritius, India, Pakistan, Thailand, Indonesia, Vietnam and the Philippines (Menzel 2001). China is the leading lychee-producing country in the world, having more than 584,000 ha area under cultivation with an annual production of 958,700 MT (Sarin et al. 2009). India is the second largest producer of lychee after China with an annual production of 585,300 MT, from 84,170 ha area (FAO 2014). There has been a year-wise expansion in the area under lychee cultivation. It has increased from 58,100 thousand ha to 84,200 ha in 1991–1992 to 2013–2014 with a similar trend in the production from 3,55,900 MT to 5,85,300 MT in the last decades. Several varieties of lychee are available throughout the world which can be distinguished from each other with respect to their morphological characteristics including fruit shape, size, shape of skin segment, colour, taste, aroma, etc. (Sarin et al. 2009). The economically most important lychee varieties cultivated in India are Dehra, Purbi, Kashba, Early and Late Bedana, China, Shahi, Deshi, etc. (Das and Rahman 2012).

Lychee is an average sized (10–15 m), evergreen, round-topped tree with smooth, grey-coloured trunk. Its leaves are pinnately divided, having leather texture and acuminate, glabrous and slightly reddish in colour when young and bright green at maturity. Flowers are small yellow in colour and are apetalous. Fruits are oval, rounded or heart shaped, dark pink to red in colour. The edible part of the fruit is called aril, which is creamy white, translucent, sweet fragrant and juicy. The seeds are oblong with smooth and glossy surface and are reddish brown in colour (Nacif et al. 2001; Menzel 2002). The lychee fruit production is affected by several biotic and abiotic stresses. Lychee tree and fruits are susceptible to several algae, fungi

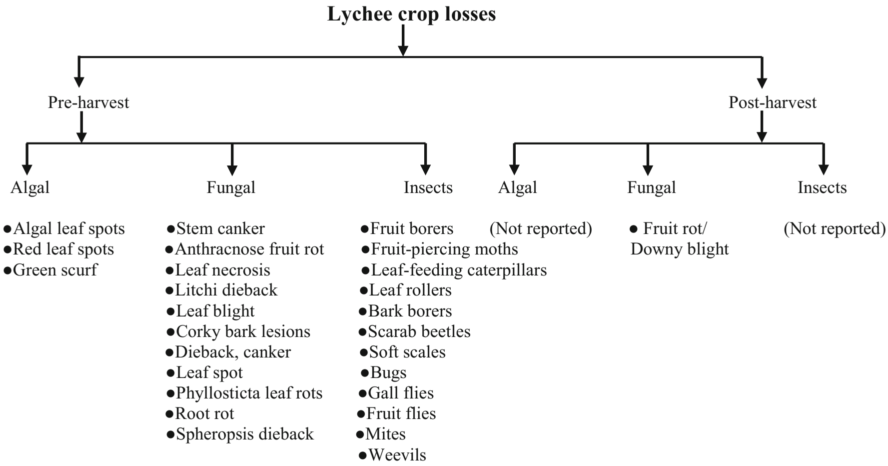

Chart 1.1 Diseases/damages (pre-harvest and post-harvest) caused by various biotic factors

and insect pests which damage the fruits and other vegetative parts. Amongst these, fungal diseases cause extensive pre- and post-harvest loss to the fruit quality and yield of the crop and hence considered as the most serious obstacle in lychee fruit production. These fungal pathogens belong to class *Dothideomycetes*, *Sordariomycetes*, *Leotiomycetes*, *Ascomycota* and *Oomycetes* (Mcmillan 1994; Menzel 2002; Wu et al. 2011). The major portion of the insects which damage the crop belongs to the order Lepidoptera. It has also been estimated that about 70% of the yield has been reported to retard as a result of the various abiotic stresses (Acquaah 2007). The lychee trees are also sensitive to salt-enriched soil. Salt stress in lychee also hinders the fruit production (Sinha and Das 2013). Hence, the cumulative effect of biotic as well as abiotic factors ultimately declines the agronomically importance of this cash crop. In this chapter, we shall solely deal with the effect of biotic stresses on lychee production as summarized in Chart 1.1.

1.2 Algal Leaf Spots, Red Leaf Spots and Green Scurf

Causative Organism *Cephaleuros virescens* (Class: Ulvophyceae)

Symptoms The algal leaf spots, red leaf spots and green scurf caused by *Cephaleuros virescens* are infrequent leaf spots of lychee (Alfieria et al. 1994). On lychee leaves, reddish brown to orange, velvety and cushion-like patches are formed. The spots are not observed on branches. The algal sporangia formed on fine hairs, germinate in moisture and produce zoospores which find their way through stomata and form mycelium-like chains of algal cells in the leaf tissues. The disease spread mostly during the rainy season from June to October. As the size of the leaf increases, the velvety growth becomes more dense and prominent. Older leaves show different types of malformations. The velvety growth turns dark brown to brick reddish in colour (Fig. 1.1a, Mcmillan 1994).

Control Measures Copper oxychloride spray (0.3%) can be done in the month of July and October. Bordeaux spray can also be done during autumn and spring season at 15-day interval. Ziram spray (0.25%) also reduces the risk of disease reoccurrence.

1.3 Fungal Diseases

1.3.1 Stem Canker

Causative Organism *Botryosphaeria* spp. (Class: *Dothideomycetes*)

Symptoms *Botryosphaeria* spp. normally attack the terminal branches of lychee tree (Alfieria et al. 1994). This fungus enters through the wounded surface on the tree and on dead and dying twigs. The disease is characterised by the presence of sunken, shrinking, irregular and dying tissues on the stem (Fig. 1.1b, Mcmillan 1994).

Control Measures Wound paint should be applied on the cut surfaces of the tree (Mcmillan 1994).

1.3.2 Anthracnose Fruit Rot

Causative Organism *Colletotrichum gloeosporioides* (Class: *Sordariomycetes*)

Symptoms Anthracnose fruit rot is the most important lychee disease (Alfieria et al. 1994). The fruit is highly susceptible to infection from flowering time. The small patches of infections coalesce and develop into large brown spots at fruit maturity. The infected fruits often develop a white mycelial layer over the fruit skin during refrigerated storage (Mcmillan 1994). Initially, the acervuli remain sub-epidermal but soon rupture the epidermis to expose the conidial mass. The fungus mostly attacks the leaves, flowers and fruits. Grey-coloured lesions appear on the leaf surface (Fig. 1.1c, Menzel 2002).

Control Measures Avoid overcrowding of trees and branches in orchard. Fungicides can be used during an initial stage but are not always effective (Menzel 2002). Application of chlorine dioxide (ClO_2) can reduce infection spreading by inhibiting the germination of fungal spores (Wu et al. 2011) Storing of the crop at lower temperature can also reduce the risk of fruit damage. Dipping of the fruits in hot benomyl at 0.05% at 52 °C for 2 min can also retard the rate of fruit deterioration.

1.3.3 Leaf Necrosis

Causative Organism *Colletotrichum gloeosporioides* (Class: *Sordariomycetes*)

Symptoms *Colletotrichum gloeosporioides* has been associated with leaf lesions caused by insect feeding and due to other mechanical injuries. In leaf necrosis, cylindrical pink-coloured conidia of *C. gloeosporioides* are produced in acervuli (Fig. 1.1d, Menzel 2002).

Control Measures Avoid overhead irrigation because the spores are spread by water splashes. Remove the highly infected plants from the orchard. In case of severe infestation, chlorothalonil, mancozeb and copper-based fungicides can be used to control the spreading of disease.

1.3.4 Litchi Dieback

Causative Organism *Diplodia* spp. (Class: *Dothideomycetes*)

Symptoms The dieback symptoms often appear after drought and other physiological stresses. The stem starts dying from tip downwards, often starting in the flowering stem. Infected wood turns brown or black and often somewhat shrivelled (Fig. 1.1e). Fungal pycnidia are produced in dead shoots (Mcmillan 1994).

Control Measures Pruning of the trees can reduce the spread of disease to some extent.

1.3.5 Leaf Blight

Causative Organism *Gloeosporium* spp. (Class: *Leotiomycetes*)

Symptoms Leaf blight is one of the important lychee diseases. The symptoms of this disease start from the tip of the leaf and then spread to the leaf margins. The disease generally starts appearing from late May to August. The leaf spots are light brown in colour and often appear to be that of scorched leaves (Fig. 1.1f). Defoliation can also occur during the rainy season (Mcmillan 1994).

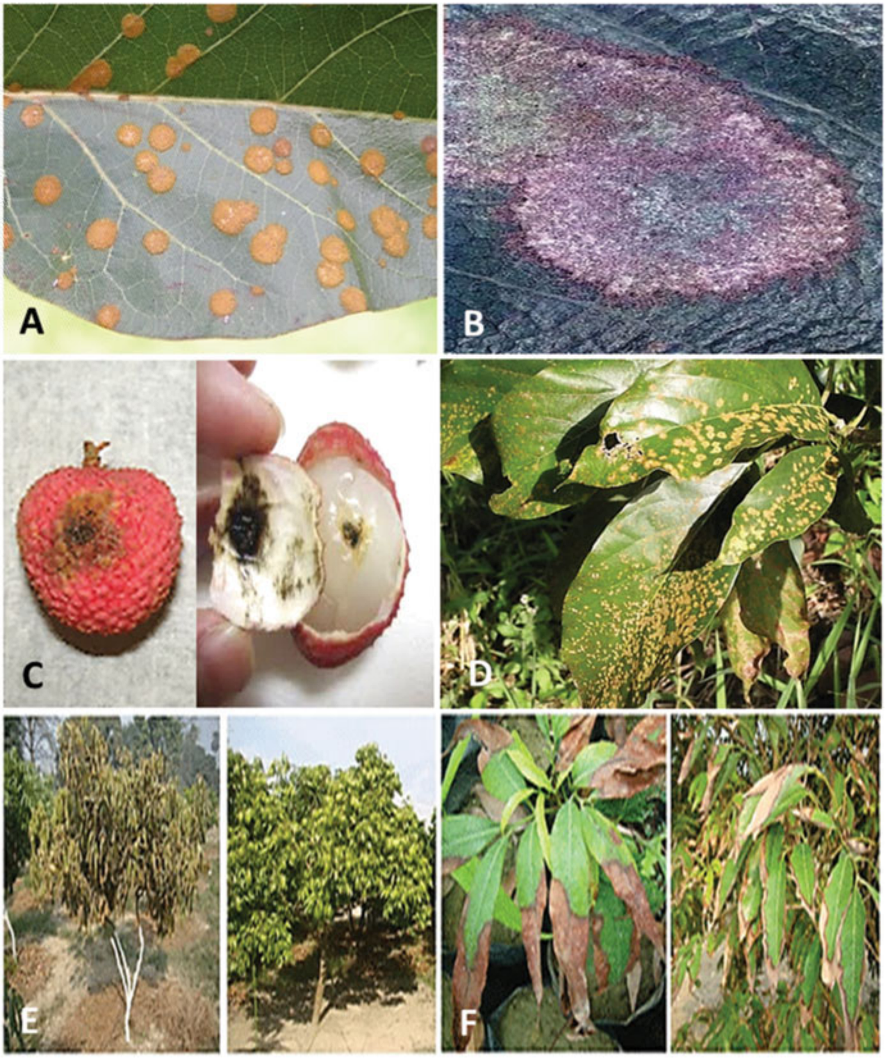

Fig. 1.1 Algal and fungal diseases of lychee. (**a**) A leaf infected with *Cephaleuros virescens* showing reddish orange patches. (**b**) Stem canker caused by the fungus *Botryosphaeria* sp. (**c**) Anthracnose fruit rot and pericarp browning caused by the fungus *Colletotrichum gloeosporioides*. (**d**) Leaf necrosis caused by *C. gloeosporioides*. (**e**) A lychee tree showing symptoms of dieback disease caused by the fungus *Diplodia* spp. (**f**) A lychee twig showing symptoms of leaf blight caused by the fungus *Gloeosporium* spp.

Control Measures Spray of fungicides including thiophanate methyl (0.15%), chlorothalonil (0.15%), difenoconazole (0.05%) and copper oxychloride (0.25%) can be done during severe infestation.

1.3.6 Corky Bark Lesions

Causative Organism *Phoma* spp. (Class: *Dothideomycetes*)

Symptoms Symptoms of the corky bark lesions appear as small to large irregular patches of dark-coloured raised bark on the main trunk and then on the lateral branches of the tree. With the growth of the tree, the lumps and lesions also increase in size and become more corky and rough in appearance (Fig. 1.2a). The branches get covered with brown-coloured rough lesions which are of ¼ to ¾ inches in diameter (Mcmillan 1994).

Control Measures No fungicides are approved to completely stop the occurrence of corky bark lesions. Pruning of the severely damaged trees is useful to control the spreading of disease.

1.3.7 Dieback, Canker and Leaf Spot

Causative Organism *Phomopsis* spp. (Class: *Sordariomycetes*)

Symptoms *Phomopsis* spp. cause the tips of the branches to turn to black (Alfieria et al. 1994). Older trees are more prone to this disease. Leaf spots are small and reddish brown to dark black in colour with an average diameter of 1/8 in., while the cankers have rough, cracked outer cork and are greyish brown in colour (Fig. 1.2b, Mcmillan 1994).

Control Measures Pruning of the tree should be done carefully in order to ensure the complete eradication of the pathogen.

1.3.8 Phyllosticta Leaf Rots

Causative Organism *Phyllosticta* spp. (Class: *Dothideomycetes*)

Symptoms The leaf spots are rounded, large and brownish to black in colour, having concentric ridges (Fig. 1.2c). The younger leaves may become curled, while the older ones become shrivelled and hang down from the stem (Mcmillan 1994).

Control Measures Remove the infected leaves from the plant and dispose them in order to prevent the spreading of disease. Spray of fungicides such as ferbam, dithane M45, mancozeb and captan will help to control the infection. But it is not possible to completely eliminate the fungus from the plant.

1.3.9 Root Rot

(a) *Causative Organism* *Pythium* spp. (Class: *Oomycota*)

Symptoms The young roots of the infected tree become flabby, with rounded root tips, and dehydrated (Mcmillan 1994). The leaves of the infected plant are generally small and pale yellow in colour. Under severe damage, defoliation may also occur (Fig. 1.2d).

Control Measures Eliminate the infected trees and destroy them. No fungicide is approved for the treatment of this fungus.

(b) *Causative Organism* *Rhizoctonia solani* (Class: *Agaricomycetes*)

Symptoms The roots of the infected plant turn dark brown to black in colour which eventually die (Fig. 1.2e). A slow decline and sudden death of the lychee tree has also been reported. It can affect the whole tree or just few branches (Mcmillan 1994).

Control Measures Eliminate the infected tree from nursery and destroy them. No fungicide is approved (Mcmillan 1994). Addition of organic manure to the soil proves useful to improve nutrient balancing in the soil. A well drainage system should be applied in order to ensure that there is no standing water in the orchard.

1.3.10 Spheropsis Dieback

Causative Organism *Spheropsis* spp. (Class: *Ascomycota*)

Symptoms The disease starts spreading along the branches and forms cankers which produces a witch's broom (Fig. 1.2f). The twigs which develop from the brooms eventually dieback (Mcmillan 1994).

Control Measures Remove (pruning) the witch's broom as soon as they appear. No fungicide is approved for the control of this fungus.

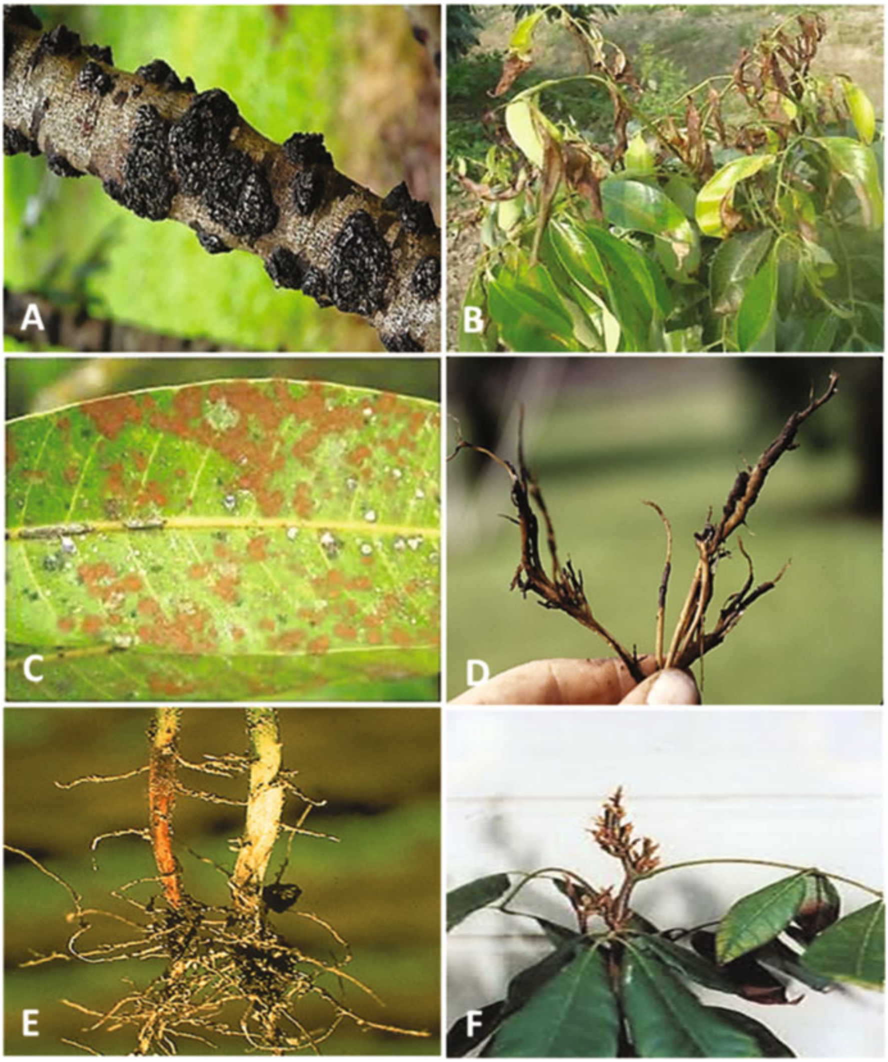

Fig. 1.2 Fungal diseases of lychee. (**a**) Corky bark lesions caused by *Phoma* species. (**b**) Dieback, canker and leaf-spot symptoms caused by fungus *Phomopsis* spp. (**c**) Leaf rot caused *Phyllosticta* spp. (**d**) Root rot symptoms caused *Pythium* spp. (**e**) Root rot caused by *Rhizoctonia solani*. (**f**) Dieback symptoms caused by *Spheropsis* spp.

1.3.11 Fruit Rot/Downy Blight

Causative Organism *Peronophythora litchi* (Class: Oomycetes)

Symptoms Fruit rot or downy blight is one of the major diseases of lychee. The fungus mostly attacks the leaves, panicles and fruits (Fig. 1.3a,b). Immature fruits turn brownish in colour and some develop white-coloured mildew on their skin (Menzel 2002). Continuous rain leads to more spreading of the disease. The infection declines the yield and shelf life of the fruit.

Control Measures Remove the infected and dead branches from time to time so as to control the spreading of infection. The crude extract sprays of *Bacillus subtilis* can be done (Jiang et al. 2001a, b). Moreover, copper oxychloride spray in winter and copper sulphate in spring season can reduce the spread of the disease (Menzel 2002). Application of fungicide mandipropamid can also significantly protect the plant from downy blight disease (Tang et al. 2011). Spray of metalaxyl during flowering and fruiting can also reduce the risk of disease occurrence.

1.4 Insect Pests

1.4.1 Fruit Borers

(a) *Causative Organism* *Conopomorpha sinensis* (Order: Lepidoptera)

Symptoms *C. sinensis* is known as the lychee fruit borer in Thailand and stem-end borer in China. *C. sinensis* lays scale-like yellow-coloured eggs (size 0.4×0.2 mm long) on the fruit, young leaves and shoots. The eggs hatch within 3–5 days and the larva immediately starts penetrating into the fruit, leaf or shoot (1. 3C). They make a tunnel through the aril of the fruit which leads to fruit fall (Menzel 2002).

Control Measures Fruits must be weekly inspected for the eggs of *C. sinensis*. Infected fruit must be removed and destroyed. In case of severe infestation, permethrin must be sprayed weekly, for 2 weeks before harvest (Menzel 2002).

(b) *Causative Organism* *Conopomorpha litchiella* (Order: Lepidoptera)

Symptoms *C. litchiella* lays their small light yellow-coloured eggs on the new shoots of the plant which hatch within 3–5 days. The newly hatched creamy white-coloured larva penetrates into shoots, midrib veins and leaf blades (Fig. 1.3d). Infected shoots lead to wilting (Menzel 2002).

Control Measures Insecticides should be sprayed on the plants.

(c) *Causative Organism* *Argyroploce illepida* (Order: Lepidoptera)

Symptoms *A. illepida* lays eggs in groups of 15 or single on the fruit surface. The size of the egg is 1.0×0.8 mm. Eggs are creamy white in colour and oval to flat having reticulate surface. Larvae feed upon the skin of the fruit and then tunnel towards the seed (Fig. 1.3e). When the fruits are ripe, the larva penetrates directly into the seed, which is completely eaten. Hence, a single larva can damage the entire fruit (Menzel 2002).

Control Measures In regions of South Africa, triflumuron and teflubenzuron sprays are recommended when the fruits are immature. Covering of panicles with paper bags also improves fruit colour and quality. In Queensland, azinphos-methyl and carbaryl are also used to prevent insect damage.

1.4.2 Fruit-Piercing Moths

Causative Organism *Eudocima fullonia*, *E. salaminia*, *E. jordani* (Order: Lepidoptera)

Symptoms These moths drill a hole in the fruit skin and suck the fruit juice. Contamination of the hole with bacteria and yeasts ultimately destroys the fruit (Fig. 1.3f). After few days of the infestation, a frothy discharge comes out from the fruit (Menzel 2002).

Control Measures The Australian farmers make traps by putting a dark shade cloth on a framed wire and bait it with fermented bananas and citrus fruits. The moths get captured in this cloth.

1.4.3 Leaf-Feeding Caterpillars

Causative Organism *Oxyodes scrobiculata*, *O. tricolor* (Order: Lepidoptera)

Symptoms The caterpillars feed on the leaves and cause severe defoliation (Fig. 1.4a).

Control Measures Shaking the tree dislodges the larvae onto the ground. Application of carbaryl is recommended in Thailand. In Australia, endosulfan and methomyl are also used as a remedy (Menzel 2002).

1.4.4 Leaf Rollers

Causative Organism *Olethreutes perdulata*, *Platypeplus aprobola*, *Adoxophyes cyrtosema* Meyr., *Homona coffearia*, *Isotenes miseran* (Order: Lepidoptera)

Symptoms These pests are more common in China and India and damage the leaves and flowers. The young leaves are more prone to pest throughout the lychee

Fig. 1.3 Fungal and insect damage of lychee. (**a**, **b**) Fruit rot, leaf and panicle damage caused by *Peronophythora litchi*. Damage caused by insect pest. (**c**) Fruit damage by larval penetration of *Conopomorpha sinensis*. (**d**) Shoot and leaf damage caused by *C. litchiella*. (**e**) Fruit damage caused by *Aegyroploce illepida*. (**f**) Fruit damage caused by *Eudocima fullonia*, *E. salaminia* and *E. jordani*

growing area. The green-coloured caterpillar rolls the leaf and feeds on lamina within the roll (Fig. 1.4b).

Control Measures Methomyl or carbaryl can be used during the initial damage. In India, rolled leaves containing larvae are destroyed manually, but phosphamidon, fenitrothion and endosulfan are sprayed in case of heavy infestation (Menzel 2002). Spray of thiodan and dursban retards the rate of damage caused by pests.

1.4.5 Bark Borers

Causative Organism *Aristobia testudo*, *Anoplophora maculate* (Order: Coleoptera)

Symptoms The female damages the branches by chewing 10 mm strip of bark and lays eggs on the wound. The larva hatches in the last week of August and lives beneath the bark until January. Larvae bore through the xylem and make tunnels of up to 60 cm long. This larval stage lasts for about 10 months and the tunnels start damaging the branches (Fig. 1.4c).

Control Measures Manual removing of the beetles, eggs and young larvae can be performed. Established larvae can be located from the appearance of their frass and can then be removed with knives and wire hooks. Alternatively, dichlorvos is injected and the tunnels sealed with clay (Zhang 1997).

1.4.6 Scarab Beetles

Causative Organism *Xylotrupes gideon* (Order: Coleoptera)

Symptoms The larvae develop in the soil where they feed on humus and roots of the plant. Large and sexually dimorphic adults emerge during spring season. They are attracted to the ripened fruits and damage them (Fig. 1.4d).

Control Measures Use of chemical sprays is not satisfactory. Manual removing of beetles can be done in smaller trees but is quite difficult for larger trees (Menzel 2002).

1.4.7 Soft Scales

Causative Organism *Pulvinaria psidii*, *Coccus hesperidum*, *Parasaissetia nigra*, *Saissetia coffeae* (Order: Hemiptera)

Symptoms Causative organisms form scale-like lesions on the fruit surface and also produce honeydew which enhanced the growth of moulds on the infected fruit and panicle (Fig. 1.4e). These discoloured fruits reduced the market value of the crop (Menzel 2002).

Control Measures Severe infections can be controlled with the application of methidathion.

1.4.8 Bugs

Causative Organism Tessaratoma papillosa, *Tessaratoma javanica* Thunberg, *Tessaratoma quadrata* (Order: Hemiptera)

Symptoms During the spring season, the female lays their eggs on the backside of the leaves and the nymphs mature in June. Adults and nymphs both feed upon the terminal branches, flowers and fruits, causing them to fall (Fig.1.4f). The bugs also feed upon the developing seeds. Infected seeds have lesions on the testa (Menzel 2002).

Control Measures Endosulfan and trichlorfon should be applied at different concentrations because the bugs vary in their susceptibility to different concentrations. A maximum of two sprays applied (2 weeks' gap) during the first 6 weeks after fruit set is sufficient (Menzel 2002).

1.4.9 Gall Flies

Causative Organism Dasineura spp. (Order: Diptera)

Symptoms Galls are formed over the leaf surfaces. Female lays eggs on the younger leaves, and the larvae form water dots over the surface which later on become galls. Galls turn brown and then fall off, leaving a hole on the leaf (Fig. 1.5a).

Control Measures The infected leaves can be removed manually and burnt. Methyl parathion (2.5%) can be sprayed on the trees. Isofenphos (0.001%) can also be sprayed (Menzel 2002).

1.4.10 Fruit Flies

Causative Organism Bactrocera tryoni (Order: Diptera)

Symptoms The female flies lay eggs over the cracks and wound on the fruit skin (Fig. 1.5b). The level of the crop damage is quite low (Menzel 2002).

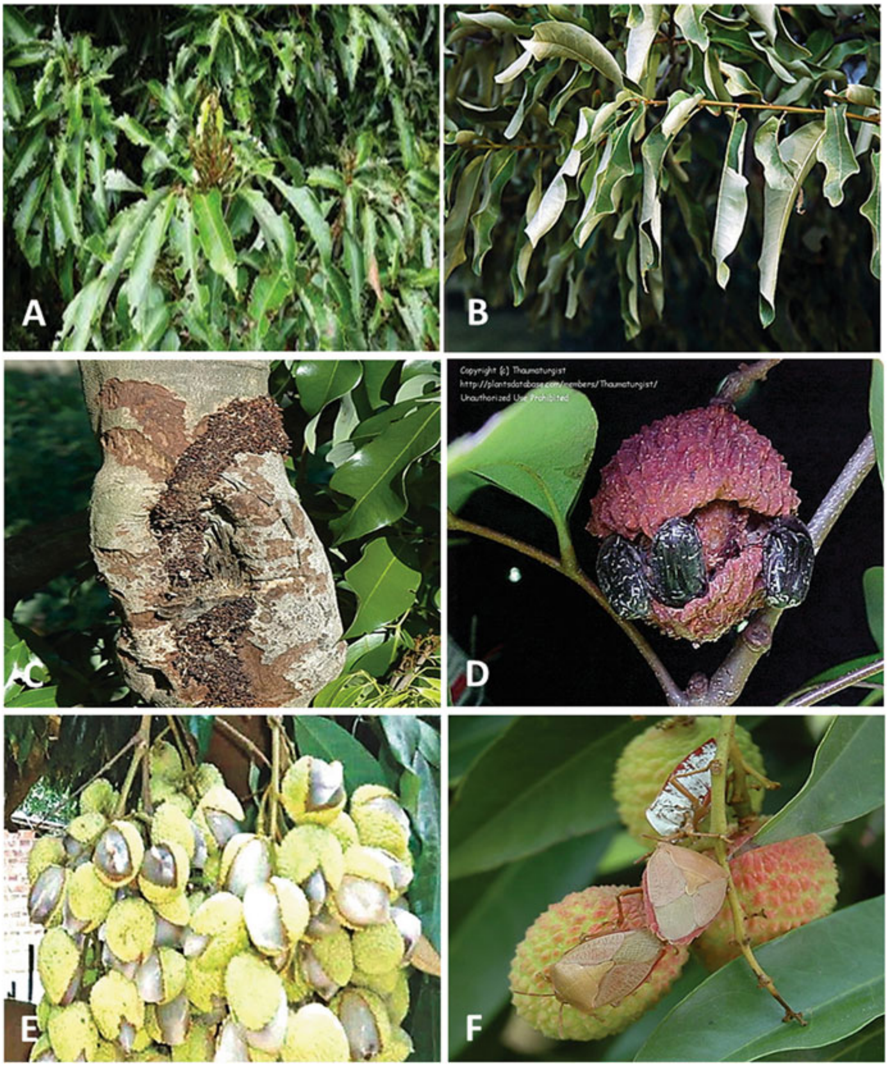

Fig. 1.4 Damage caused by insects. (**a**) Defoliation caused by *Oxyodes scrobiculata* and *O*. *tricolor*. (**b**) Leaf rolling and defoliation caused by *Olethreutes perdulata*, *Platypeplus aprobola*, *Adoxophyes cyrtosema*, *Homona coffearia* and *Isotenes miserana*. (**c**) Stem damage (tunnel formation) caused by *Aristobia testudo* and *Anoplophora maculata*. (**d**) Fruit damage caused by Scarab beetle (*Xylotrupes gideon*). (**e**) Discolouring of fruits and damage of leaves, flower and twigs caused by *Pulvinaria psidii*, *Coccus hesperidum*, *Parasaissetia nigra* and *Saissetia coffeae*. (**f**) Fruit damage and fruit fall caused by bugs: *Tessaratoma papillosa*, *Tessaratoma javanica* Thunberg and *Tessaratoma quadrata*

Control Measures In South Africa, pheromone-baited nets are used to capture the flies. The nets are sprayed with a combination of trichlorfon, mercaptothion and protein hydrolysate. The panicles can also be covered with paper bags (Menzel 2002).

1.4.11 Mites

Causative Organism *Aceria litchii* (Orders: Trombidiformes)

Symptoms *Aceria litchii* is also known as hairy mite, erinose mite, hairy spider and dog ear mite.
The female lays small and translucent white-coloured eggs on leaf surface. Mites are small and pinkish white in colour. All the stages of the life cycle are easily covered in moving from old leaves to young leaves. Their feeding stimulates the formation of hairy growth (erineum) over the leaf surface. Erenium covers the entire leaf and leads to leaf curling (Fig. 1.5c). In case of severe infestation, leaves are fully damaged. Mites can also damage the fruits and cause fruit disruption (Menzel 2002).

Control Measures Infected branches should be removed and burnt. Some insecticides can also be used. Three sprays of dimethoate can be applied during the emergence of leaves. In China dimethoate, chlorpyrifos, isocarbophos, dichlorvos, omethoate and dicofol are recommended to control the mites (Zhang 1997). Spray of wettable sulphur (4 g/l of water) after the fruit harvest can provide sufficient control over the mites. Rogor spray should be applied at the rate of 2 ml/l before and after the flowering season.

1.4.12 Weevils

Causative Organism *Apoderus* sp., *Conopomorpha cramerella* (Order: Coleoptera, Lepidoptera)

Symptoms The insects feed upon the leaf surface, and as a result of it, the leaves dry up giving a blighted appearance to the twigs (Fig. 1.5d). Young trees are totally devastated. Tan spots appear over the leaf surface giving the appearance of leaf burn (Kumar et al. 2011). The weevils remain active throughout the flushing period and the larvae of the weevils feed upon the roots of the plant.

Control Measures Pheromone traps and various biochemical agents including prophylactic spray of neem-based (*Azadirachta indica*) insecticide can be used to control the insects (Kumar et al. 2011).
Sevin spray at the rate of 3 g/l and dursban and thiodan at the rate of 2 ml/l can control the pest.

Fig. 1.5 Damage caused by insects. (a) Formation of galls on the leaf surface caused by *Dasineura* spp. (**b**) Fruit pericarp damage caused by *Bactrocera tryoni* (Froggatt). (**c**) **Leaf** bristles, leaf galls and leaf curling caused by *Aceria litchii* (Keifer). (**d**) Tan spots on leaf surface caused by Weevils: *Apoderus* sp. and *Conopomorpha cramerella*

1.5 Transgenic Approaches for Lychee Improvement

The economic importance of this fruit crops has led to selection and breeding over two decades. But, this practice resulted in relatively fewer genotypes containing restricted germplasm. Such kind of genetic uniformity expands the susceptibility of the crop towards various insects and pest's diseases. This ultimately leads to the immoderate use of the chemical pesticides (Norelli et al. 1994). Moreover, the biotechnological approaches can provide an alternative pathway to introduce a foreign gene which encodes for desirable traits (Hammerschlag and Litz 1992). Much attention has been focused on crop improvement, by incorporating genes for bacterial, fungal and insect resistance. It has now become possible to attain crop modification by genetic transformation to overcome the time-consuming conventional strategies. However, proper methodology is required for development of new cultivars with desirable characteristics (Puchooa 2004).

Puchooa (2004) introduced and successfully expressed a *gfp* gene (green-fluorescent protein gene) in lychee leaf tissue through *Agrobacterium*-mediated transformation. Screening for *gfp* gene expression may prove useful to improve transformation efficiency and to facilitate detection of transformed lychee plants. Ouyang and Zheng (1985) reported the transfer of T-DNA and formation of tumour induced by *Agrobacterium tumefaciens* in lychee. Hence, the use of *Agrobacterium* in transformation may provide better approach to produce genetically modified lychee plants with all the desirable traits. Nuclear technologies which include in vitro mutagenesis also have the potential to genetically transform the crop (Jain 2005). Both physical and chemical mutagens are used to induce the mutations, and this approach may provide mutant varieties within a short time period (Sarin et al. 2009).

In recent years, RAPD and AFLP markers have been successfully exploited for assessing genetic diversity in lychee (Ding et al. 2000; Tongpamnak et al. 2002; Kumar et al. 2006). There are two reports available on the production of transgenic lychee varieties. Das and Rahman (2012) transferred a gene named 'rice chitinase' through *Agrobacterium tumefaciens*-mediated transformation. PCR, RT-PCR and Western and Southern blotting techniques were used to confirm gene integration. Polyacrylamide in-gel assay was used to analyse the chitinase activity. It was found that transformed plants exhibited significant chitinase activity as compared to the non-transformed ones.

Sinha and Das (2013) transformed lychee with salt-tolerant Gly I and II genes in order to alter the glyoxylate pathway to enhance the salt tolerance. The integration of the genes was analysed by PCR and Southern and Western immunoblotting. The transformed plant showed significant tolerance towards salt as compared to the wild plants. The above findings suggest that transgenic approaches have the promising potential to produce lychee cultivars with fungal- and insect-resistant traits also. However, much work is still needed in order to understand the molecular basis of the transgene integrity and stability and to enhance the transformation efficiency as the level of the gene expression must be high in the transformed plant.

1.6 Post-harvest Strategies to Cope with Crop Loss

The lychee fruits are harvested selectively so as to ensure that only the mature ones are plucked and marketed (Lemmer and Kruger 2002). Hence, fruit picking is carried out repeatedly at regular intervals. During the peak of the harvest season, the fruits are harvested in clusters with the panicle at uniform maturity. Fruits are generally harvested manually by using ladders. They are mostly harvested in early morning in order to decrease the loss of moisture and weight. After that individual fruit is plucked from the panicles with the help of a cutter. The fruit separation process must be performed under shade, and the fruits are collected in clean plastic crates. The transfer of the harvested fruits from the orchard to packhouse is done rapidly in order to maintain the fruit quality.

1.6.1 Grading

Grading involves the separation of fruits into different grades according to fruit size, colour and quality. Grading system depends greatly upon the market requirement (Menzel 2002). Grading process should be carried out in well-ventilated, shady and temperature-controlled packing houses (Holcroft et al. 2005). FAO of the United Nations has established CODEX quality standard for lychee. According to CODEX standard, the mature fruit must have dominant red pericarp. The diameter for the superior class fruit must be 33 mm, while for standard class, it must be 20 mm (CODEX standards 2005). After grading of the fruits, post-harvest treatment is done to retain the fruit quality of the superior as well as standard fruits. Several researches are available on the post-harvest physiology of lychee. Moreover, there are numerous post-harvest technologies or strategies which can maintain the fruit standard for 3–4 weeks (Sivakumar et al. 2011). The following are the strategies which are performed after harvest in order to retain the overall fruit quality.

1.6.2 Sulphur Dioxide Fumigation

The lychee industry has been using SO_2 fumigation method commercially in order to prevent the post-harvest browning and infection by several post-harvest pathogens (Swarts 1983). Fumigation can be performed by burning 100 g of 90% sulphur powder per m^3 of fruit at a temperature of 25–28 °C for 20 min (Holcroft and Mitcham 1996). If excessive sulphur is used, the fruits changes to pale green or light yellow in colour (Timberlake and Bridle 1967). Treatment of HCl (hydrochloric acid) after the fumigation can also help to retain the red colour of the fruit (Zauberman et al. 1990). Some undesirable results of SO_2 fumigation have also been reported (Kremer-Köhne 1993).

1.6.3 HCl Dips

The hydrochloric dip treatment is performed to retain the original bright red colour of fruit fumigated with SO_2. The dip treatment should be given for 4–8 min. Moreover, the treatment time can be increased to increase the red colour intensity (Sivakumar et al. 2011).

1.6.4 Use of Metabisulphite Salts

Sheets impregnated with sodium metabisulphite are also helpful to control the browning and desiccation of fruit (Schutte et al. 1990). Combination of the above HCl dip and sodium metabisulphite treatment can effectively reduce the pericarp browning for 28 days (Sivakumar et al. 2011).