Chapter 5

Diseases and pests

It is believed that numerous diseases have been attacking citrus trees already in their region of origin and that their actual widespread occurrence is the man-made consequence of international travel and trade. The pathogen organisms are bacteria, fungi, viruses, and viroids. The diseases are spread by biological natural vectors such as insects, by winds and rain, or by humans and man-made devices. Many of the diseases have been qualified as "devastating." This is no exaggeration, considering that each one of the diseases has almost caused destruction of the citrus industry, in some part of the world, at one time or another.

5.1 DISEASES

5.1.1 Huanglongbing (HLB)

Huanglongbing (HLB), also known as the "Citrus greening disease" (da Graça, 1991) is a serious microbial disease affecting major citrus-growing areas and spreading to new citrus-growing regions. It is caused by a gram-negative bacterium named *Candidatus Liberibacter*, spread by the psyllids *Trioza erytrea* and *Diaphorina citri*, acting as natural vectors. The disease is also propagated by grafting. Three species of the bacterium are known. They are named after the continent in which they are prominent *Liberibacter asiaticus*, *L. africanus*, and *L. americanus* (Bové, 2006). The pathogens penetrate the phloem and attack the vascular system, clogging the veins and drastically reducing the transport of water and nutrients. The disease was described in China, already in 1919. In the first half of the 20th century, it affected large citrus-producing areas in South-East Asia, India, and South Africa and caused serious damage to the production of citrus in many countries. In 2004, it was discovered in Brazil (Coletta-Filho, 2004; Teixeira et al., 2005) and in 2005 it appeared in Florida (Spreen and Baldwin, 2013). The bacterium found in Florida is *L. asiaticus* and the one detected in Brazil is *L. americanus*. The occurrence of HLB in Florida is believed to have seriously affected the citrus production there already. Realizing the potential devastating effect of the disease, many Florida growers abandoned citriculture and sold their orchards to real estate developers.

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The growing area was reduced, in addition to the decline of the yield per hectare. The impact of HLB on the citrus economy of Florida is estimated at several billion dollars but the long-range effect on the industry is believed to be far more serious. Spreen and Baldwin (2013) estimate that, in the future, the presence of HLB will have a negative influence on the drive for planting new citrus trees. In summary, there is a good reason for defining HLB as the most serious calamity threatening the citrus industry of Florida today.

Huanglongbing is a Chinese word meaning the "yellow dragon disease," probably due to the appearance of conspicuous yellow shoots as one of the first symptoms of the disease. Another early symptom is yellowing of the leaf veins. Other symptoms include yellowing and mottling and eventually fall of the leaves, loss of fibrous rootlets, and ultimately death of the plant. Sick trees produce few small and deformed fruits that remain green at the stylar end, all along maturation. Fruit fall is extensive and the fruits are bitter and devoid of commercial value. The name of "citrus greening disease" originated in South Africa where the disease was known for a long time but was mistaken for some sort of mineral deficiency of the tree.

The three species of *Liberibacter* differ in their reaction to temperature. *L. asiaticus* is heat-tolerant and can survive at temperatures superior to 30°C, while *L. africanus* is thermo-labile and prefers temperatures in the range of 22–25°C. Detection of the pathogen in the infected plant or in the vector is difficult (Manjunath et al., 2008). The bacteria were identified using electron microscopy (Bové, 2006).

At present, there are no known methods for curing HLB. Control of the disease relies, therefore, on prevention. Considerable sums have been allocated for research toward the development of methods for the control of HLB. One approach which does not cure diseased trees but seems to counteract its deleterious effects is based on feeding the trees via foliar sprays. Control by prevention includes the destruction of all diseased trees, chemical and biological (natural enemies) control of the psyllids and observance of strict quarantine procedures (Bové, 2006). Affected trees may not show characteristic symptoms for up to 5 years, which hampers the efficiency of prevention measures.

5.1.2 Citrus canker

Citrus canker is a serious disease caused by *Xanthomonas axonopodis citri*, a gram-negative, slender, rod-shaped bacterium. Citrus canker can be particularly dangerous under certain climatic conditions such as rain and warm weather at the beginning of the fruit development period. It is not considered a potential threat in California and Arizona where the warm season is also dry (Klotz, 1978). The disease manifests itself as dark spots and lesions on the leaves and fruits (Verniere et al., 2002). The lesions are initially small but they

may grow to large spots, up to 10 mm in diameter. A greenish yellow-brown ring or "halo" around the lesions is the most easily recognized sign of the disease. As the pathogen multiplies profusely in the lesions, infected trees become active sources of contamination. The pathogen penetrates the plant through the stomata of the leaves or through open wounds. It attacks the young, developing organs of the tree. The vigor and growth of the tree are compromised by the extensive and premature drop of the leaves and shoot dieback. The spotty appearance of the fruit makes it unmarketable. The pathogen does not require a biological vector, but lesions caused by certain insects, particularly the pest insect citrus leafminer, serve as available openings for penetration.

Citrus canker is believed to have originated in Southeast Asia or northwest India (Klotz, 1978), but being easily propagated by rains and winds (Bock et al., 2005), it has infected orchards in almost every part of the world. Tropical storms are known to propagate the disease, which is also disseminated by machinery, containers, and humans carrying the bacterium. It is a very persistent disease. Florida has known a number of serious outbreaks. A few years after the disease had been declared eradicated a new outbreak was detected (Graham et al., 2004).

Citrus fruits vary in their susceptibility to canker. Grapefruit and Mexican limes are highly susceptible. Sweet oranges and lemons are moderately susceptible. Mandarins are moderately resistant. However, even resistant varieties may succumb to the disease after serious insect infestation. There are several types of citrus canker, caused by different variants of *Xanthomonas axonopodis*. The so-called canker A, caused by strains of *X. axonopodis citri*, is the most widespread type. Cancrosis B, caused by *X. axonopodis aurantifolii*, originally detected in South America is a serious threat to the lemons of Argentina and attacks also key lime, bitter orange, and pomelo. Cancrosis C infects only bitter orange and key lime.

Citrus cancer is a relatively latent disease. The length of time between infection and appearance of the first symptoms in the field may be a few weeks to a few months. Latency is increased by cool weather. Early detection is important for efficient management. The bacterium can be detected and identified by genetic methods based on polymerase chain reaction (Cubero et al., 2000). Improved methods based on image processing, for the diagnosis of canker and its distinction from other types of external disorders, have been developed (Li et al., 2012; Qin et al., 2009, 2012).

Control of citrus canker is based on prevention and eradication. Prevention requires strict quarantine measures, establishing windbreaks (Gottwald and Timmer, 1994), copper sprays and disinfection of machinery, vehicles, containers, and workers in contact with the plants. Eradication implies cutting down and destroying infected trees and all trees within a certain radius from

an infected tree. Eradication is costly as it may amount to the destruction of millions of trees. Yet, according to Graham et al. (2004), "living with canker" is a more costly option.

5.1.3 Citrus Tristeza

Triteza (also known as Citrus tristeza virus (CTV)) is the name of an important citrus disease caused by different strains of a virus (Bar-Joseph et al., 1989; Rocha-Pena et al., 1995). The name, which means "sadness, melancholy" in Portuguese and Spanish, describes well the aspect of trees infected with the disease. It is caused by various species of the *Closterovirus* genus. Wallace (1978) suggests that Tristeza is not a single disorder but a complex made up from several distinct diseases. The disease is transmitted mainly by aphids that penetrate the phloem to feed on the sap. The brown citrus aphid, *Toxoptera citricida*, is the most efficient vector. The cotton/melon aphid, *Toxoptera gossypii*, is a less efficient but significant vector, because it is more abundant. Citrus varieties grafted on sour orange rootstock are particularly vulnerable.

Characterizing CTV by the symptoms is problematic, because each one of the different strains of the virus produces a different group of symptoms on different hosts. Following Wallace's concept of a "complex," each group of symptoms can be regarded as a different malady. The general effect of CTV infection on citrus is stunting of the trees and reduction of the fruit size. More severe and specific syndromes may develop. Decline is probably the most spectacular of CTV syndroms. It can be quick or slow. It occurs mainly in sweet oranges, mandarins, and grapefruit on sour orange rootstock (Spiegel-Roy and Goldschmidt, 1996). All the leaves suddenly wilt and dry (Wallace, 1978). The root system is severely reduced. The starch stock of the plant is depleted. In the case of quick decline, the tree dies a few days after the first symptoms are visible. Trees that appear to be dying may recover but they never return to their normal vigor and productivity. Young trees are particularly prone to quick decline. Old trees usually decline slowly (Wallace, 1978). Stem pitting is another group of CTV syndroms. The term "stem pitting" refers to the occurrence of depressions in the wood of plants. In citrus trees, stem pitting caused by CTV consists of depressions of various sizes and shapes on the outer face of the bark. The third group of syndroms is called "seedling yellows," caused by a certain strain of CTV, first described in Australia. When applied by tissue grafts on seedlings of a number of citrus varieties, this virus was found to induce severe stunting and yellowing (Wallace, 1978).

CTV was traditionally diagnosed by graft-inoculating Mexican lime with tissue from the suspected plant and watching for the appearance of

symptoms such as leaf chlorosis. At present, the disease can be diagnosed also by immunoassay techniques and electron microscopy.

For the control of CTV, strict quarantine as well as chemical and biological inactivation of the vector aphids are necessary but insufficient measures. Immunization of the trees by inoculation with a mild type of the virus is a promising approach. Development of resistant rootstock–scion combinations is an effective way to exclude Tristeza from the citrus orchards.

5.1.4 Mal secco

Mal secco is a destructive vascular disease caused by the fungus *Phoma traceiphila Petri* (Klotz 1978; Migheli et al., 2009). It attacks particularly lemon and sour orange trees. Sweet oranges, grapefruit, and mandarins are seldom affected (Solel and Salerno, 2000).

The disease has caused severe damage to lemon plantings in several countries. Mal secco occurs in the Eastern Mediterranean region, around the Black Sea and in Asia minor (Spiegel-Roy and Goldschmidt, 1996) where the climate is optimal for the growth of the fungus. It has not been reported from Spain, Portugal, and Morocco. Infection by fungal spores occurs mainly in winter via the rain. Overhead irrigation sprinklers and winds are also propagating agents. Penetration is primarily through wounds. The first symptom is sudden wilting and drying of the leaves, hence the name "mal secco" (dry disease in Italian). Extensive leaf drop and twig dieback follow. The seeds are discolored and necrosis of the fruit occurs at the stem end. Death of the whole tree may occur within 1 or 2 years after infection. The causal agent is apparently a glycoprotein toxin, named malseccin, excreted by the fungus (Reverberi et al., 2008).

Mal secco can be detected visually by examining the leaves for chlorosis around the veins or by the pink-brown discoloration of the phloem under the bark. Specific and accurate diagnosis at the laboratory makes use of molecular methods such as polymerase chain reaction test.

Containment of mal secco is possible by replacing infected trees by less susceptible varieties. Unfortunately, the replacements are often of inferior quality. Pruning of the infected branches and twigs helps. It is recommended to burn the pruned material. Chemical control by repeated sprays of copper-based fungicides is practiced in nurseries.

5.1.5 Stubborn

The Citrus stubborn disease (CSD) is caused by *Spiroplasma citri,* a bacterium without a cell wall (Saglio et al., 1973). The disease is particularly

important in the hot and arid regions like California, the Middle East, and North Africa (Spiegel-Roy and Goldschmidt, 1996). Oranges, grapefruit, and mandarins are the most sensitive varieties, Young trees are more vulnerable. The pathogen dwells principally in the phloem of the host and is transmitted by various kinds of leafhoppers. Weeds, ornamental flowers, and certain herbaceous vegetables serve as hosts to the vector insects and are, therefore, a significant source of infection. CSD is also transmissible by grafting.

CSD infected trees do not die but they are severely stunted. They produce small leaves and small, lopsided fruits with unacceptable sensory quality (Dreistadt, 2012). Control and prevention measures are applied primarily in nurseries and on young trees in the orchard. Frequent inspection and removal of unproductive trees is suggested. Use of infected budwood should be avoided. Treatment of budwood with antibiotics has been tried (Wallace, 1978). Elimination of the weeds and good orchard sanitation are essential.

5.1.6 Root rot and brown rot: diseases induced by Phytophthora

The root system of citrus trees is attacked by soil-born fungi and fungus-like organisms such as *Phytophthora*, *Fusarium*, and *Armillaria*. The most important and widespread root rot disease is caused by *Phytophthora* species (Dreistadt, 2012; Spiegel-Roy and Goldschmidt, 1996). *Phytoptora* is a fungus-like parasite, an oomycete, but not a true fungus. (Oomycetes are a distinct group of eukaryotic microorganisms, closely related to brown algae and diatoms). It thrives in humid ground and in free water near the roots. It multiplies and propagates through oospores, highly motile in water. *Phytophthora* infection occurs through wounds and cracks on the bark of roots and the lower parts of the trunk. The rot caused is known as gummosis.

Phytophthora may also infect fruit near or touching the ground and cause a disease known as "brown rot." The disease occurs mainly on mature fruit. At its advanced stage the disease is visible as brown lesions of the fruit but when recently infected the fruit shows no abnormal symptoms. After harvest, the infected fruit may contaminate healthy fruit during storage and transport (Dreistadt, 2012).

Prevention of *Phytophthora*-induced diseases includes planting, as much as possible, in well-drained soil, selecting resistant rootstocks (see Table 4.2), removing soil at the foot of the trunk above the principal lateral root, avoiding flood irrigation, disinfection of irrigation water, application of systemic fungicides, and observance of good sanitation rules, particularly in nurseries. Fumigation of the soil in nurseries is widely practiced. One of the most

common fumigants is methyl bromide. One of the problems with soil fumigation is the risk of eliminating beneficial root fungi (mycorrhizae).

5.1.7 Citrus psorosis

Citrus psorosis is a serious disease attacking mainly sweet orange. It is caused by a virus, Citrus Psorosis Virus CPsV (Sofy et al., 2007) and transmitted mainly by seeds and grafting. The visible symptoms, which are usually slow to appear, include flaking of the bark of the trunk and branches. Young leaves develop chlorosis near the veins and lose their oil glands. Trees infected with the disease do not die but their performance declines considerably. Removal and replacement of the infected tree is often the best option. Prevention measures include avoiding the use of contaminated budwood and proper disinfection of budding and pruning tools.

5.1.8 Citrus exocortis

Citrus exocortis, known also as scalybutt, is caused by the Citrus exocortis viroid (ceVd). Viroids are infectious molecules of RNA (Garnsey and Jones, 1967). The rootstocks of trifoliated orange, Rangpur lime, and Swingle citrumelo are particularly sensitive to the disease. Exocortis have not been found on trees grown on sweet orange, rough lemon, and mandarin. The symptoms are moderate to severe stunting and peeling of strips of bark. The disease has been kept under control by removing and destroying infected trees from the orchard and, primarily, by avoiding use of diseased trees as a source of budwood.

5.2 PESTS

In the context of citriculture, pests may be defined, simply and practically, as harmful animals, although vegetal organisms, such as weeds, are sometimes included in the definition. Pests may damage citrus production directly, for example, by feeding on leaves, roots, or fruits, or indirectly, by serving as vectors to pathogen microorganisms. Attack by pests is classified as "biotic stress" (Spiegel-Roy and Goldschmidt, 1996) in contrast to "abiotic stress" caused by unanimated factors such as climatic conditions. Citrus pests include insects, mites, snails, nematodes, and some vertebrates (eg, rodents, birds, wild pigs). They are too numerous to be treated in detail in this chapter. A partial list is given in Tables 5.1 and 5.2. A colorful book, "Integrated Pest Management for Citrus," published by the University of California gives a detailed account of citrus pests, illustrated by many pictures (Dreistadt, 2012). Although emphasis is put on pests encountered in California, most of the species described in the book infest citrus groves in many other parts of the world.

Table 5.1 Partial List of Citrus Pests: Insects

Group	Common Name	Type of Injury
Scales	Florida wax scale California red scale Citricola scale White wax scale Brown wax scale Black scale	Scales suck phloem fluids from leaves and twigs, reducing tree vigor. Some scales excrete honeydew on which mold can grow. Many are controlled by natural enemies.
Thrips	Citrus thrips Flower thrips Geenhouse thrips	Thrips feed on epidermal tissue, destroy leaves, scar fruit. Are attacked by natural predator insects.
Caterpillars	Citrus leaf miner Cirus peel miner Bark-eating borer Light brown apple moth Citrus moth borer	Caterpillars are larvae of moths and butterflies. They feed on plants, chew leaves, flowers and fruits, bore tunnels in fruits, and leaves. Bark borer damages root and trunk tissue and may kill young trees.
Mealybugs	Citrus mealybug Citrophilus mealybug Citriculus mealybug	Mealybugs are covered with white' powdery wax. They suck phloem sap reducing tree vigor. They excrete honeydew. They are efficiently controlled by natural enemies.
Psyllids	Citrus psyllid	Vector of different types of the bacterium *Candidatus Liberibacter*, causing Huanglongbing disease.
Aphids	Cotton (melon) aphid Black citrus aphid Brown citrus aphid	Brown aphid and cotton aphid are vectors of the Tristeza virus. Direct damage (curling of leaves, honeydew production, blossom drop) is mild.
Fruit flies	Mediterranean fruit fly Mexican fruit fly Caribbean fruit fly	Particularly dangerous at the end of the season when the fruit is ripe. The females lye eggs in the rind. Causes rejection or downgrading of fruit.
Chewing insects	Grasshoppers	Grasshoppers chew leaves of young trees and cause economic damage when in large number.
	Forktailed Katydid	Nymphs chew young fruit and leave scars in the grown fruit.
Ants	Leaf-cutting ant Argentine ant	May cause serious damage to foliage. May attack natural protecting enemies.

Table 5.2 Partial List of Citrus Pests: Non-Insect Pests

Group-Class	Common Name	Type of Injury
Mites	Citrus red mite Citrus flat mite Citrus rust mite	Mites feed on buds, stunting trees. Cause chlorosis in leaves, leaf and fruit drop, reduction in fruit size.
Gastropods	Garden snail	Snails chew fruit, young leaves and the bark of young trees in nurseries.
Nematodes	Citrus nematode Burrowing nematode	Nematodes impair growth of feeder roots, cause decline of the tree, reduction of fruit size and number.

Most pests are attacked by natural enemies. Biological control relies on the activity of natural enemies. Wide spectrum pesticides affecting pests and their enemies alike are therefore counterproductive. Repeated application of the same pesticide may induce development of resistant types of the pest.

5.2.1 Insects

Insects damage citrus by chewing various parts of the plant, sucking sap, depositing eggs or larvae, boring tunnels in leaves and fruit, excreting honeydew. Honeydew is an excretion consisting of modified plant sap. It soils the fruit and may attract other pests. It provides growing medium to molds, causing a deposit of dark mycelium known as "sooty mold." In certain cases, the damage results from the action of more than one insect. Thus, for example, the citrus flat mite feeds on peel tissue injury made previously by thrips, creating a more serious scar.

5.2.2 Mites

Mites are relatives of spiders and ticks. They are very small. Most are barely visible to the naked eye. They are serious pests of fruit intended for the fresh market. Some mites are vectors of pathogenic viruses. Mites degrade fruit quality, reduce fruit size, and may cause excessive fruit drop. Control of mites is less critical in the case of fruit grown for processing.

5.2.3 Nematodes

Nematodes of interest in citriculture are soil-borne, nonsegmented round worms. They attack only the roots and their specific above-ground symptoms are usually unnoticed (Baines et al., 1978). They do not kill trees but cause serious decline, reducing growth and fruit yield. Crop reduction of 30–50% in oranges and lemons has been reported. Citrus nematodes are present in all types of soils in citrus-growing regions of the world (Duncan, 2005). Nematodes lack motility and are not present on the fruit. Their widespread occurrence suggests, therefore, dissemination by the transport of plants and planting material. Citrus rootstocks differ in their sensitivity to nematodes. Citrus nematodes are attacked by several bacteria, fungi, and predator nematodes but heavy infestation may require the use of chemical nematicides. Infestation with nematodes in areas where citrus trees have been growing requires protective measures if replanting the area with citrus is planned. Unless young trees on highly resistant rootstocks are to be used, preplant fumigation of the soil with nematicides is recommended.

5.2.4 Snails

Snails chew young leaves and the bark of young trees. As such, they are primarily damaging in nurseries. They also chew fruit, at all stages of maturity and leave large, visible wounds. They are mostly active at night. They are attacked by natural enemies.

5.2.5 Vertebrates

Vertebrate citrus pests are rabbits, squirrels, rats, gophers, wild pigs, deer, and birds. Some of these pests are protected animals and their elimination is permitted only when the damage they cause is economically important. Control methods are variable and depend on the target species. They include baits, traps, shooting, fumigation, and habitat modification (Dreistadt, 2012).

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